Denys J. Charles

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Contents

Part I

1 Introduction 3

2 Antioxidant Assays 9

3 Natural Antioxidants 39

4 Sources of Natural Antioxidants and Their Activities 65

Part II

5 Ajowan 141

6 Allspice 145

7 Angelica 151

8 Anise 159

9 Anise Star 165

10 Asafoetida 169

11 Basil 173

12 Bay 181

13 Capsicum 189

14 Caraway 199

15 Cardamom 207

16 Celery Seed 213

17 Chervil 221

18 Chives 225
19 Cinnamon 231
20 Clove 245
21 Coriander 255
22 Cumin 265
23 Curry Leaf 273
24 Dill 281
25 Fennel 287
26 Fenugreek 295
27 Garlic 305
28 Geranium 329
29 Ginger 335
30 Horseradish 347
31 Hyssop 353
32 Juniper 357
33 Lavender 363
34 Lemon Balm 371
35 Lemongrass 377
36 Licorice 385
37 Marjoram Sweet 393
38 Mustard 401
39 Myrtle 409
40 Nigella 415
41 Nutmeg 427
42 Onion 435
43 Oregano 449
44 Black Pepper 459
45 Peppermint 469
46 Pomegranate 477
47 Poppy 489

48 Rosemary 495
49 Saffron 509
50 Sage 521
51 Savory 531
52 Spearmint 537
53 Tarragon 545
54 Thyme 553
55 Turmeric 563
56 Vanilla 581

Index 589

Part I

Chapter 1
Introduction

Natural antioxidants (AH) are more readily acceptable than synthetic antioxidants. Recently, much focus has been given to the involvement of active oxygen and free radicals in aging and in disease processes like heart disease, inflammation, arthritis, immune system impairment, and cancer (Cai et al. 2004; Kaefer and Milner 2008; Huang et al. 2010). Oxidative stress is defined by an imbalance between increased levels of reactive oxygen species (ROS) and a low activity of antioxidant mechanisms. An increased oxidative stress can induce damage to the cellular structure and potentially destroy tissues. The oxidative damage to cellular components has been found to be responsible for a number of chronic diseases including cancer. It has been shown beyond any doubt that these damaging events are caused by free radicals. The free radicals identified to induce such oxidative damages are the reactive oxygen species (ROS) and reactive nitrogen species (RNS). ROS and RNS are normally generated by tightly regulated enzymes, such as NO synthase (NOS) and NAD(P)H oxidase isoforms, respectively. The ROS and RNS like the superoxide, hydrogen peroxide and singlet oxygen, and other free radicals like nitrogen free radical are generated in the human body from various factors both inside and outside sources. The cumulative production of ROS/RNS through either endogenous or exogenous factors is termed oxidative stress and is common for many types of cancer cells that are linked with altered redox regulation of cellular signaling pathways. The production of excess ROS and RNS, and other radicals, has been shown to be involved in the oxidative deterioration of food products and to be inducers of tissue injury in several pathological conditions including cardiovascular diseases, cancer, atherosclerosis, diabetes, neurodegenerative diseases like Alzheimer and Parkinson, ischemic reperfusion injuries, rheumatoid arthritis, and aging (Fenkel and Holbrook 2000; Govindarajan et al. 2005; Valko et al. 2006, 2007). The reactive oxygen species (ROS) capable of causing damage to DNA have been postulated to promote carcinogenesis, coronary heart diseases, and other health problems related to advancing age. ROS are produced during normal physiological events and they can initiate the peroxidation of membrane lipids causing accumulation of lipid peroxides. They induce oxidative damage to lipids, carbohydrates, proteins, and nucleic

D.J. Charles, *Antioxidant Properties of Spices, Herbs and Other Sources*,
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acids and hence cause cancer, aging, and other diseases (Aruoma 1994). There are several sources of specific ROS in human organism. The hydroxyl radical is highly reactive and needs immediate reaction at the place of origin. The peroxyl radicals are generated in the process of lipid peroxidation and the hydroxyl radical can start this reaction sequence (Reaven and Witztum 1996). In lipid peroxidation, other products like alkoxyl radicals and organic hydroperoxides are generated, which can lead to the production of aldehydes. These aldehydes are involved in the modification of the protein part of lipoproteins (Diplock et al. 1998). The nitric oxide radical is very cytotoxic and leads to the formation of peroxynitrite which is capable of inducing lipid peroxidation in lipoproteins (Packer 1996). The non-radicals, hydrogen peroxide and singlet oxygen, are involved in signal transduction regulating the expression of genes through the nuclear factor kappa B (NF-kappaB) and activator protein (AP-1) pathways and targeting double bonds for example in PUFA or guanine in DNA bases (Sen and Packer 1996; Stahl and Sies 1993; Valko et al. 2006). The redox active metals like iron (Fe), copper (Cu), chromium (Cr), cobalt (Co), and other metals undergo redox cycling reactions and hence possess the ability to produce reactive radicals such as superoxide anion radical and nitric oxide in biological systems. The disruption of any metal ion homeostasis leads to oxidative stress, a state where increased formation of ROS overwhelms body antioxidant protection and subsequently induces DNA damage, lipid peroxidation, protein modification, and other effects, all symptomatic for numerous diseases, including cancer, cardiovascular disease, diabetes, atherosclerosis, neurological disorders (Alzheimer's disease, Parkinson's disease), chronic inflammation, and others (Jomova and Valko 2011). Thus reducing the oxidative damage may be the most important approach to the prevention of these diseases and health problems. We, aerobic organisms, are protected from such oxidative stress by a great defense network in which various antioxidants with different functions play important roles. This includes antioxidant enzymes and antioxidant constituents to remove or repair the damaged molecules. As is the case with chemical antioxidants, cells are protected against oxidative stress by an interacting network of antioxidant enzymes (Davies 1995). Moreover, enzymes have been evaluated as new types of natural antioxidants in some food applications. They can be used beneficially to remove oxygen and reactive oxygen species and to reduce lipid hydroperoxides (Frankel 1998). Two major antioxidant enzymes, superoxide dismutase (SOD) and catalase, contain metal ions as an integral part of their active sites to battle against toxic effects of metal-induced free radicals. Antioxidants terminate ROS attacks and thus help prevent these diseases and health problems. There is a general trend to seek safe and effective antioxidants from natural sources. The beneficial influence of many foodstuffs and beverages including teas, fruits, vegetables, herbs, spices, coffee, and cacao on human health has been recently recognized to originate from their antioxidant activity. Consumption of fruits and vegetables is associated with reduced risk of some chronic diseases and epidemiological studies have shown an inverse relation between the intake of fruits and vegetables and mortality from age-related diseases, which may be attributed to their antioxidant activity (Rimm et al. 1996a, b, Eberhardt et al. 2000; Ganesan et al. 2011). The significance of the natural

antioxidants found in foods in preserving the foods themselves and providing essential antioxidants in vivo is very well appreciated. Foods are an important source of these antioxidants, components, and trace elements. Renewed attention has been given to the importance and role of antioxidants due to the increasing experimental, clinical, and epidemiological data which show the beneficial effects of these antioxidants against oxidative stress-induced degenerative and age-related diseases, aging and cancer. Various abiotic stresses lead to the overproduction of reactive oxygen species (ROS) in plants which are highly reactive and cause damage to proteins, lipids, carbohydrates, and DNA which ultimately results in oxidative stress. The ROS comprises free radical ($O_2^{\bullet -}$, superoxide radicals; $OH^{\bullet}$, hydroxyl radical; $HO_2^{\bullet}$, perhydroxy radical and $RO^{\bullet}$, alkoxy radicals) and non-radical (molecular) forms (H_2O_2, hydrogen peroxide and $^1O_2$, singlet oxygen). In chloroplasts, photosystem I and II (PSI and PSII) are the major sites for the production of $^1O_2$ and $O_2^{\bullet -}$. In mitochondria, complex I, ubiquinone and complex III of electron transport chain (ETC) are the major sites for the generation of $O_2^{\bullet -}$. Plants possess a strong antioxidant defense machinery that protects them against oxidative stress damages. These include very efficient nonenzymatic (ascorbic acid, ASH; glutathione, GSH; phenolic compounds, alkaloids, non-protein amino acids, and α-tocopherols) and enzymatic (superoxide dismutase, SOD; catalase, CAT; ascorbate peroxidase, APX; glutathione reductase, GR; monodehydroascorbate reductase, MDHAR; dehydroascorbate reductase, DHAR; glutathione peroxidase, GPX; guaiacol peroxidase, GOPX; and glutathione-S-transferase, GST) antioxidant defense systems which control the uncontrolled oxidation and protect plant cells from oxidative damages by scavenging ROS. The ROS also influences the expression of a number of genes and therefore control many processes like growth, cell cycle, programmed cell death (PCD), abiotic stress responses, pathogen defense, systemic signaling, and development. Food tissues are constantly under oxidative stress from free radicals and, thus, many of these tissues have developed antioxidant systems to control the free radicals, lipid oxidation catalysts, oxidation intermediates, and secondary breakdown products (Nakatani 2003; Brown and Kelly 2007; Chen 2008; Iacopini et al. 2008; Sharma et al. 2010; Rao et al. 2011). The antioxidant compounds in these tissues include phenolic acids, flavonoids, carotenoids, tocopherols, and others that can inhibit Fe^{3+}/AA-induced oxidation, scavenge free radicals, and act as reductants (Ozsoy et al. 2009; Kolacek et al. 2010; Petacci et al. 2010; Gao et al. 2011; Hua et al. 2011; Jakesevic et al. 2011; Maoka et al. 2011).

These antioxidants are a class of compounds that vary in chemical structure and have diverse mechanisms of action. Antioxidants were first used before World War II for food preservation. These early antioxidants were natural substances and the antioxidant activity depends on many factors. An antioxidant is a molecule capable of inhibiting the oxidation of other molecules. In terms of food, the antioxidant has been defined as any substance that when present in low concentrations compared to that of an oxidizable substrate significantly delays or inhibits the oxidation of that substrate (Sies 1993; Halliwell 1995; Halliwell and Gutteridge 1989). The natural antioxidants were later replaced by synthetic substances which were cheaper and had more consistent antioxidant properties. However, the increased use of various

synthetic antioxidants was challenged by consumers, and the demand for natural antioxidants grew, as they were considered to be more acceptable as dietary components. Much attention has been given over the last few decades and lately to naturally occurring antioxidants because of the worldwide trend to minimize or avoid the use of synthetic or artificial food additives. Most natural antioxidants are common food components and have been used in diets for thousands of years.

Antioxidants are the defense system in vivo and there are several lines of defense. The inhibition of the formation of reactive oxygen species and free radicals by sequestering metal ions, reducing hydroperoxides, hydrogen peroxide, and quenching superoxide and singlet oxygen is a great line of defense. Vitamins E and C are important lipophilic and hydrophilic radical scavenging antioxidants. Polyphenolic compounds are the other important radical scavenging antioxidants. Another line of defense is the repair, de novo, and clearance of oxidatively damaged lipids, proteins, sugars, and DNA. There are various enzymes like the lipases, proteases, and DNA repair enzymes responsible for such defense. This has attracted the attention of both the scientists and the general public to the role of these antioxidants in daily health and disease prevention.

All of these interests have led to the development of various suitable methodologies for the study of individual constituents and/or extracts from different sources. Various different methods for the assessment of antioxidant activity and antioxidant content have been developed and reported in the literature over the years. The various methodologies can be classified into those evaluating changes in a lipid substrate and those measuring free radical scavenging activity, either directly or employing a suitable probe.

The first part of the book describes the methods used to measure the antioxidant capacity and antioxidant contents in different food sources, the natural antioxidants present in different sources, and the sources of these natural antioxidants. The second part describes the sources of natural antioxidants in detail. The individual herbs and spices are described in separate chapters which include descriptions on their botany, constituents, and functional properties. Their functional properties and the antioxidant activities are presented in detail. The regulatory status numbers are the Generally Recognized as Safe (GRAS) (2012) numbers for the individual herbs and spices as described by US Food and Drug Administration. The standards refer to the specifications as described by the International Organization for Standardization. The antioxidant content, ORAC values, active constituents, and contents of different antioxidants present in different sources are presented in Tables 4.1, 4.2, 4.3, 4.4, 4.5, 4.6, 4.7, 4.8, 4.9, 4.10, 4.11, 4.12, 4.13, 4.14, and 4.15. The nutrient composition and ORAC values are presented for different sources in Tables 6.1, 8.1, 11.1, 12.1, 13.1, 14.1, 15.1, 16.1, 16.2, 17.1, 18.1, 19.1, 20.1, 21.1, 21.2, 21.3, 22.1, 24.1, 24.2, 25.1, 25.2, 26.1, 27.1, 27.2, 29.1, 30.1, 37.1, 38.1, 41.1, 42.1, 43.1, 44.1, 45.1, 47.1, 48.1, 49.1, 50.1, 51.1, 52.1, 53.1, 54.1, 55.1, and 56.1. The H-ORAC values represent the hydrophilic-ORAC, L-ORAC represents the lipophilic-ORAC, and TP represents total phenolics (USDA 2010).

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Chapter 2
Antioxidant Assays

Recent interest in antioxidants due to their involvement in the health benefits has led to the development of a number of antioxidant capacity assays. Plants contain high concentrations of numerous redox-active secondary metabolites or antioxidants, such as ascorbic acid, carotenoids, polyphenols, glutathione, tocopherols, tocotrienols, and enzymes with high antioxidant activity to help them protect against hazardous oxidative damage. Living systems contain some complex enzymatic antioxidants like catalase, glutathione peroxidase, and superoxide dismutase that can block the initiation of •OH and the free radical chain reaction (Petersen et al. 2000). There are other important nonenzymatic antioxidants that can break free radical chain reactions (Fukutomi et al. 2006; Leonard et al. 2006). In animal cells, however, the de novo antioxidant production is much limited and hence oxidative damage is involved in aging and other chronic degenerative diseases. The simple definition of an antioxidant as described by Halliwell is "a molecule which, when present in small concentrations compared to that of an oxidizable substrate, significantly delays or prevents the oxidation of that substrate" (Halliwell 2002). Plant foods are rich sources of natural antioxidants like ascorbic acid (vit. C), phenolic acids, flavonoids, carotenoids, and tocopherols and they prevent free-radical damage. They are found to provide the phenolic hydroxyl group to react with the free radicals and consequently inhibit the oxidative mechanisms that cause diseases.

The antioxidant activity is the rate constant of the reaction between a unique antioxidant and a given free radical. The antioxidant capacity is the number of moles of free radicals scavenged by an antioxidant testing solution that could lead to a different result for the same radical. The antioxidant capacity (AOC) of natural products has been measured by a variety of methods, and is determined by several factors and thus it should be mentioned which factor is being measured by the method employed (Perez-Jimenez and Saura-Calixto 2006; Huang et al. 2005; Tarpey et al. 2004; Niki and Noguchi 2000). It is well documented that antioxidants act cooperatively and even synergistically with other antioxidants (Niki and Noguchi 2000; Ghiselli et al. 2000; Scalzo et al. 2005). There is no universal method that can measure the antioxidant capacity very accurately and quantitatively because the antioxidant activity estimation

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is highly affected by the ROS or RNS employed in the assay, even though the chemical structure of the selected antioxidant molecule primarily determines its antioxidant capacity. It has been shown that many available methods result in inconsistent results, inappropriate application and interpretation of assays, and improper specification of antioxidant capacity. For any system, it is generally recognized that the properties of the assay system can greatly influence the effectiveness of an antioxidant and hence the results with different methods employed (Takeshita and Ozawa 2004). It is thus important to employ multiple antioxidant assays to characterize the nature of the selected antioxidant preparation. It is also important to develop a simple and selective method for determining the $^{\bullet}OH$ scavenging capacity of various antioxidants. Prior et al. (2005) have given a series of requirements for a standard method for antioxidant activity of a food component.

Antioxidants are known to scavenge free radicals through a number of mechanisms like hydrogen atom transfer (HAT), single electron transfer followed by proton transfer (SET or ET-PT), and the sequential proton loss electron transfer (SPLET) mechanism, and each mechanism involves different kinetics (Zhou et al. 2004).

$$AH + ROO^{\bullet} \rightarrow A^{\bullet} + ROOH$$

$$AH + ROO^{\bullet} \rightarrow ROO^{-}\text{-}AH^{\bullet+} \rightarrow ROOH + A^{\bullet}$$

The net result of SPLET is the same as in HAT mechanism to the free radicals, from an antioxidant point of view. The 7-OH group in the flavonoids has been shown to play a very important role as the site of ionization and of electron transfer according to SPLET mechanism (Litwinienko and Ingold 2004, 2005). The reactions of electron-deficient radicals with flavonoids are accelerated by the SPLET mechanism so that there is minimized accumulation of the ROS (Musialik et al. 2009). The analysis of structure–acidity and structure–activity relationships for ten flavonoids clearly indicated that hydroxyl group at position 7 is the most acidic site. Thus, in polar solvents, this group can participate in radical reaction via SPLET. In nonpolar solvents, the most active site in quercetin (a flavonoid antioxidant commonly found in plants) is 3′,4′-dihydroxyl moiety and HAT/PCET occurs. However, in ionization-supporting solvents an anion formed at position 7 is responsible for very fast kinetics of quercetin/dpph(*) reaction because both mechanisms participate: HAT (from catechol moiety in ring B) and SPLET (from ionized 7-hydroxyl in ring A). Because of the conjugation of rings A, B, and C, the final structure of the formed quercetin radical (or quercetin anion radical) is the same for the SPLET and HAT/PCET mechanisms (Musialik et al. 2009). In ionization supporting solvents besides hydrogen atom transfer (HAT), the kinetics of the process is partially governed by sequential proton loss electron transfer (SPLET). Addition of acetic acid reduced the rate by eliminating SPLET to leave only HAT, while addition of water increased the rate by enhancing phenol deprotonation (Musialik and Litwinienko 2005).

Published review articles cover a series of methods that are classified on the basis of mechanism of reaction of radical species with antioxidants, in terms of substrate type (synthetic probe or lipid substrate or in terms of commonly used protocols).

The methods commonly used for in vitro determination of antioxidant capacity of food constituents are the inhibition of lipid peroxidation in linoleic acid system, oxygen radical absorbance capacity (ORAC) assay, ferric ions reducing antioxidant power assay (FRAP), total radical trapping antioxidant parameter (TRAP) assay, cupric ions reducing antioxidant power assay (CUPRAC), Folin–Ciocalteau reducing capacity assay (FCR), Fe^{3+}–Fe^{2+} transformation assay, DPPH radical scavenging assay, ABTS radical scavenging assay, DMPD radical scavenging assay, superoxide anion radical scavenging and ferrous ions chelating activities. These assay methods could be divided according to the reaction mechanisms in HAT and SET. HAT-based methods measure the ability of the antioxidant to quench free radicals by hydrogen donation. These reactions are solvent and pH independent and are quite rapid. The presence of reducing agents including metals could lead to high reactivity in HAT assays (Prior et al. 2005; Miguel 2010). The methods based on the HAT reaction mechanism are ORAC assay, TRAP assay, inhibition of induced low-density lipoprotein (LDL) oxidation, total oxyradical scavenging capacity assay (TOSCA), crocin bleaching assay, and chemiluminescent assay. The SET-based assays detect the ability of an antioxidant to transfer one electron to reduce any compound, including metals, carbonyls, and radicals. SET-based reactions are used to assess the ability of the antioxidant to reduce a specific oxidant. The relative reactivity is based on deprotonation and ionization potential of the reactive functional group (Lemanska et al. 2001; Wright et al. 2001; Prior et al. 2005). Thus, these reactions are pH dependent. These reactions are generally slow and require multistep processes. The major assays based on SET reaction include DPPH assay, TEAC assay, FRAP assay, CUPRAC assay, ABTS assay, DMPD assay, and Folin–Ciocalteay assay. There are other assays like the superoxide anion radical scavenging assay, hydroxyl radical scavenging assay, and hydrogen peroxide scavenging assays (Huang et al. 2005; Miguel 2010).

Several factors can influence the results of antioxidant capacity assays like the polarity, pH, and hydrogen bond accepting ability of the solvent, the ability of the solvent to donate hydrogen atoms to free radicals, and antioxidant themselves becoming radical species that will alter the results. Several studies have reported on the interference of this type in electron spin resonance spin trapping assays (Moore et al. 2006; Perez-Jimenez and Saura-Calixto 2006). Antioxidants are used in food products, and their activity could vary depending on food composition, food structure, temperature, and also the availability of oxygen. It has been observed that a nonpolar antioxidant such as α-tocopherol is relatively ineffective in an oil–water emulsion. However, a polar antioxidant like ascorbic acid or trolox is more effective in an oil than in an emulsion. Enzyme-based biosensors such as monophenol monooxygenase (tyrosinase), catechol oxidase (laccase), and horseradish peroxidase (HRP) are the most commonly used biosensors used for the detection of polyphenols and flavonoids content (Litescu et al. 2010). The following pages will describe the different antioxidant capacity assays that have been employed to evaluate the antioxidant properties of natural compounds in foods, botanicals, nutraceuticals, dietary supplements, and biological fluids.

Crocin Bleaching Assay

This method was first introduced by Bors et al. (1984) and later modified by Tubaro et al. (1996). It assesses the ability of phenolic antioxidants to protect crocin, a naturally occurring carotenoid derivative, from bleaching due to competitive reactions with radicals. Crocin is a natural carotenoid present in flowers belonging to genus such as *Crocus* and *Gardenia*. In the presence of AAPH radical, crocin is bleached, but when an antioxidant species is added, the bleaching rate decreases and the antioxidant capacity can be calculated as a function of bleaching inhibition. The antioxidant capacity is the ratio between the crocin bleaching rate in the presence and absence of antioxidants (Bors et al. 1978, 1984). Though this assay is considered to be applicable to "water-soluble" radical scavengers and related compounds, a modification of the method using either canthaxanthin as a probe (Bors et al. 1984) or a lipophilic initiator in organic solvents like toluene (Tubaro et al. 1996; Finotti and Di Majo 2003) has been proposed when "lipid-soluble" compounds are being tested. Recently, Kampa et al. (2002) introduced a new automated version of this assay using microplates for the estimation of the plasma total antioxidant capacity. It was also proposed to calculate the antioxidant capacity of plasma after a subtraction of all interferences deriving from endogenous and/or exogenous metabolites. The antioxidant capacity of plasma thus calculated can then be used as a useful indicator of the antioxidant value of foods and beverages in the daily diet. This assay has been used in SAR studies of simple phenols, phenolic acids, and flavonoids (Natella et al. 1999; Di Majo et al. 2005; Notas et al. 2005; Ordoudi et al. 2006; Ordoudi and Tsimidou 2006a, b; Bortolomeazzi et al. 2007; Soldera et al. 2008).

Ferric Thiocyanate Assay

This method was used to measure the peroxide level during the initial stages of lipid oxidation. In this method, the peroxides formed during the linoleic acid oxidation react with Fe^{2+} to form Fe^{3+}, which then reacts with thiocyanate to form a complex which has maximum absorbance at 500 nm. The presence of antioxidants slows down the oxidation of linoleic acid and this is measured at 500 nm (Ono et al. 1999; Gulcin and Dastan 2007).

DPPH Radical Scavenging Capacity Assay

This is a spectrophotometric assay based on the scavenging of DPPH (2,2-diphenyl-1-picrylhydrazyl) radicals (DPPH$^{\bullet}$). This method was first reported by Blois (1958). This is a decolorization assay that measures the capacity of antioxidants (AH) to directly react with DPPH radicals by monitoring the decrease in absorbance at 517 nm due to the reduction by antioxidants or reaction with a radical species (R$^{\bullet}$)

(Brand-Williams et al. 1995). DPPH is a stable free radical showing a maximum absorbance at 517 nm. However, when it encounters a proton-donor substrate like an antioxidant, the radicals are scavenged and absorbance is reduced (Blois 1958). The reduction of absorbance is the measure of free DPPH due to the action of the AH (Samadi et al. 2011). The DPPH is the most common synthetic radical to be used for the study of the contribution of structural characteristics to the radical scavenging activity of phenolic compounds (Nenadis et al. 2007; Kozlowski et al. 2007; Bortolomeazzi et al. 2007; Ordoudi et al. 2006; Brand-Williams et al. 1995; Blois 1958). Various versions of the DPPH$^{\bullet}$ test have been reported in the literature, regarding the reaction conditions as well as expression of results (Brand-Williams et al. 1995; Calliste et al. 2001; Huang et al. 2005; Milardovic et al. 2005; Stasko et al. 2007; Magalhaes et al. 2008) The DPPH radical is a purple-colored stable organic nitrogen centered free radical which becomes colorless when reduced to its non-radical form by AH.

$$\mathrm{DPPH}^{\bullet} + \mathrm{AH} \rightarrow \mathrm{DPPH\text{-}H} + \mathrm{A}^{\bullet}$$

$$\mathrm{DPPH}^{\bullet} + \mathrm{R}^{\bullet} \rightarrow \mathrm{DPPH\text{-}R}$$

The reaction between phenols and DPPH proceeds through both the direct HAT and SPLET mechanisms (Foti et al. 2004; Musialik and Litwinienko 2005):

$$\text{(HAT)} \quad \mathrm{Ar\text{-}OH} + \mathrm{DPPH}^{\bullet} \rightarrow \mathrm{Ar\text{-}O}^{\bullet} + \mathrm{DPPH-H}$$

$$\text{(SPLET)} \quad \mathrm{Ar-OH} \rightleftarrows \mathrm{Ar-O}^{-} + \mathrm{H}^{+}$$

$$\mathrm{Ar-O}^{-} + \mathrm{DPPH}^{\bullet} \rightarrow \mathrm{Ar-O}^{\bullet} + \mathrm{DPPH}^{-}$$

$$\mathrm{DPPH}^{-} + \mathrm{H}^{+} \rightarrow \mathrm{DPPH-H}$$

The first method published was by Brand-Williams et al. (1995) though the measurements date back to the 1950s (Blois 1958). The data are commonly reported as EC_{50} which is the AH concentration required to reduce the initial DPPH$^{\bullet}$ concentration by 50% in the specified time period. A lower EC_{50} value represents a stronger DPPH radical scavenging capacity under identical conditions. These results are also reported as antiradical power (ARP) calculated as $1/EC_{50}$, in which larger ARP values represent larger scavenging capacity. Since it became impossible to compare the results obtained by different groups at different laboratories, several new changes were proposed to this method. Sanchez-Moreno et al. (1998) reported a term antiradical efficiency (AE) where $AE = 1/EC_{50} \times T_{EC50}$, where T_{EC50} was the time to reach steady state. De Beer et al. (2003) and Cheng et al. (2006) reported a calculation based on different reaction rate and using a standard as antioxidant. De Beer et al. (2003) introduced the term radical scavenging efficiency (RSE) which took into account both the initial reaction rate and EC_{50}. Cheng et al. (2006) introduced the RDSC (relative DPPH$^{\bullet}$ scavenging capacity) estimation method which measures the DPPH radical scavenging capacity relative to that of an antioxidant standard like trolox. The RDSC method allows for comparison of AOC results done at different

concentrations and in different laboratories because it is independent of either sample or initial DPPH• concentrations in the assay system. Recently, carotenoids have been reported to interfere with the assay because they absorb light at 515 nm (Jimenez-Escrig et al. 2000).

The DPPH radical scavenging capacity estimation is simple and as such has been used in screening the antioxidant properties of pure compounds and botanical extracts. The major advantage of this method over other assays is its broad solvent compatibility with aqueous and polar and nonpolar organic solvents (Cheng et al. 2006), allowing it to evaluate both hydrophilic and lipophilic antioxidant compounds for their DPPH• scavenging capacities under same experimental conditions without the use of stabilizing agents. The DPPH assay is the quickest and easiest assay to perform, but it diverges from biological conditions the most, using an artificial DPPH radical and methanol as the solvent (Cao et al. 1997). This method is only able to measure direct reactions with the DPPH radical, which is dependent on the structure of an antioxidant compound and can only give a general indication of the radical scavenging abilities of antioxidants. However, it is a rapid and convenient method for screening many samples as well as not requiring expensive reagents or sophisticated equipment (Frankel. 1993; Frankel and Meyer 2000).

Oxygen Radical Absorbing Capacity Assay

This method was originally introduced as an alternative to the DPPH• assay (Glazer 1990). The oxygen radical absorbing capacity (ORAC) assay measures the degree and length of time the extracts take to inhibit the action of an oxidizing agent. It therefore takes into account the kinetics of the reaction, unlike the DPPH assay, as well as being performed at a physiological pH and producing a biologically relevant radical, the peroxyl radical (Cao et al. 1993). The assay was developed to measure the hydrophilic chain-breaking capacity of antioxidants and utilizes the fluorescent protein R-PE (R-phycoerythrin) as a detector of antioxidant activity. The ORAC assay makes use of the hydrogen atom transfer (HAT) reaction between an oxidant and a free radical and uses AAPH [2,2′-azobis(2-amidinopropane) dihydrochloride] as a peroxyl radical generator, which is a commonly found free radical in the body (Prior et al. 1998). The peroxyl radicals generated by AAPH can either react with the antioxidant extract by removing a hydrogen atom from it or by damaging R-PE, resulting in a loss of fluorescence. The efficiency of the extract to inhibit the decline of R-PE fluorescence is measured (Cao et al. 1993). The ORAC assay measures the antioxidant activity of the extracts against the biologically relevant peroxyl radical, as well as taking into account the kinetics of the chain-breaking reactions and using the Cobas Fara II system (Cao et al. 1995). Ou et al. (2001) reported an improved method using a more stable and less expensive fluorescent probe, fluorescein (FL) (3′,6′-dihydroxyspiro[isobenzofuran-1[3H],9′[9H]-xanthen]-3-one). In this method, the oxidized FL products induced by peroxyl radical were identified by LC/MS, and the reaction mechanism was determined to follow a classic hydrogen atom transfer

mechanism. The lag time, rate, and total inhibition are taken into consideration in a single value, and thus this assay estimates the "capacity" and not just the "reactivity" of the tested antioxidant. Huang et al. (2002a) developed a more automated analysis using a microplate reader and robotic handling system. They also (Huang et al. 2002b) developed an alternative ORAC assay for lipophilic antioxidants and extracts using β-cyclodextrin as a solubility enhancer. In the ORAC assay, the peroxy radicals generated by APPH react with FL to yield a nonfluorescent product which is monitored by measuring the loss of fluorescence of FL with a fluorometer. Trolox is a commonly used standard and the results are expressed as micromoles of trolox equivalents per unit of the sample. Recently, the ORAC values were found to be higher when ethylenediaminetetraacetic acid (EDTA) was used in the assay as a metal chelator (Nkhili and Brat 2011).The ORAC-EPR method is based on electron paramagnetic resonance and measures the decrease in AAPH radical by the scavenging action of the antioxidant (Kohri et al. 2009).

The ORAC assay has some advantages over other antioxidant scavenging capacity assays. It measures scavenging activity against a biologically relevant radical, the peroxy radical, which is involved in the oxidation of lipids in food systems (Huang et al. 2005). The ORAC assay is also conducted under physiological pH and takes into account both kinetic and thermodynamic properties of antioxidant–radical reactions. The other benefit is that it takes into account samples with and without lag phases of their antioxidant capacities and this is beneficial when measuring foods and supplements that have complex ingredients with slow- and fast-acting antioxidants. However, the ORAC assay does not measure the total antioxidant activity because other biologically relevant ROS, such as superoxide, the hydroxyl radical, and singlet oxygen, exist. Because different ROS have different reaction mechanisms, to completely determine antioxidant activity against a wide range of ROS, a more comprehensive set of assays needs to be carried out (Wang et al. 1996). Moore et al. (2006) and Cheng et al. (2007) reported the formation of carbon-centered radicals during the reaction of hydroxyl radicals with solubilizing agent and organic solvents. It was also found that gallic acid, known to be an efficient antioxidant, was estimated to be of low potency by the ORAC assay, while tyrosine and tryptophan that are not strong antioxidants were shown by ORAC assay to be very efficient with high ORAC values (Davalos et al. 2004; Perez-Jimenez and Saura-Calixto 2006).

Total Radical-Trapping Antioxidant Parameter Assay

The TRAP assay measures the ability of antioxidants to interfere with the reaction between $ROO^{\bullet}$ generated by AAPH and a target probe (Wayner et al. 1985; Niki 1990; Prior et al; 2005; Bentayeb et al. 2012). This method was developed by Wayner et al. (1985) and was one of the earliest methods used to measure the total antioxidant capacity of blood plasma or serum (Wayner et al. 1985; Leinonen et al. 1998). Ghiselli et al. (1995) introduced some modifications to this method to address the interferences from plasma proteins, lipids, and metal ions. The TRAP

assay uses $ROO^{\bullet}$ generated from the thermolysis of AAPH and the peroxidizable materials contained in the plasma or other biological fluids (Prior and Cao 1999). The inhibition of oxidation by the antioxidant species is the principle of this method. After adding AAPH to the plasma, the oxidation of the oxidizable components is monitored by measuring the oxygen consumed during the reaction at the surface of an oxygen electrode. The time interval of the reaction induction is compared to the interval time generated by the reference compound Trolox and then quantitatively related to the antioxidant capacity of food constituents. The major drawback of the original TRAP assay lies in the lack of stability of the oxygen electrode (Rice-Evans and Miller 1994). Different variations of this method have used oxygen uptake, fluorescence of R-phycoerythrin, and absorbance of ABTS as reaction probe (Wayner et al. 1985, 1987; DeLange and Glazer 1989; Ghiselli et al. 1995; Bartosz et al. 1998; Ozenırler et al. 2011). The drawback of the oxygen electrode was overcome using chemiluminescence to detect the reaction endpoint. The plasma oxidation, mediated by peroxyl radicals derived from AAPH, is accompanied by a significant chemiluminescence. This chemiluminescence is quenched when an antioxidant is added to the reaction system. The degree of quenching is proportional to the radical trapping ability of the antioxidant sample (Alho and Leinonen 1999).

ABTS Cation Radical ($ABTS^{\bullet+}$) Scavenging Capacity Assay

The ABTS [2,2′-Azinobis-(3-ethylbenzothiazoline-6-sulfonate)] cation radical ($ABTS^{\bullet+}$) scavenging capacity assay measures the capacity of antioxidants that react directly with (scavenge) ABTS cation radicals generated by a chemical method. This is a decolorization assay and it quantifies scavenging capacity by measuring the absorbance of the antioxidant–radical reaction mixture at 734 nm at a selected time point with a spectrophotometer. $ABTS^{\bullet+}$ is a nitrogen-centered cation radical which has a characteristic blue-green color, and this becomes colorless when reduced to its non-radical form (ABTS) by antioxidants. Scavenging takes place via electron donation (Huang et al. 2005). The results are expressed relative to a standard, generally trolox.

This method is a variation of the original trolox equivalent antioxidant capacity (TEAC) assay developed by Miller et al. (1993). In this original method, the $ABTS^{\bullet+}$ was generated using the peroxidase activity of metmyoglobin (Fe^{3+}) which is oxidized by H_2O_2 to ferrylmyoglobin (Fe^{4+}) radical species, to which ABTS donates an electron and forms $ABTS^{\bullet+}$. The scavenging capacity was measured at 734 nm at a preselected time. Several modifications were made to this assay later by several workers (Arnao et al. 1996, 2001; Cano et al. 1998; Miller et al. 1996; Van den Berg et al. 1999; Re et al. 1999; Cano et al. 2000; Chen et al. 2004; Erel 2004). Both methods developed by Miller et al. (1993) and Arnao et al. (1996) have been subjected to criticism because of the possible interference by test compounds with radical formation by enzyme inhibition or reaction with H_2O_2 and/or scavenge $ABTS^{\bullet+}$.

The differences in the assays are the approaches for generating ABTS$^{\bullet+}$ like using manganese dioxide or potassium persulfate or use of an azo radical initiator such as ABAP (Miller et al. 1996; Van den Berg et al. 1999). The assay also uses AAPH [2,2′-azobis(2-amidinopropane) dihydrochloride] as a peroxyl radical generator, which is a commonly found free radical in the body (Prior et al. 1998). The method was used in SAR studies of numerous flavonoids and phenolic acids (Rice-Evans et al. 1996), as well as in studying the effect of pH on the antioxidant mechanism of benzoic acids and certain flavonoids (Lemanska et al. 2001; Tyrakowska et al. 1999). Pinto et al. (2005) introduced an automated sequential injection analysis system (SIA) for the measurement of antioxidant capacity of white and red wines. Recently Wang et al. (2010) developed a colorimetric DNAzyme-based method to detect radical-scavenging capacity of antioxidant. In this new strategy, horseradish peroxidase mimicking DNAzyme catalyzes the oxidation of ABTS by H_2O_2 to generate blue/green ABTS radical, which can then be scavenged by antioxidants resulting in color change.

The ABTS$^{\bullet+}$ scavenging capacity assay system has been accepted as a reliable method both in food analysis and clinical research. This spectrophotometric assay is simple, rapid, and is suitable for antioxidants in food components. In this assay system, the pH is controlled to the physiological level at pH 7.4. The ABTS$^{\bullet+}$ is soluble in both organic solvents and water and is adapted for both the lipophilic and hydrophilic antioxidant compounds (Prior et al. 2005). ABTS$^{\bullet+}$ is applicable for both hydrophilic and lipophilic compounds and is more reactive than the DPPH radicals. This reaction involves both HAT and SET. The only disadvantage of this method is the radical, which is a nonphysiologically relevant radical.

DMPD$^{\bullet+}$ Scavenging Assay

This method was introduced by Fogliano et al. (1999) where ABTS$^{\bullet+}$ was changed for the stable DMPD$^{\bullet+}$ radical cation derived from *N*,*N*-dimethylphenylenediamine. This method was reported to be simple, more productive, and less expensive compared to the ABTS method (Schlesier et al. 2002). The endpoint of the reaction is the measure of the antioxidant efficiency (Ak and Gulcin 2008). In this assay, DMPD in the presence of an oxidant or an acidic pH is converted to a very stable and colored radical cation (DMPD$^{\bullet+}$) which has a maximum absorbance at 505 nm. In the presence of antioxidants which transfer a hydrogen atom to DMPD$^{\bullet+}$, the color is quenched and a decoloration of the solution occurs. Thus this reaction shows the ability of radical hydrogen donors to scavenge the single electron from DMPD$^{\bullet+}$. Unlike the ABTS method, this assay gives a very stable endpoint which is advantageous when large-scale testing is required. This assay has been shown to be particularly suitable for hydrophilic antioxidants. This method has been reported and used for different constituents (Fiore et al. 2005; Corral-Aguayo et al. 2008; Gulcin 2008; Jagtap et al. 2010; Gulcin et al. 2010; Dorman et al. 2011).

The major drawback of this method lies in the fact that its sensitivity and reproducibility decreased dramatically when hydrophobic antioxidants were used and organic acids also were shown to cause interference (Sanchez-Moreno 2002).

Ferric Reducing Antioxidant Power Assay

This assay measures the antioxidant capacity by measuring the reduction of the ferric tripyridyl triazine (FeIII-TPTZ) to the intensely blue-colored ferrous complex FeII-TPTZ, at low pH (Benzie and Strain 1996, 1999; Benzie et al. 1999). The FRAP method is based on a redox reaction in which an easily reduced oxidant (Fe^{3+}) is used in stoichiometric excess and antioxidants act as reductants. The reduction of ferric ions to ferrous ions causes a change in color which can be measured spectrophotometrically at 593 nm (Ou et al. 2002b). It provides fast and reliable results for plasma, single antioxidants in a pure solution, and mixtures of antioxidants in aqueous solutions and is also inexpensive (Pellegrini et al. 2003; Benzie and Szeto 1999; Gil et al. 2000; Gulcin et al. 2004, 2011; Ou et al. 2002a, b; Mukherjee et al. 2011; Zhou et al. 2011; Patil et al. 2012). However, the major drawback is that it cannot be used to determine antioxidants with oxidizable groups like –SH or those which react with Fe(II) (Somogyi et al. 2007). In this assay, it is not possible to determine the reducing ability of thiols and carotenoids (Ou et al. 2002a, b). Benzie and Strain (1999) found high FRAP values for bilirubin because it was oxidized to biliverdin which absorbs strongly at 593 nm. Moreover, the low pH in this assay also leads to protein precipitation (Chen et al. 2003).

Cupric Ion Reducing Antioxidant Capacity Assay

The CUPRAC assay was introduced by Apak et al. (2004, 2006). They utilized the copper(II)–neocuproine [Cu(II)–Nc] reagent as the chromogenic oxidizing agent (CUPRAC method). In this assay, the basis is the reduction of Cu^{2+} to Cu^{+} by the combined action of antioxidants or reducing in aqueous-ethanolic medium in the presence of neocuproine, by polyphenols, yielding the complexes with absorbance at 450 nm (Apak et al. 2004, 2010; Ozturk et al. 2007; Gulcin 2008; Celik et al. 2010; Bekdeser et al. 2011; Lee et al. 2011; Pekal et al. 2011; Turkkan et al. 2012). The reduction of Cu^{2+} by a reducing agent in the presence of neocuproine results in a Cu^{+} complex, with maximum absorption at 450 nm (Tutem et al. 1991; Apak et al. 2006, 2010). The redox chemistry of copper(II) involves faster kinetics as opposed to that of ferric ion and thus should be advantageous (Apak et al. 2004). This method is rapid, stable, selective, and suitable for a large variety of antioxidants. It is selective because it has lower redox potential than those of Folin or ferric ion based oxidative reagents. This assay measures both lipophilic and hydrophilic antioxidants (Apak et al. 2008). Since the pH 7.0 is almost physiological pH, the reaction is

simulating antioxidant action almost under normal conditions. Campos et al. (2009) used bathocuproinedisulfonic acid disodium salt as the chelating agent for their CUPRAC-BCS assay. Wei et al. (2010) used a profluorescent probe to detect oxidative stress promoted by Fe or Cu and H_2O_2 in living cells.

Superoxide Anion Radical ($O_2^{\bullet-}$) Scavenging Capacity (SOSA)

This assay was developed to measure the ability of hydrophilic antioxidants to directly react with this radical. This assay reports $O_2^{\bullet-}$ scavenging capacity as percent $O_2^{\bullet-}$ remaining and measures the ability of the selected antioxidant to compete with nitroblue tetrazolium (NBT), a molecular probe to scavenge $O_2^{\bullet-}$ which is generated by an enzymatic hypoxanthine–xanthine oxidase (HPX-XOD) system or xanthine–xanthine oxidase (X-XOD) system. The $O_2^{\bullet-}$ generated by the enzymatic system reacts with the yellow-colored NBT to form a blue-colored formazan which is measured at 560 nm spectrophotometrically (Robak and Gryglewski 1988). Superoxide anion radicals have been used extensively to determine the activity of various phenolic antioxidants (Aruoma et al. 1993; Furuno et al. 2002; Taubert et al. 2003; Rahman et al. 2006).

The anion superoxide radicals have been linked to cellular oxidative damage and cause changes in the redox environment on a cellular level (Brand et al. 2004; Schwarzlander et al. 2008). The superoxide anion ($O_2^{\bullet-}$) is formed by single electron transfer from over-reduced redox enzymes to molecular oxygen. It has a very short lifetime in living cells and is disproportioned to H_2O_2 and molecular oxygen. It is generated in vivo from the mitochondrial electron transport and can form other reactive chemical species like H_2O_2, hydroxyl radical ($^{\bullet}OH$), and peroxnitrite ($OONO^-$). In vivo $O_2^{\bullet-}$ can be enzymatically dismutated by superoxide dismutase (SOD). Plants possess several superoxide dismutases scavenging superoxide anions enzymatically (Alscher et al. 2002; Scandalios 1993; Bowler et al. 1992). Plants also have nonenzymatic $O_2^{\bullet-}$ scavengers (Hagerman et al. 1998).

Several modifications of this method are available. The first method reported used X-XOD system and to generate $O_2^{\bullet-}$ and ferricytochrome c as reducible detector probe (McCord and Fridovich 1969). Because of several issues with this method, several researchers reported improved methods based on HPX-XOD system (Paya et al. 1992), horseradish peroxidase (Pascual et al. 1992), chemical generation of $O_2^{\bullet-}$ (Flohe and Otting 1984), and new detector probes like NBT (Beauchamp and Fridovich 1971) and NBD-Cl (Olojo et al. 2005). This method has been adapted to micro-plate format using cytochrome c instead of NBT and read at 550 nm (MacDonald-Wicks et al. 2006). Saleh and Plieth (2009) used a chemiluminescence method where the light-yielding substrate is coelenterazine (CTZ), a specific $O_2^{\bullet-}$ generator (Lucas and Solano 1992). In this method, $O_2^{\bullet-}$ is generated in situ by XOD. Zhang et al. (2009) introduced a superoxide radical absorbance capacity assay based on radical production using XOD/xanthine and detection via fluorescence. The nonfluorescent probe, hydroethidine, is converted to the

fluorescent compound 2-hydroxyethidium when oxidized. This method has been validated using catechin derivatives, relative to the precision, linearity, robustness, and accuracy. Other methods based on chemiluminescence and electron spin resonance have been reported (Taubert et al. 2003; Rahman et al. 2006; Yoshida et al. 2011; Wang et al. 2012).

This method does have many disadvantages compared to the other AOC assays and as such needs improvement to be a very effect method to compare the results between samples and across laboratories.

Hydroxyl Radical (•OH) Scavenging Capacity Assay for Hydrophilic Antioxidants (HOSC)

Among the various oxygen-derived free radicals, the hydroxyl radical (•OH) is one of the most highly reactive species and harmful oxygen-derived free radicals in a living organism. When •OH is generated in excess and the cellular antioxidant defense is deficient, some free radical chain reactions can attack proteins, lipids, and nucleic acids, leading to cellular damage (Ogasawara et al. 2007). Living systems contain complex enzymatic antioxidants such as superoxide dismutase, glutathione peroxidase, and catalase which can block the initiation of •OH and the free radical chain reaction. There are also some important nonenzymatic antioxidants that can break free radical chain reactions (Fukutomi et al. 2006; Leonard et al. 2006). Thus, in order to prevent several diseases, it is necessary to develop a very simple and selective method for determining the •OH scavenging capacity of various antioxidants.

The commonly used methods for detecting •OH include electron spin resonance (ESR) (Li et al. 2004), chemiluminescence (Ogawa et al. 1999; Giokas et al. 2007), and high-performance liquid chromatography (HPLC) with ultraviolet (UV) detection (Takemura et al. 1993), electrochemical detection (ED) (Diez et al. 2001; Kilinc 2005), and fluorometric detection (Tai et al. 2002; Tang et al. 2005). The ESR method has been widely accepted to measure •OH scavenging capacity, but it requires expensive instrumentation and cannot be readily used to obtain quantitative estimates of •OH adducts because the •OH spin is unstable and may react with other products. The luminol chemiluminescence method has some advantages for •OH determination, but the luminal used also reacts with superoxide and hydrogen peroxide, resulting in measurement errors. HPLC methods involve complicated procedures. Various reagents are used to trap •OH to form a stable adduct. Then, the reagent and •OH adducts are separated by HPLC, and the procedure is time consuming.

Chemiluminescence has become a very valuable detection method in recent years in analytical chemistry because of its high sensitivity and wide linear dynamic range and the need for relatively simple instrumentation (Nakajima 1996). Tris(2,2′-bipyridine)ruthenium(III), or $Ru(bpy)_3^{3+}$, has been shown to be an important chemiluminescence reagent. When coupled with flow injection analysis (FIA) (Ukeda 2004), chemiluminescence-based methods provide a simple, rapid, and reproducible means of detection.

Chemiluminescence is generated when $Ru(bpy)_3^{3+}$ comes in contact with hydroxide ion (HO^-). It is suggested that •OH generates excited $Ru(bpy)_3^{2+*}$ in an electron transfer reaction with $Ru(bpy)_3^{3+}$. When this excited state decays to the ground state, the background emission is generated as follows:

$$Ru(bpy)_3^{2+} \rightarrow Ru(bpy)_3^{3+} + e^-$$

$$Ru(bpy)_3^{3+} + \cdot OH \rightarrow \left[Ru(bpy)_3^{2+}\right]^* + 1/2O_2 + H^+$$

$$\left[Ru(bpy)_3^{2+}\right]^* \rightarrow Ru(bpy)_3^{2+} + hv$$

The •OH radical is generated by the Fenton reaction:

$$\left(Fe^{2+} + H_2O_2 \rightarrow Fe^{3+} + \cdot OH + OH^-\right)$$

Fenton-like reaction:

$$LmMn^+ + H_2O_2 \rightarrow \cdot\ OH + OH^- + LmMn^{2+}$$

Haber–Weiss reaction:

$$O_2^{\bullet -} + H_2O_2 + \text{metal catalyst} \rightarrow \cdot\ OH + OH^- + O_2$$

$$Fe^{3+} + O_2^{\bullet -} \rightarrow\ Fe^{2+} + O_2$$

$$Fe^{2+} + H_2O_2 \rightarrow \cdot OH\ + OH^- + Fe^{3+}$$

And photodynamically:

$$H_2O_2 + \text{energy} \rightarrow 2 \cdot OH$$

$$H_2O + \text{energy} \rightarrow \cdot OH + H$$

$Ru(bpy)_3^{3+}$ and •OH are in contact in the spiral cell in the detector, and thus, the chemiluminescence is continuously maintained. Constant chemiluminescence is generated and recorded as background emission. The background emission decreases in proportion to the •OH scavenging capacity. In the fluorescent method, hydroxyl radicals react with FL to yield the nonfluorescent product which is monitored by measuring the fluorescent reduction of FL with the fluorometer. Trolox can be used as a standard and the results expressed as micromoles of trolox equivalents per unit of sample. Other methods have been reported that use different hydroxyl radical generating systems (Aruoma 1994; Li et al. 1997; Ou et al. 2002a, b; Yang and Guo 2001; Tobin et al. 2002; Moore et al. 2006; Nobushi and Uchikura 2010).

The HOSC assay has both the advantages and disadvantages compared to the other AOC assays. This method measures scavenging capacity against a physiologically important free radical unlike the ABTS and DPPH methods. This method generates pure hydroxyl radicals and has been validated with ESR technique. Similar to ORAC and RDSC assays, this HOSC assay takes into account both kinetic and thermodynamic properties of the antioxidant–radical reaction.

The HOSC method is a more complicated assay system requiring skilled operators and cannot be used to measure the scavenging properties of lipophilic compounds. Another disadvantage is that carbon-centered radicals can be formed in the reaction and this can interfere with the assay (Moore et al. 2006).

Hydroxyl Radical ($^{\bullet}OH$) Scavenging Capacity Assay for Lipophilic Antioxidants Using ESR

This assay, unlike the HOSC assay, is for lipophilic antioxidants and utilizes a Fe^{2+}/H_2O_2 system to generate the hydroxyl radicals at physiological pH and uses acetonitrile to dissolve the lipophilic antioxidants. The results are expressed relative to trolox as standard. The electron spin resonance (ESR) spin trapping is used as the detection technique. Cheng et al. (2007) developed a method using ESR and in vitro radical scavenging capacity.

The major advantage of this assay is that it can measure the scavenging capacity of lipophilic antioxidants against the highly reactive hydroxyl radicals. However, the major disadvantage of this assay is the equipment cost and reproducibility. The values from different laboratories and values obtained on different days cannot be quantitatively compared.

IRON(II) Chelating Capacity Assay

The ferrous ion chelating assay measures the capacity of antioxidants to compete with a chelator (2,2′-bipyridine or ferrozine) to form chelating complexes with iron (II). In 2,2′-bipyridine reactions, the chelating complex have a red color and are quantified at 522 nm with a spectrophotometer. In the ferrozine reaction, the color is violet which is decreased and is measured at 562 nm with a spectrophotometer. Ethylenediaminetetraacetic acid (EDTA) is used as positive control to report the relative Fe^{2+} chelating capacity of antioxidants (Yamaguchi et al. 2000; Zhou et al. 2004; Haro-Vicente et al. 2006).

The advantage of this method is that it is simple and can be used for a large number of samples with a simple spectrophotometer. It also has the disadvantage that it does not evaluate other chelator properties (Liu and Hider 2002; Buss et al. 2003).

Copper(II) Chelating Capacity Assay

Several spectrophotometric methods are reported for the Cu^{2+} chelating assay. Hydroxyl radicals can be formed from superoxide anion and hydrogen peroxide in the presence of the transition metal ions like Cu^{2+} and Fe^{2+}. Chelating metal ions can inhibit the formation of hydroxyl radicals. Neurodegenerative diseases like Alzheimer's and Parkinson's diseases have been linked to the copper-induced oxidative damage (Offen et al. 2004). Copper has also been reported to be involved in the pathogenesis of atherosclerosis (Lodge et al. 1998).

Several reports have shown the spectrophotometric assay as simple and reliable (Briante et al. 2003; Apak et al. 2004, 2010; Kong and Xiong 2006; Campos et al. 2009; Xu et al. 2010). Several groups have reported the use of electron spin resonance (ESR) to characterize antioxidant–Cu^{2+} complexes (Krishnamurthy and John 2005; Zhou et al. 2005; Su et al. 2007). However, the major disadvantage with ESR is that it cannot quantify the Cu^{2+} chelating capacity and hence makes it difficult to compare the results between samples and laboratories.

Lipid Peroxidation Inhibition Assay (OSI)

Lipids occur in nearly all food raw materials and most of them are in the form of triacylglycerols, which are esters of fatty acids and glycerol. Two major components involved in lipid oxidation are unsaturated fatty acids and oxygen. Autoxidation (spontaneous reaction of atmospheric oxygen with lipids) is the most common process leading to oxidative deterioration. The components formed in the initial stage of autoxidation are the hydroperoxides, and these are also the products formed in lipoxygenase-catalyzed oxidation. Lipid oxidation in foods leads to off-flavors, rancidity and reduction in nutritional quality. Antioxidants in food may be defined as any substance capable of delaying, retarding or preventing the development in food of rancidity or other flavor deterioration due to oxidation. In theory, if hydroperoxides are absorbed they are a potential source of radicals, which may cause damaging effects in vivo. In vivo, lipid oxidation can lead to a number of chronic inflammatory and neurodegenerative diseases and, as such, it is important for dietary or endogenous antioxidants to ensure human tissues remain healthy.

The OSI method was developed to evaluate the oxidative stability of fats and oils under accelerated conditions such as elevated temperature, and it measures the capacity of a selected antioxidant to suppress lipid oxidation in fats and oils (AOCS 1992; Akoh 1994). The capacity of the antioxidant sample in preventing lipid oxidation is measured by comparing the induction time of an oil with or without the antioxidant. The capacity results may be reported in hours beyond control, or protection factor or index calculated as induction time of sample divided by induction time of control (Liang and Schwarzer 1998).

This OSI method is a relative simple assay, but it has several disadvantages like the changes in reaction temperature. The OSI method does not measure antioxidant capacity by one single mechanism but rather measures inhibition of overall lipid oxidation that could happen through several mechanisms. There is no standardized condition and hence difficult to compare the results between laboratories and samples. Recently, Nakatani et al. (2001) reported the use of methyl linoleate as model oil substrate for OSI assays.

Low-Density Lipoprotein Peroxidation Inhibition Assay

This assay measures the amount of secondary lipid oxidation products capable of reacting with thiobarbituric acid (TBA) of samples at 532 nm with a spectrophotometer. It estimates the capacity of the samples to prevent copper(II)-induced lipid oxidation to LDL. The secondary lipid oxidation products, thiobarbituric acid reactive substances (TBARS), are quantified using 1,1,3,3-tetraethoxypropane as standard. The oxidation of LDL to malondialdehyde can be measured using the TBARS assay. Results are expressed as milligrams of TBARS reduction per gram of sample relative to a solvent control.

Oxidative modifications of LDL have been implicated in the pathogenesis of atherosclerosis. LDL oxidation can be mediated by various processes, such as by the action of transition metal ions (copper or iron), nitric oxide/superoxide radicals or by the action of peroxidase enzymes (Berliner and Heinecke 1996; Dimmeler et al. 1999a, b; Fujita et al. 2000; Kamiyama et al. 2009). For example, the free-radical mediated oxidation of LDL leads to lipid peroxidation, which actually is the autoxidation of the polyunsaturated fatty acid chains of lipids by a radical chain reaction (Mao et al. 1991; Porter et al. 1995). A diet rich in antioxidants thus could be helpful in preventing the formation of oxidized LDL and thus useful in reducing the atherogenicity associated with modified LDL.

The TBARS method has been criticized by several workers for the lack of specificity in measuring lipid oxidation products (Halliwell 2002; Roginsky and Lissi 2005). The major advantage is its relevance to in vivo events and as such has found widespread use.

Nitric Oxide Radical (NO•) Scavenging Capacity Assay

Nitric oxide is an important free radical formed in vivo, which can participate in both physiological and pathological processes (Pacher et al. 2007). It is an important cell signaling molecule in mammals, including humans (Hou et al. 1999). $NO^{\bullet}$ can react with superoxides to form peroxynitrite, which can promote the oxidation of lipids (Brannan et al. 2001). The $NO^{\bullet}$ consumption over time in the presence of antioxidants was followed using a NO-meter while testing a series of flavonoids in

aqueous solution (pH 7.4). The NO• solution was prepared by commercial NO gas dissolved in water that was deoxygenated with gaseous nitrogen (Van Acker et al. 1995). The reaction was pseudo-first-order kinetics, as the tested compound was in excess. This pseudo-first-order rate constant was then divided with the concentration of the antioxidant to get the scavenging rate constant. A simple method was developed for the quantification of NO• scavenging capacity of sulfur-containing compounds in aqueous solution using an amperometric NO sensor (Vriesman et al. 1997). After correction for spontaneous degradation of NO•, second-order rate kinetics of the scavenging reaction was determined. The chemical production of NO• and subsequently its determination via reaction with Griess reagent was another method developed. The sodium nitroprusside gives rise to nitric oxide that under interaction with oxygen produces nitrite ions measured by Griess Illosvoy reaction (Hazra et al. 2008). This method was used to test curcumin and related compounds (Sreejayan and Rao 1997). Fluorescence detection of NO is promising as various probes are being developed for such purposes (Gomes et al. 2006). ESR spectroscopy could also be employed for NO• scavenging testing using methods described for phenolic compounds isolated from *Agrimonia pilosa* (Taira et al. 2009). Qiang and Zhou (2009) developed a method to determine nitric oxide using horseradish peroxidase by UV second-order derivative spectrometry.

Cellular Antioxidant Activity Assay

This method was developed at Cornell University. This is a cell-culture method designed to register bioavailability, uptake and metabolism of antioxidants. It measures the ability of antioxidants to prevent oxidation of dichlorofluorescein by azide-generated peroxyl radicals in human hepatocarcinoma HepG2 cells. The decrease in cellular fluorescence compared to the control cells indicates the antioxidant capacity of the compounds (Carini et al. 2000; Rota et al. 1999).

Total Phenolic Content Assay

The Folin–Ciocalteu (FC) assay is the most popular method for total phenolic compound estimation. This method measures the change in color from yellow of the FC reagent to dark blue in the presence of antioxidant samples and is measured with a spectrophotometer at 750–765 nm. Gallic acid is the commonly used TPC standard and the results are expressed as milligrams GE per gram sample. The chemistry behind this assay relies on the SET mechanism in alkaline medium from phenolic compounds and other reducing species forming blue complexes (Singleton et al. 1999)

This method was originally developed by Folin and Ciocalteu in 1927 (Folin and Ciocalteu 1927). The method has been revised which includes automation of analysis (Singleton and Rossi 1965; Slinkard and Singleton 1977; Singleton et al. 1999;

Prior et al. 2005; Magalhaes et al. 2006; Roura et al. 2006; Medina-Remon et al. 2009; Kontogianni and Gerothanassis 2012). A new enzymatic method was introduced by Stevanato et al. (2004) for total phenolic compound estimation.

The major advantage of this TPC assay is that it is very simple, popular, inexpensive and reproducible. Several disadvantages have been reported for this method such as possible interferences by other reducing agents, but it still remains a very popular method.

Recently, enzyme-based biosensors like monophenol monooxygenase (tyrosinase), catechol oxidase (laccase) and horseradish peroxidase (HRP) have been developed for the detection and determination of polyphenols and flavonoids content (Mello et al. 2003; Jarosz-Wilkolazka et al. 2004; Gamella et al. 2006; Li et al. 2006; Abhijith et al. 2007). Biosensors allow quantitative and semi-quantitative analyses and this is based on the use of biological recognition elements or biochemical receptors, which are in direct contact with a transductor element. The use of these polyphenol-oxidase based biosensors to measure the phenol content from foodstuffs and plant extracts gives a higher selectivity compared to the traditional Folin Ciocalteu method. In addition, the biosensor method is exempt from interferences caused by various other compounds present in different plant materials (Prior et al. 2005).

Total Flavonoid Content Assay

Flavonoids are one of the most diverse and widespread group of natural compounds and are probably the most natural phenolics. The total flavonoid content is measured by the aluminum chloride colorimetric assay. In this method, an aliquot (2 mL) of the sample is mixed with 0.2 mL of 5% sodium nitrite. After 5 min, 0.2 mL of 10% aluminium chloride is added to the mixture. After 6 min, 2 mL of 1 M NaOH is added to the mixture. The final volume is made up to 5 mL with 50% ethanol and the absorbance iss measured at 510 nm against a blank. The total flavonoid content is expressed as quercetin equivalents (Liu et al. 2008; Prasad et al. 2010; Hazra et al. 2010). Other variations of this method are also employed (Aiyegoro and Okoh 2010; Yang et al. 2009).

Total Anthocyanin Determination by pH-Differential Method

Anthocyanins are metabolic products of flvanones and hence are placed in the flavonoid group. The content of total anthocyanin can be determined by the pH-differential method (Giusti and Wrolstad 2001). The sample is diluted with KCl buffer (0.025 M, pH 1.0) and sodium acetate buffer (0.4 M, pH 4.5), and then put in the dark at room temperature for 15 min. The absorbances at 510 nm and at 700 nm are measured, respectively. The absorbance (A) is calculated as follows: $A = (\mathrm{Abs}_{510\ \mathrm{nm}} - \mathrm{Abs}_{700\ \mathrm{nm}})_{\mathrm{pH\ 1.0}} - (\mathrm{Abs}_{510\ \mathrm{nm}} - \mathrm{Abs}_{700\ \mathrm{nm}})_{\mathrm{pH\ 4.5}}$. The total anthocyanin

concentration in the original sample is calculated using the following equation: Total anthocyanin (mg L^{-1}) = ($A \times MW \times DF \times 1{,}000$)/($\varepsilon \times L$), where MW = 449.2, the molecular weight of Cyanidin 3-*O*-glucoside chloride (Cyd-3-glu); DF, dilution factor; ε = 26,900, the molar absorptivity of Cyd-3-glu; L = 1 cm, the path length of cuvette.

Several high-resolution screening assays have been developed during the last decade, combining HPLC with fast post column reaction, often with a solution of a chromagen free radical. The radical scavengers are identified by a UV detector as negative peaks. Several in-line coupling methods have been employed such as diode array or UV detectors with mass spectrometers, or sample preparation with solid phase extraction followed by characterization with nuclear magnetic resonance spectrophotometers (Niederländer et al. 2008; Van Beek et al. 2009). Recently electrochemical biosensors have been used and these are fast with simple operation protocols. Several amperometric biosensors have been developed for the detection of mono- and polyphenols (antioxidants) on the basis of enzymes such as tyrosinase, laccase or peroxidase (Mello and Kubota 2002). These allow the estimation of the total phenol content. There are the other biosensors for measuring the antioxidant capacity which are electrochemical and use ROS in their configurations. For the measurement of the superoxide radical ($O_2^{\bullet -}$), usually generated through the xanthine/XOD enzymatic system, the cytochrome c and superoxide dismutase biosensors are used. The cytochrome c biosensors are based on the direct electron transfer between the immobilized redox protein and electrode surface, promoted by SAMs. However, only first generation SOD sensors have been employed to estimate the antioxidant capacity. These SOD sensors are more selective and sensitive. DNA-based sensors have also been developed to determine the $OH^{\bullet}$, generated by Fenton reaction (Tammeveski et al. 1998; Manning et al. 1998; Ignatov et al. 2002).

There is a large diversity of methods or assays for the determination of antioxidant capacity of food components as reported here and elsewhere. The total antioxidant capacity of components is dependent on a multitude of factors. The most commonly accepted methods for antioxidant capacity estimations rely on the inhibition of radical chain reactions caused by a presumed antioxidant. The most commonly employed methods are based on the decrease of absorbancy of a long-lived free radical in the presence of an antioxidant. However, these diverse methods differ from each other in terms of the reaction mechanisms, reaction conditions, oxidant and target species and the expression form of results. Therefore, comparison of data from different studies is difficult.

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Chapter 3
Natural Antioxidants

The importance of the antioxidants present in foods is well appreciated for both preserving the foods themselves and supplying essential antioxidants in vivo. It is widely accepted that plant-based diets with high intake of fruits, vegetables, and other nutrient-rich plant foods help reduce the risk of oxidative stress-related diseases (Johnson 2004; Joshipura et al. 2001; Riboli and Norat 2003; Stanner et al. 2004; American Institute of Cancer Research 2007; Carlsen et al. 2010). Plants contain high concentrations of numerous antioxidants, such as polyphenols, carotenoids, tocopherols, tocotrienols, glutathione, ascorbic acid, and enzymes with antioxidant activity, which help to protect them from hazardous oxidative damage (Demmig-Adams and Adams 2002; Benzie 2003). There are numerous antioxidants in plants consumed in the diet including carotenoids and phenolic compounds like benzoic acid derivatives, flavonoids, proanthocyanidins, stilbenes, coumarins, lignans, and lignins (Lindsay and Astley 2002). Some low-molecular-weight peptides derived from plant and animal sources have been shown to possess antioxidant properties (Brown et al. 1999). Natural antioxidants are found in plants, microorganisms, fungi, and even animal tissues. Primary antioxidants inhibit or retard oxidation by scavenging free radicals and include phenolic compounds like α-tocopherol. Secondary antioxidants operate by a number of mechanisms such as binding of metal ions, scavenging ROS, converting hydroperoxides to non-radical species, absorbing UV radiation, or deactivating singlet oxygen. The following pages describe these antioxidants in more detail. The structures of the important compounds are presented in Figs. 3.1, 3.2, 3.3, 3.4, 3.5, and 3.6.

Plant Phenolics

Phenolic compounds or polyphenols are the important groups of compounds occurring in plants, where they are widely distributed, and comprising atleast 8,000 different known structures (Bravo 1998). Polyphenols are a large family of naturally occurring plant products that are very widely distributed in plant foods, including

D.J. Charles, *Antioxidant Properties of Spices, Herbs and Other Sources*,
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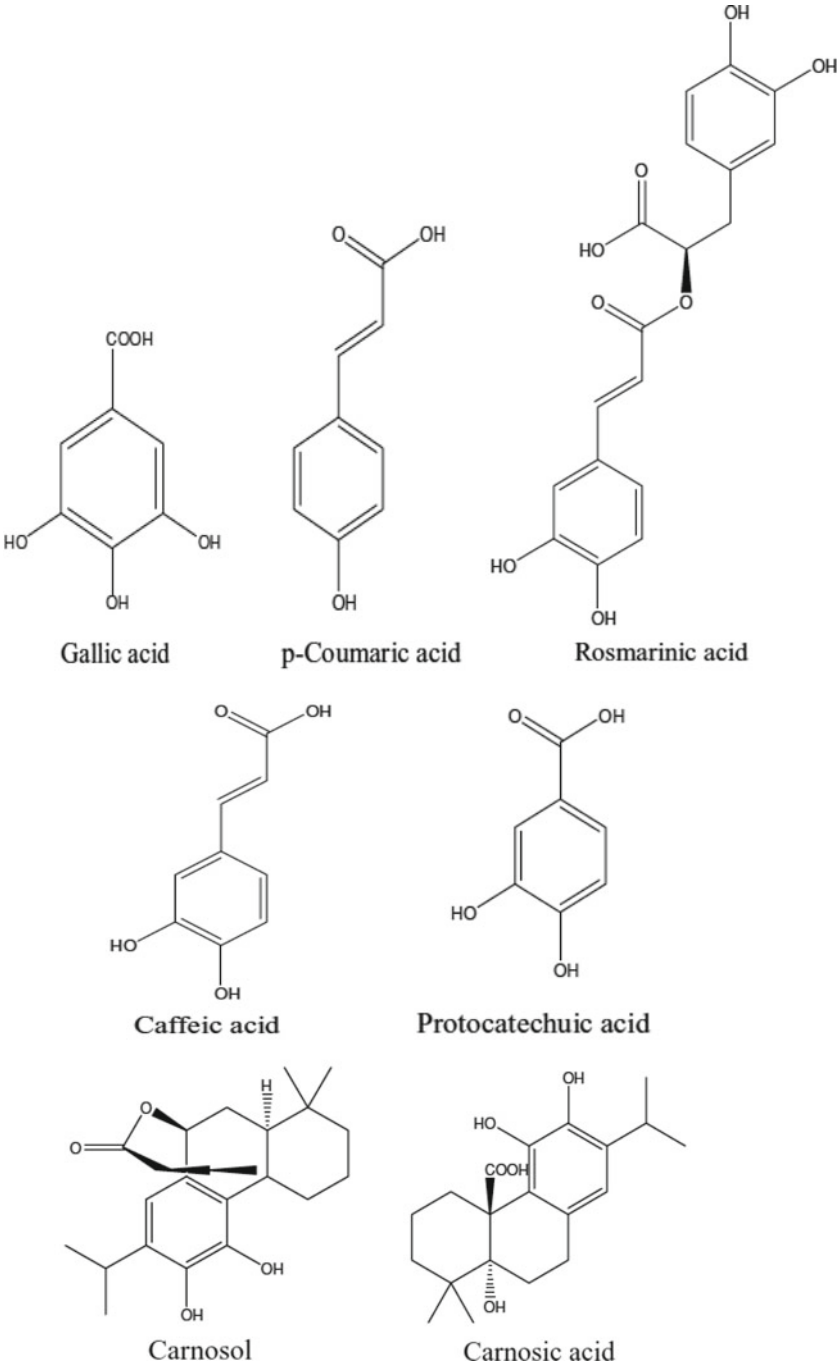
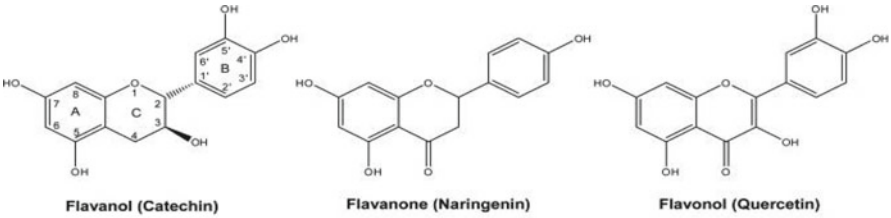
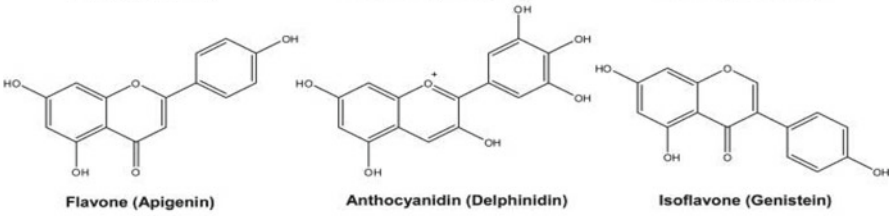
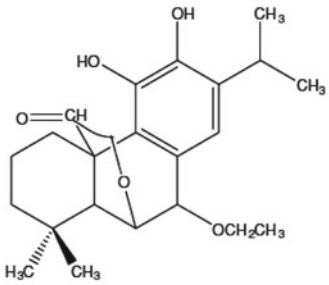
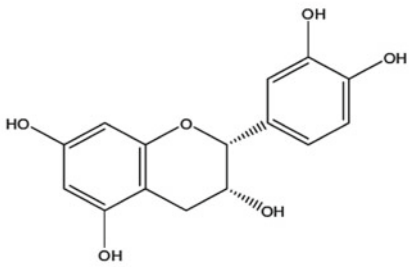


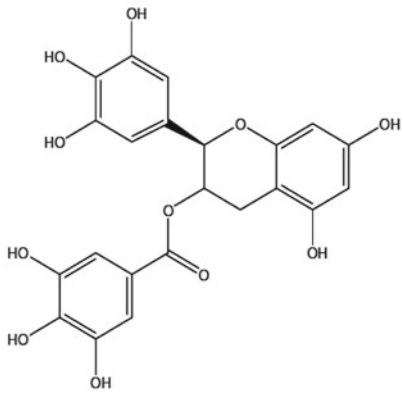
Fig. 3.1 Important phenolic compounds






Rosmanol


Epicatechin


Epicatechin gallate

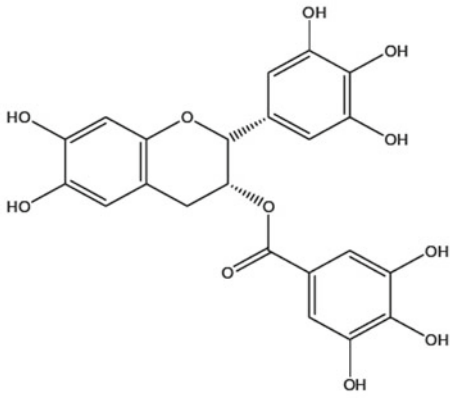

Epigallocatechin gallate

Fig. 3.1 (continued)

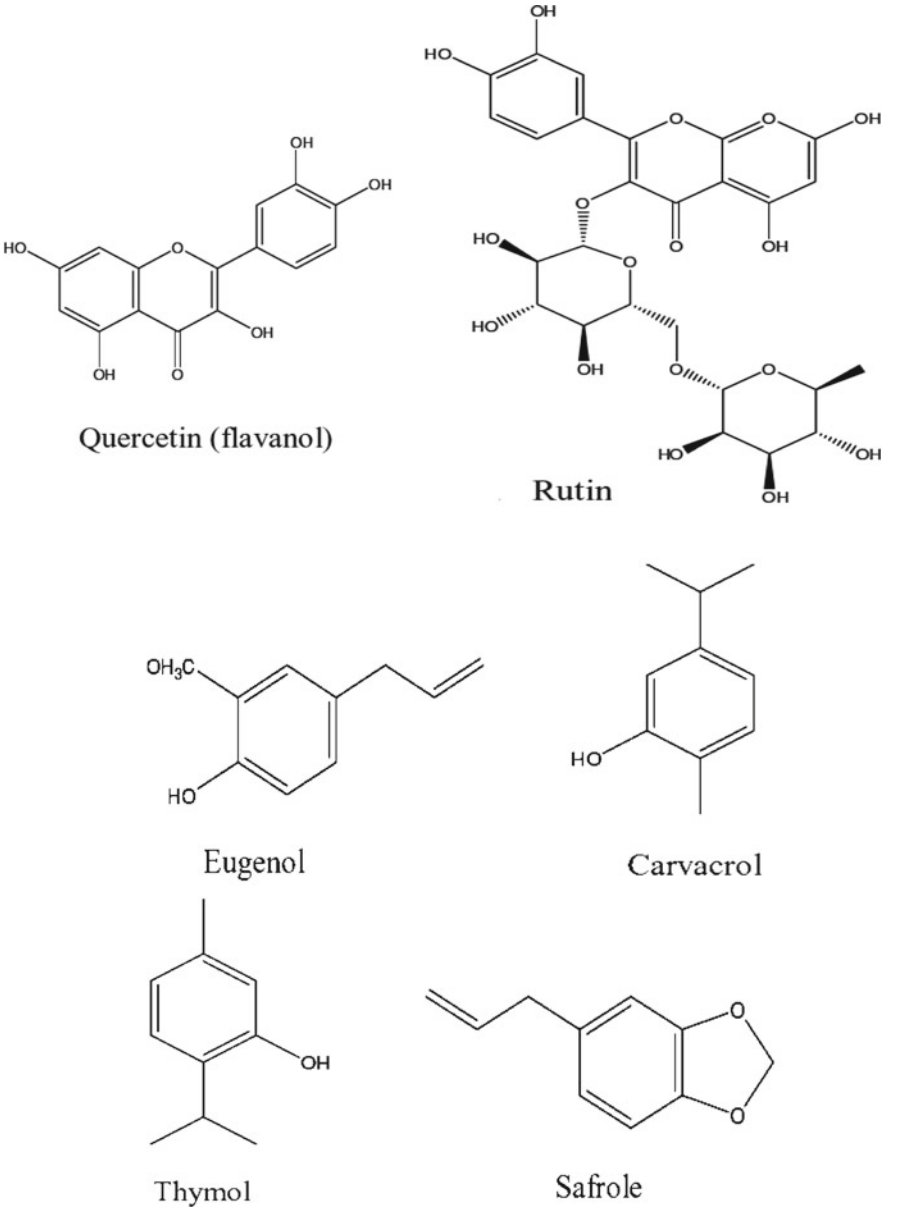


Fig. 3.1 (continued)

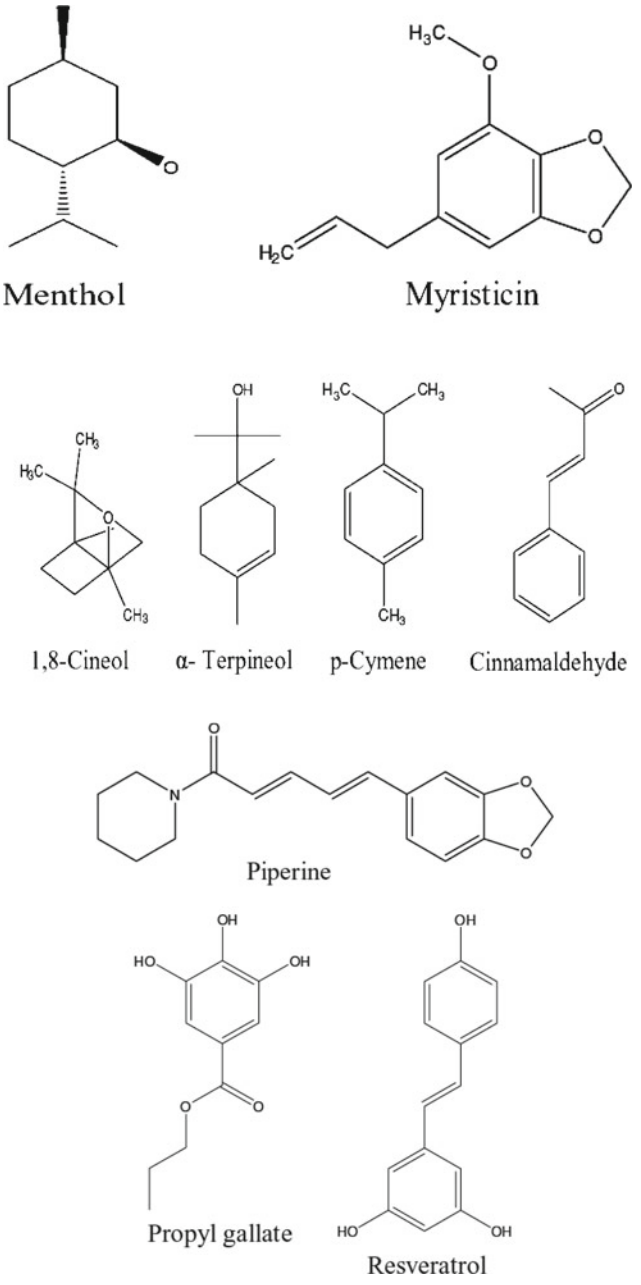


Fig. 3.1 (continued)

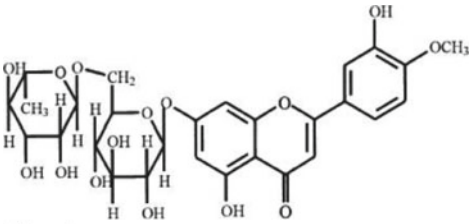


Fig. 3.1 (continued)

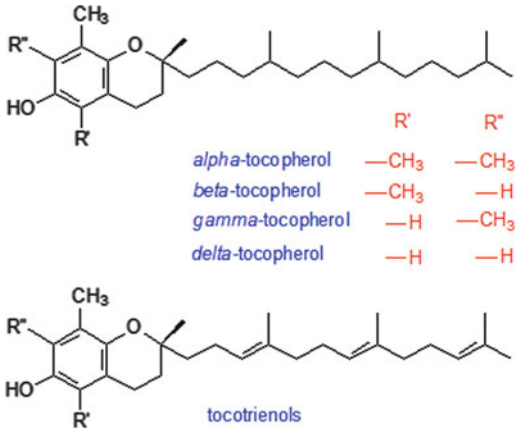


Fig. 3.2 Alpha-, beta-, gamma-, and delta-tocopherols and tocotrienols

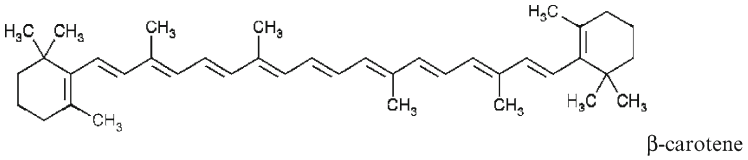


Fig. 3.3 Beta-carotene

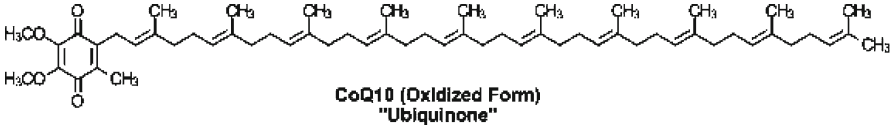


Fig. 3.4 Ubiquinone

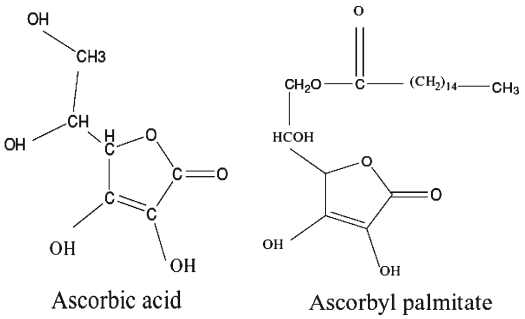
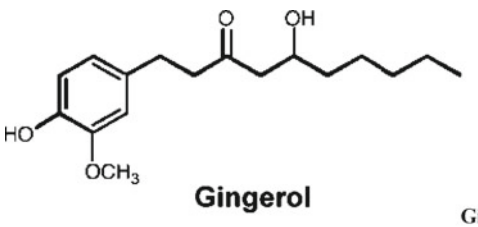
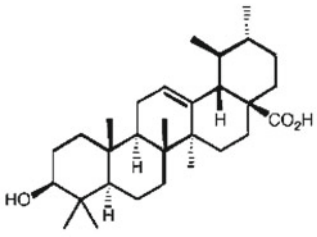


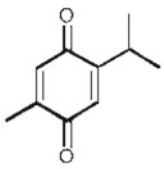
Fig. 3.5 Structure of ascorbic acid and ascorbyl palmitate



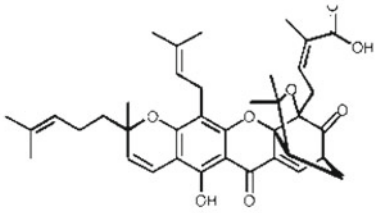
Ginger



Rosemary



Kalonji (Nigella sativa)



Kokum(Garcinia indica)

Fig. 3.6 Some important spice chemicals

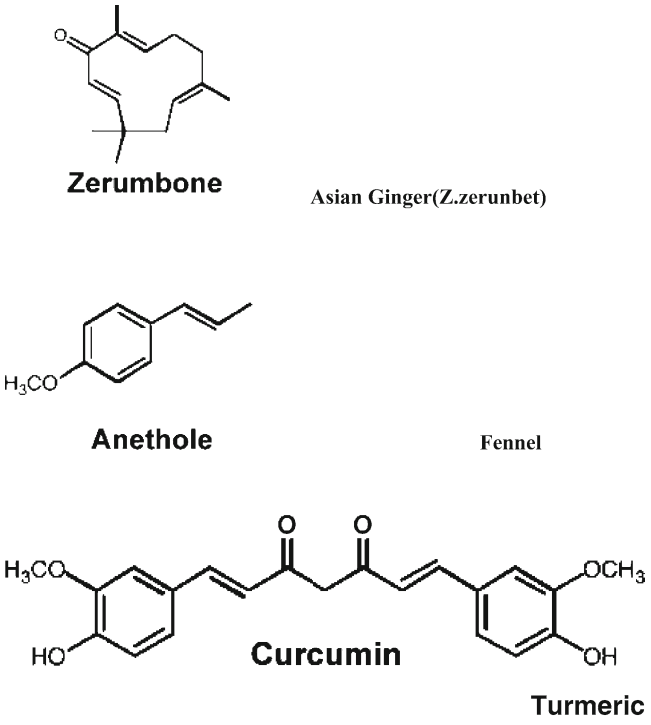


Fig. 3.6 (continued)

fruits, vegetables, nuts, seeds, flowers, and bark. Many phenolic compounds have been reported to possess potent antioxidant activity and to have anticarcinogenic/antimutagenic, antiatherosclerotic, antibacterial, antiviral, and anti-inflammatory activities (Veeriah et al. 2006; Baidez et al. 2007; Han et al. 2007). Epidemiological studies have associated these polyphenols with a reduced risk of cardiovascular diseases, and this is attributable, at least in part, to their direct effect on blood vessels, and in particular on endothelial cells. Polyphenols from teas, grapes, berries, and plants have also been found to activate endothelial cells to increase the formation of potent vasoprotective factors including nitric oxide (NO) and endothelium-derived hyperpolarizing factor. There are several experimental and clinical studies indicating that chronic intake of several polyphenol-rich natural products is able to improve endothelial dysfunction and to decrease vascular oxidative stress associated with major cardiovascular diseases such as hypertension. These observations suggest that polyphenol-rich sources of natural products have the potential to improve the function of blood vessels and, hence, to protect the vascular system. Phenolic compounds from medicinal herbs and dietary plants possess a range of bioactivities and play an important role in prevention of diseases. They have complementary and overlapping mechanisms of action including antioxidant activity and scavenging free radicals (Mitchell et al. 1999; Chen et al. 2000; Yamauchi et al. 2005; Han et al. 2007; Shih et al. 2007; Takahama et al. 2007). Phenolic compounds are generally categorized as

phenolic acids and analogs, flavonoids, tannins, stilbenes, curcuminoids, coumarins, lignans, quinones, and others based on the number of phenolic rings and of the structural elements that link these rings (Fresco et al. 2006). Increased consumption of antioxidant-rich foods in general, and of polyphenols in particular, is associated with better cognitive performance in elderly subjects at high cardiovascular risk (Valls-Pedret et al. 2012).

The synthesis of mono- and polyphenolic compounds is from the carbohydrates by way of shikimic acid, phenylpropanoid, and flavonoid biosynthetic pathways. Important dietary sources of polyphenols are onions (flavonols); cacao, grape seeds (proanthocyanidins); tea, apples, and red wine (flavonols and catechins); citrus fruits (flavanones); berries and cherries (anthocyanidins); and soy (isoflavones) (Nichols and Katiyar 2010; Manach et al. 2004). Numerous lines of evidence suggest that dietary polyphenols such as resveratrol, (−)-epigallocatechin-3-gallate (EGCG), and curcumin have the capacity to mitigate age-associated cellular damage induced via metabolic production of reactive oxygen species (Queen and Tollefsbol 2010). Recent evidence suggests that these polyphenols are capable of preventing formation of new vasculature in neoplastic tissues and thus have a role as anticancer agents. Polyphenols have also demonstrated their inhibitory effects against chronic vascular inflammation associated with atherosclerosis. Polyphenols can induce detoxifying enzymes like GST and quinine reductase (QR), and this can protect cells from carcinogenic intermediates, exogenous or endogenous (Fiander and Schneider 2000; Nair et al. 2007; Duthie 2007). These polyphenols are also produced by plants as a secondary metabolite. Plants contain a diverse group of phenolic compounds including simple phenols, phenolic acids (like rosmarinic and carnosic acid), anthocyanins (delphinidin), hydroxybenzoic acids (vanillic acid), hydroxycinnamic acid (ferulic and chlorogenic acid), tannins (procyanidin and tannic acid), lignans (sesaminol), stilbenes (resveratrol), coumarins (α-coumarin), essential oils (limonene, carvacrol, and eugenol), and flavonoids (apigenin, quercetin, catechin, and rutin) coming from foods such as fruits, tea, herbs, spices, coffee, seeds, nuts, and grains. The plant phenolics have numerous hydroxyl groups and hence could scavenge multiple free radicals. The major plant phenolics can be divided into four general groups: phenolic acids (gallic, protocatechuic, caffeic, rosmarinic acids), phenolic diterpenes (carnosol and carnosic acid), flavonoids (quercetin and catechin), and volatile essential oils (eugenol, carvacrol, thymol, menthol). Phenolic acids generally act as antioxidants by trapping the free radicals. The flavonoids act by scavenging free radicals and also by chelating metals. Polyphenols are the most significant compounds for the antioxidant properties of plant raw materials. The antioxidant activity of polyphenols is mainly due to their redox properties, which allow them to act as reducing agents, hydrogen donors, singlet oxygen quenchers, metal chelators, and reductants of ferryl hemoglobin (Rice-Evans et al. 1995; 1997; Prior et al. 2005; Lopez et al. 2007; Ciz et al. 2008; Gebicka and Banasiak 2009). Various dietary phenolics have been reported to attenuate reactive oxygen species (ROS) generation through inhibition of redox sensitive transcription factors such as NF-κB and AP-1 responsible for the expression of the ROS-induced inflammatory enzyme cascade. Xanthine oxidase, COX-II, and LOX have also been shown to be reduced by dietary phenolics

like curcumin, silymarin, and resveratrol (Ferrero et al. 1998; Suhr 2003; Kundu and Suhr 2004; Aggarwal and Shishodia 2006).

Phenolic acids are a major class of phenolic compounds, widely occurring in the plant kingdom and include hydroxybenzoic acids (e.g., gallic acid, *p*-hydroxybenzoic acid, protocatechuic acid, vanillic acid, and syringic acid) and hydroxycinnamic acids (e.g., ferulic acid, caffeic acid, *p*-coumaric acid, chlorogenic acid, and sinapic acid). Natural phenolic acids, either occurring in the free or conjugated forms, usually appear as esters or amides. Several other polyphenols are considered as phenolic acid analogs such as capsaicin, rosmarinic acid, gingerol, gossypol, paradol, tyrosol, hydroxytyrosol, ellagic acid, cynarin, and salvianolic acid B (Cai et al. 2004, 2006; Fresco et al. 2006; Han et al. 2007). Red fruits (blueberry, blackberry, chokeberry, strawberry, red raspberry, sweet cherry, sour cherry, elderberry, black currant, and red currant) are rich in the hydroxycinnamic acids (caffeic, ferulic, *p*-coumaric acid) and *p*-hydroxybenzoic, ellagic acid, and these contribute to their antioxidant activity (Jakobek et al. 2007). Rosmarinic acid an antioxidant phenolic compound is found in many dietary spices such as mint, sweet basil, oregano, rosemary, sage, and thyme (Shan et al. 2005). Gallic acid as a natural antioxidant was found to show significant inhibitory effects on cell proliferation, induced apoptosis in a series of cancer cell lines, and showed selective cytotoxicity against tumor cells with higher sensitivity than normal cells (Faried et al. 2007). Hydroxytyrosol inhibited cell proliferation and the activities of lipoxygenases (LOXs), increased catalase (CAT) and superoxide dismutase (SOD) activities, reduced leukotriene B4 production, decreased vascular cell adhesion molecule-1 (VCAM-1) mRNA and protein, slowed the lipid peroxidation process, attenuated Fe^{2+}- and NO-induced cytotoxicity, and induced apoptosis by arresting the cells in the G0/G1 phase (Fabiani et al. 2002; Fki et al. 2007; Schaffer et al. 2007). Phenolic acids present in fruits and vegetables show a protective role against oxidative damage diseases like heart disease, cancers, and strokes and antiglaucoma (Gulcin et al. 2010a, b; Innocenti et al. 2010a, b; Ozturk Sarikaya et al. 2011; Senturk et al. 2011).

In certain phenolics like flavonoids, the OH group at 1 and 3 positions in the B-ring is active, but the OH group at 2 position in the A-ring does not scavenge free radicals (Thavasi et al. 2009). Flavonoids have been recognized as one of the largest and most widespread groups of plant secondary metabolites, with marked antioxidant properties. The general name flavonoid refers to a class of more than 6,500 molecules based upon a 15-carbon skeleton (Corradini et al. 2011). They are found in leaf epidermis and fruit skins in high concentrations and have important functions in plants as secondary metabolites in a range of processes such as pigmentation, protection against UV radiation, and disease resistance (Liu 2004; Aggarwal and Shishodia 2006). They are the natural antioxidants exhibiting a wide range of biological effects including antibacterial, anti-inflammatory, antiallergic, antithrombotic, and vasodilatory actions (Cook and Samman 1996). Flavonoids are characterized by a C_6–C_3–C_6 configuration consisting of two aromatic rings (A and B rings), and can readily participate in hydrogen donating, radical scavenging, and metal chelating mechanisms (Dziedzic and Hudson 1983; Rice-Evans et al. 1996; Cao et al. 1997). As is the case with other phenolic antioxidants, the position and the

number of hydroxyl groups dictate the antioxidant activity of flavonoids (Dziedzic and Hudson 1983; Cao et al. 1997). The metal chelating activity of flavonoids requires the presence of the 3′,4′-dihydroxy configuration and more importantly the C-4 quinone and a C-3 or C-5 OH.

The major subclasses of flavonoids are the flavones, flavonols, flavanols, chalcones, flavanones, isoflavonoids, neoflavonoids, biflavonoids, flavanonols, and anthocyanins.

Flavonols are the most widespread of all the flavonoids and numerous flavonol conjugates exist with over 200 different sugar conjugates of kaempferol. These flavonols are present in a large range of food sources such as onions, cherries, blueberries, apples, broccoli, kale, tomato, berries, tea, red wine, caraway, cumin, and buckwheat. The major flavonols such as myricetin, quercetin, morin, galangin, kaempferol, and isorhamnetin most commonly occur as *O*-glycosides (rutin, quercitrin, and astragalin) (Liu 2004; Aggarwal and Shishodia 2006). Quercetin, one of the major dietary flavonoids, is found in fruits, vegetables, and beverages. Flavones are not very widespread and occur in parsley, celery, thyme, broccoli, tea, legumes, and certain other herbs. Apigenin, luteolin, baicalein, chrysin, and their glycosides (apigetrin, vitexin, and baicalin) are the major flavones. The skin of citrus fruit contains large quantities of polymethoxylated flavones: tangeretin, nobiletin, and sinensetin (up to 6.5 gL^{-1} of essential oil of mandarin) (Shahidi and Naczk 1995). These polymethoxylated flavones are the most hydrophobic flavonoids. Flavanones such as naringenin, hesperetin, eriodictyol, and their glycosides (naringin, hesperidin, and liquiritin) and flavanonols (taxifolin) are present in citrus fruits (oranges, lemons), grape, and the medicinal herbs of Rutaceae, Rosaceae, and Leguminosae (Ren et al. 2003; Cai et al. 2004). Flavanones are highly reactive compounds and are present in high concentrations in citrus fruits (hesperidin-flavanone rutiside, naringenin from grapefruit peel). The main aglycones are naringenin in grapefruit, hesperetin in oranges, and eriodictyol in lemons. Flavanols, such as catechin, epicatechin, epigallocatechin, epicatechin gallate (ECG), and epigallocatechin gallate (EGCG), are present in tea, apples, berries, cocoa, and catechu (Fresco et al. 2006). Flavanols occur as simple monomers of (+)-catechin and (−)-epicatechin and are the most complex of the flavonoids. Flavanols can be hydroxylated to form gallocatechins and can also be esterified to gallic acid. These are abundant in black grapes and thus in red wine. Green tea is rich in (−)-epigallocatechin, (−)-epigallocatechin galate and (−)-epicatechin gallate. Catechin and epicatechin are the main flavanols in fruit, whereas gallocatechin, epigallocatechin, and epigallocatechin gallate are found in certain seeds of leguminous plants, in grapes, and more importantly in tea (Arts et al. 2000a, b).

The hydroxycinnamic acids (caffeic, chlorogenic, *o*-coumaric, ferulic acids) exhibited antioxidant activity in a fish muscle system by donating electrons (bond dissociation energies) and this appeared to play the most significant role in delaying rancidity while the ability to chelate metals and the distribution between oily and aqueous phases were not correlated with inhibitory activities (Medina et al. 2007). Anthocyanins, including anthocyanidins (cyanidin, delphinidin, malvidin, peonidin, pelargonidin) and their glycosides, are widely distributed. Grape skins, blueberries, bayberry, red cabbages, beans, red/purple rice and corn, and purple sweet potatoes contain anthocyanins. The most common anthocyanidins are pelargonidin, cyanidin, delphinidin, peonidin, petunidin, and malvidin. Chalcones (butein, phloretin,

sappanchalcone, carthamin, etc.) are detected in herbs. The isoflavones termed phytoestrogens are genistein, daidzein, glycitein, formononetin, and their glycosides (genistin, daidzin), derived from soya, legumes, and clovers with high estrogenic activity. Soya and its processed products are the main source of isoflavones (genistein, daidzein, glycitein) in the human diet.

Flavonoids have been shown to reduce the risk of major chronic diseases, because they have powerful antioxidant activities in vitro, and can scavenge a wide range of reactive species (hydroxyl radicals, peroxyl radicals, hypochlorous acid, and superoxide radicals). Many flavonoids chelate transition metal ions such as iron and copper, decreasing their ability to promote reactive species formation. Flavonoids also inhibit biomolecular damage by peroxynitrite in vitro, prevent carcinogen metabolic activation, induce apoptosis by arresting cell cycle, promote differentiation, modulate multidrug resistance, and inhibit proliferation and angiogenic process. Flavonols like myricetin, quercetin, rutin, and quercitrin, containing more hydroxyl groups, exhibit very high radical scavenging activity, and are potent antioxidants. Kaempferol, a flavonol widely distributed in tea, broccoli, grape fruit, brussels sprouts, and apple, showed significant chemopreventive action in colorectal cancer, and this was attributed to the lowering of 1,2-dimethyl hydrazine-induced erythrocyte lysate and liver thiobarbituric acid reactive substance level and rejuvenation of antioxidant enzyme catalase, super oxide dismutase, and glutathione peroxidase (Nirmala and Ramanathan 2011). Flavanols with additional catechol structure (3-galloyl group) have significantly enhanced antiradical activity. The catechins EGCG and EGC have been shown to have significant radical scavenging ability, chelate metal ions, and prevent the generation of free radicals. Their specific chemical structures (vicinal dihydroxy or trihydroxy structure) possibly contribute to their antioxidant activity (Cai et al. 2006). Quercetin, a strong antioxidant, increases the expression of nicotinamide adenine dinucleotide phosphate (NADPH):quinine oxidoreductase and activity of SOD, CAT, GSH; decreases lipoperoxidation, NO production and inducible nitric oxide synthase (iNOS) protein expression, and levels of some oxidative metabolites; prevents lactate dehydrogenase (LDH) leakage; and enhances Nrf2-mediated (NF-E2-related factor-2, a basic region-leucine zipper transcription factor to regulate transactivation of antioxidant genes) transcription activity (Fresco et al. 2006; Han et al. 2007: Johnson 2007).

Coumarins are lactones obtained by cyclization of *cis-ortho*-hydroxycinnamic acid, belonging to the phenolics with the basic skeleton of C_6+C_3 (Cai et al. 2004). Coumarins occur in fruits, olive oil, vegetables, wine, and beverages like tea and coffee, and have been shown to have antioxidant and anticancer effects in cells and animal models (Fylaktakidou et al. 2004). The major coumarin constituents are simple hydroxycoumarins (aesculin, esculetin, scopoletin, and escopoletin), furocoumarins and isofurocoumarin (psoralen and isopsoralen), pyranocoumarins (xanthyletin, xanthoxyletin, seselin, khellactone, praeuptorin A), bicoumarins, dihydro-isocoumarins (bergenin), and others (wedelolactone) (Cai et al. 2006). The two adjacent phenolic hydroxyl groups at the C-6 and C-7 positions in the coumarin skeleton were shown to be necessary for the potent antiproliferative and antioxidant effect of esculetin and eight other coumarin derivatives.

Curcuminoids are ferulic acid derivatives and include three main chemical compounds: curcumin, demethoxycurcumin, and bisdemethoxycurcumin. Curcumin and other phenolic agents similar in structure to curcumin have been shown to stimulate the HO-1 pathway and this most likely accounts for the powerful antioxidant/anti-inflammatory properties of these compounds (Martin et al. 2004; Goel et al. 2008; Surh et al. 2008). Curcuminoids possess unique antioxidant, anti-inflammatory, anticarcinogenic/antimutagenic, antithrombotic, hepatoprotective, antifibrosis, antimicrobial, antiviral, and antiparasitic properties and play important roles in cancer chemotherapy and act by different actions (Huang et al. 1991; Zhang et al. 1999; Rao 2007).

Lignans are formed of 2 phenylpropane units and are mainly present in plants in the free form and as glycosides (Fresco et al. 2006). Main lignan constituents are lignanolides (arctigenin, arctiin, secoisolariciresinol, and matairesinol), cyclolignanolides (chinensin), bisepoxylignans (forsythigenol and forsythin), neolignans (magnolol), and others (schizandrins, schizatherins, and wulignan; pinoresinol and furofuran lignans) (Cai et al. 2004; Surveswaran et al. 2007). Flaxseed (mainly secoisolariciresinol), sesame seeds, and Brassica vegetables (mainly pinoresinol and lariciresinol) contain unexpectedly high levels of lignans (Milder et al. 2005). The richest dietary source is linseed, which contains secoisolariciresinol (up to 3.7 $g\,kg^{-1}$ dry wt) and low quantities of matairesinol. Lignans have been shown to have antioxidant activities and other properties like anti-inflammatory, antibacterial, antiviral, antiallodynic, antiangiogenesis, and antimutagenic.

Tannins are another group of polyphenols with antioxidant and anti-inflammatory effects in human cancer cells (Liu 2004; Aggarwal and Shishodia 2006). Tannins are powerful antioxidant agents because they have many hydroxyl groups, especially many *ortho*-dihydroxyl or galloyl groups. They are classified into two classes: hydrolysable tannins (gallo- and ellagi-tannins) and condensed tannins (proanthocyanidins). Proanthocyanidins are dimers, oligomers, and polymers of catechins that are bound together by links between C4 and C8 (or C6). Tyrosol and hydroxytyrosol are monophenolic compounds found in olive oil, other edible oils, and wine with antioxidant and pro-apoptotic effects in various human cancer cells. Oleuropein found in olive oil is also important as an antioxidant (Liu 2004; Aggarwal and Shishodia 2006: Colomer and Menendez 2006).

Quinones, especially hydroxyanthraquinones, are natural phenolic antioxidants. Among the hydroxyanthraquinones, purpurin, pseudopurpurin, and alizarin were found to be most effective, while others like emodin, chrysazine, rhein, chrysophanol, and Aloe-emodin, without the *ortho*-dihydroxy structure, were far less effective (Cai et al. 2006). Natural quinones fall into four categories, that is, anthraquinones, phenanthraquinones, naphthoquinones, and benzoquinones (Cai et al. 2004).

Stilbenes are phenolic compounds displaying two aromatic rings linked by an ethane bridge, and exist in the form of oligomers and in monomeric form (resveratrol, oxyresveratrol) and as dimeric, trimeric, and polymeric stilbenes or as glycosides. Resveratrol is a stilbene-type aromatic phytoalexin and is predominantly found in grapes, peanuts, berries, turmeric, and other food products. Resveratrol is a potent antioxidant. Resveratrol has been shown to exhibit several physiological activities including anticancer and anti-inflammatory activities in vitro and in experimental

animal models as well as in humans. Anticancer activity of this compound is mainly due to induction of apoptosis via several pathways, as well as alteration of gene expressions, all leading to a decrease in tumor initiation, promotion, and progression. Resveratrol exhibits anti-inflammatory activity through modulation of enzymes and pathways that produce mediators of inflammation and also induction of programmed cell death in activated immune cells. Resveratrol has been shown to produce no adverse effects, even when consumed at high concentrations. Hence, resveratrol possesses good potential to be used as an adjunctive or alternative therapy for cancer and inflammatory diseases (Udenigwe et al. 2008).

Tocopherols

Tocopherols originate in plants and eventually end up in animal foods via the diet (Parker 1989). Tocopherols and tocotrienols belong to the vitamin E family discovered in 1922 by Evans and Bishop. Discovery of vitamin E was published in a paper in Science entitled "On the existence of a hitherto unrecognized dietary factor essential for reproduction" (Evans and Bishop 1922). Tocopherols are usually present in nuts (almonds) and vegetable oils (wheat germ, sunflower), while tocotrienols are generally present in cereal grains (barley, oat, and rye) and some vegetable oils (palm oil and rice bran oil). Vitamin E and the tocotrienol and tocopherol homologs possess strong antioxidant activity and protect against cardiovascular disease, atherosclerosis, and some cancers. Vitamin E tocopherols are stable and very effective lipid-soluble antioxidants that are available in large scale. They are generally used in oils, fats, baked goods, and meat. The tocopherols consist of four different congeners known as α-tocopherol (vitamin E), β-tocopherol, δ-tocopherol, and γ-tocopherol. Tocopherols and tocotrienols have been widely documented as having antioxidant activity, due primarily to the phenolic hydrogen at the C_6 position. Tocopherols are a group of eight different homologs that have a hydroxylated ring system (chromanol ring) with a phytol chain. In tocopherols, the ring has a 15-carbon side chain at the C-2 position while in tocotrienols the structure is similar except for the presence of three trans double bonds in the hydrocarbon tail (Sen et al. 2006; Zingg 2007). The differences in the tocopherols are due to the different degrees of methylation on the chromanol ring, with α- being trimethylated, β- and γ- being dimethylated and δ- being monomethylated. Tocotrienols have three double bonds in the phytol chain while the phytol chain of tocopherols is saturated. The principal mode of antioxidant action of tocopherols is through radical scavenging of both peroxyl and alkoxyl radicals (Frankel 1996). Tocopherols are also good singlet oxygen quenchers through a charge transfer mechanism (Kim and Min 2008). Studies have found tocopherols to be very effective in butterfat containing foods (Dougherty 1993). They are effective in slowing lipid oxidation in fish oil-enriched energy bars if prooxidative concentrations are avoided and fish fillets (Sant'Ana and Mancini-Filho 2000; Jacobsen et al. 2008). Tocopherols are also useful antioxidants when added directly in both raw and cooked meat as well as when supplemented with the feed (Lavelle et al. 1995; McCarthy et al. 2001; Formanek et al. 2001). α-Tocopherol

is a fat-soluble carotenoid whose antioxidative capacity has been studied extensively. Generally, α-tocopherol (vitamin E) is the most reactive and less stable form of all tocopherols, followed by β-, γ-, and γ-tocopherols. It is the major vitamin E compound in plant leaves where it is located in the chloroplast envelope and thylakoid membranes in proximity to phospholipids (Onibi et al. 2000). α-Tocopherol exerts its antioxidant activity by both scavenging the radicals that are responsible for the propagation of lipid peroxidation chain reaction and decreasing the assembly of active NADP-oxidase responsible for the reactive oxygen species production, which is involved in lipid peroxidation. α-Tocopherol supplementation in human subjects and animal models has been shown to decrease lipid peroxidation and superoxide (O_2^-) production by impairing the assembly of nicotinamide adenine dinucleotide phosphate (reduced form) oxidase as well as by decreasing the expression of scavenger receptors (SR-A and CD36), particularly important in the formation of foam cells. α-Tocopherol therapy, especially at high doses, has been shown to decrease the release of proinflammatory cytokines, the chemokine IL-8, and plasminogen activator inhibitor-1 (PAI-1) levels as well as decrease adhesion of monocytes to endothelium (Singh et al. 2005). Vitamin E is an important natural antioxidant, and its most common and biologically active form is α-tocopherol. Vitamin E shows beneficial effects as anti-tumorigenic, photoprotective, and skin barrier stabilizer that accounts for its wide use in cosmetic and skin care products (Sen et al. 2006; Zingg 2007; Reiter et al. 2007). The principal reserve of vitamin E is vegetable oil where its function is to protect tissue from oxidative damage. Vitamin E is a liposoluble molecule and, therefore, after dietary intake, it is easily absorbed from the intestinal lumen, and also dispersed between lipids and proteins in cell membranes. They interrupt free radical chain reactions by capturing the free radical, and this imparts them their antioxidant properties. The free hydroxyl group on the aromatic ring is responsible for the antioxidant properties of vitamin E. This hydrogen from this hydroxyl group is donated to the free radical, resulting in a relatively stable free radical form of vitamin E (Engin 2009; Sies and Murphy 1991). Estevez and Heinonen (2010) demonstrated that α-tocopherol reduced formation of α-aminoadipic acid and γ-glutamic semialdehydes from oxidized myofibrillar proteins. Dietary supplementation is also beneficial as it increases incorporation of the antioxidant into the phospholipid membrane region where the polyunsaturated fatty acids are located. There is a significant increase in antioxidant activities of the livestock tissues and the stability of the meat derived from them, when they are fed α-tocopherol in their diets (Lahucky et al. 2010). Human symptoms of vitamin E deficiency suggest that its antioxidant properties play a major role in protecting erythrocyte membranes and nervous tissues.

Carotenoids

Carotenoids are the fat-soluble yellow, orange, or red pigments synthesized in plants, algae, fungi, bacteria, and yeasts. In humans, carotenoids are part of the antioxidant defense system. In plants, they have antioxidant properties because of

their chemical structure (Stahl and Sies 2003). They play a protective role in plants against photooxidative processes. They are potent antioxidants in scavenging peroxyl radicals and singlet molecular oxygen (Di Mascio et al. 1989; Stahl and Sies 2003). Human plasma and tissues contain only about 20 carotenoids, and these are mainly β-carotene, lycopene, lutein, β-cryptoxanthin, and α-carotene (Delgado-Vargas et al. 2000; Rao and Rao 2007). They belong to the tetraterpene family, and these compounds are characterized by a polyisoprenoid structure with a long conjugated chain of double bond and a near bilateral symmetry around the central double bond. They can be classified into two classes: carotenes, which contain carbon and hydrogen atoms and xanthophylls (oxycarotenoids) that contain carbon, hydrogen, and at least one oxygen atom. Carotenoids contain 3–13 conjugated double bonds and in certain cases 6 carbon hydroxylated ring structures at one or both ends of the molecule (Olson 1993). Lycopene, β-carotene, lutein, zeaxanthin, and astaxanthin are some of the more than 600 naturally occurring carotenoids. These carotenoids are lipid-soluble color pigments in fruits and vegetables whose orange, red, or yellow coloration arises from their extensively conjugated double bond systems. The major sources of dietary carotenoids include the orange and yellow fruits and vegetables, as well as green leafy vegetables. The health effects of these carotenoids are associated with their antioxidant properties. Epidemiological studies have found a relationship between the ingestion of carotenoids and good health (Paiva and Russel 1999). There is strong evidence showing that a diet rich in carotenoids prevents cardiovascular diseases and certain cancers like breast, colon, lung, and prostate (Tapiero et al. 2004; Rao and Rao 2007). Carotenoids have been reported to possess strong antioxidant activity and their antioxidant properties are believed to be the main mechanism involved in their beneficial effects. The important carotenoids in human diet are lycopene, β-carotene, lutein, zeaxanthin, β-cryptoxanthin, and astaxanthin (Riccioni 2009).

The driving force behind the radical scavenging ability of these natural antioxidants is the extended electron delocalization in carotenoids. The influence of these carotenoids has been studied in great deal in diverse food systems (Dondeena and Kilara 1992). These carotenoids act as singlet oxygen quenchers and hydrogen peroxide scavengers at high oxygen pressure, and chain-breaking primary antioxidants at low oxygen pressure when singlet oxygen is not present, and can synergistically act with other antioxidants (Rajalakshmi and Narasimhan 1996; Tapiero et al. 2004). The carotenoid, β-carotene, is the major dietary source of vitamin A, and it contributes to the oxidative stability of food systems where they are naturally present such as palm oil and carrot. It is considered to be the most powerful physical singlet oxygen quenching agent in foods. One molecule of β-carotene can quench 250–1,000 molecules of singlet oxygen (Foote 1976). The rate of singlet oxygen quenching by these carotenes is very highly dependent on the number of conjugate double bonds in the carotenoid. The number and type of functional groups on the ring portion of the molecule also play an important role. These functional groups are strongly linked to the solubility of the carotenoids (Kobayashi and Sakamoto 1999). The number of double bonds in the skeleton plays a significant role in the effectiveness of the carotenoids. Carotenoids with fewer than seven

double bonds have been shown to be ineffective as quenchers, being unable to accept the energy from singlet oxygen. A comparison of the quenching rates of several polyenes and carotenoids has been studied and reported (Beutner et al. 2000). Carotenoids contribute to the oxidative stability of food systems when used as additives in water-in-oil emulsions and synergistically in oil-in-water emulsions when combined with other carotenoids and when combined with α-tocopherol (Li et al. 1995; Thyrion 1999; Kiokias and Gordon 2003; Nanditha and Prabhasankar 2009). Carotenoids are reported to reduce the incidence of age-related diseases of the eye, like cataract and age-related macular degeneration disease, probably by their ability to quench active oxygen species (Fraser and Bramley 2004). Oxidative stress plays an important role in the pathophysiology of chronic pancreatitis, and supplementation with antioxidants (β-carotene) leads to significant pain relief in patients with this disease (Tandon and Garg 2011).

Ubiquinone

Ubiquinone or coenzyme Q is a phenolic conjugated to an isoprenoid chain and is found mainly in the mitochondria (Zubay 1983). Coenzyme Q10, also known as coenzyme Q, ubidecarenone, and ubiquinone, is found in all human cells, with the highest concentrations in the heart, liver, kidney, and pancreas (Wyman et al. 2010). It is a lipophilic molecule present in all tissues and cells that is located mainly in the inner mitochondrial membrane. It is composed of a redox active benzoquinone ring conjugated to an isoprenoid chain. The length of the chain differs among species; in humans, ubiquinone contains predominantly 10 isoprenyl units and is designated CoQ10. CoQ shuttles electrons from complexes I and II to complex III of the mitochondrial respiratory chain; it also functions as a lipid-soluble antioxidant, scavenges oxygen reactive species, and is involved in multiple aspects of cellular metabolism (Turunen et al. 2004). The reduced form of ubiquinone is great in inactivating peroxyl radicals, but they have a lower radical-scavenging activity than α-tocopherol. This lower free radical-scavenging activity of reduced ubiquinone has been reported to be due to the internal hydrogen bonding, which makes hydrogen abstraction difficult (Ingold et al. 1993). However, it inhibits lipid oxidation in liposomes (Frei et al. 1990) and low-density lipoprotein (Stocker et al. 1991), and thus can be an important endogenous antioxidant in many foods including red meats that contain large amounts of mitochondria. Coenzyme Q10 (a basic quinone containing moiety) a major antioxidant principle found in human body plays a vital role in maintaining several biochemical pathways of body. It acts as a potential mediator in transferring electrons in oxidoreductive reactions of electron transport chain. Deficiency of this compound in the body can lead to several potential disorders like dysfunctions in cellular energetics, neurological degeneration, higher oxidative stress induced damage, breast cancer, etc. (Beg et al. 2010). Respiratory chain defects, ROS production, and apoptosis variably contribute to the pathogenesis of primary CoQ(10) deficiencies (Quinzii and Hirano 2011).

Ascorbic Acid

Ascorbic acid is one of the major water-soluble free radical scavengers found in biological tissues and is effective at scavenging free radicals and forming low energy radicals (Buettner 1993). It is considered to be one of the most powerful, least toxic natural antioxidant (Weber et al. 1996). This sugar acid was discovered in the twentieth century, and L-ascorbic acid is vitamin C. The major dietary sources of ascorbic acid are fruits, especially the citrus fruits, cherries, kiwi fruits, melons, and vegetables like tomatoes, leafy greens, cauliflower, broccoli, cabbage, and Brussels sprouts. Ascorbic acid can act as a metal chelator, an oxygen scavenger, and a reducing agent. Ascorbic acid is widely used as an oxygen scavenger and synergist in numerous food applications and has a higher oxidation potential (greater reducing capacity) than most phenolic antioxidants. It acts synergistically with tocopherols and thus allows for lower levels of tocopherols to be used, as they are regenerated by the synergist.

$$\mathrm{ROO}^{\bullet} + \mathrm{TocOH} \rightarrow \mathrm{ROOH}^{\bullet} + \mathrm{TocO}$$

$$\mathrm{TocO}^{\bullet} + \text{Ascorbic acid} \rightarrow \mathrm{TocOH} + \text{ascorbate}$$

Ascorbic acid is very useful in stabilizing oils and lipid-containing foods, especially when used in combination with other natural antioxidants that function synergistically with it. The human plasma contains about 60 μmol ascorbate which reacts with ROS to be oxidized to dehydroascorbate via the intermediate ascorbyl free radical. The dehydroascorbate is converted back by dehydroascorbate reductase to ascorbic acid. Ascorbic acid has four –OH groups that can donate hydrogen to an oxidizing system. Because the –OH groups (2 pairs of 2) are on adjacent carbon atoms, it is able to chelate metal ions (Fe^{++}). The formation of protein carbonyls in the cerebral hemispheres of the aging mice was shown to be prevented by the antioxidative effects of melatonin and ascorbic acid and that could in turn be beneficial in having health benefits from age-related neurodegenerative diseases (Dkhar and Sharma 2011). Ascorbic acid supplementation was shown to have a neurotrophic effect on all neurons studied in aging rats, suggesting a neuroprotective role (Veit and Zanoni 2012). Aging and vitamin C deficiency led to an increase in the expression of peroxisome proliferators-activated receptor γ (PPARγ), which is a protein related to lipid metabolism and HSC quiescence, in hypertrophic HSCs, whereas these phenomena were dramatically reduced by antioxidant treatment (Hong et al. 2012). Taniguchi et al. (2012) reported that a stable ascorbic acid derivative, 2-*O*-α-glucopyranosyl-L-ascorbic acid (AA-2G) and ascorbic acid, protected dermal fibroblasts from oxidative stress and cellular senescence. However, AA-2G was superior to ascorbic acid.

Antioxidant Enzymes

The three major antioxidant enzymes are superoxide dismutase, catalase, and glutathione peroxidase.

Superoxide dismutase and the peroxide-removing system ensure that the steady-state levels of superoxide and H_2O_2 remain relatively low. The reactive superoxide radical ($^{\bullet}O_2$) is produced by the reduction of ground-state oxygen ($^3O_2$) at physiological pH. This radical is less reactive than hydroxyl radical ($^{\bullet}OH$) and the hydroperoxyl radical ($^{\bullet}O_2H$). Thus it is not capable of reacting with most biological molecules in aqueous solution (Halliwell and Gutteridge 2007). Superoxide is capable of promoting the peroxidation of unsaturated fatty acids and hence controlling it is important in minimizing the oxidative damage in vivo.

The enzyme superoxide dismutase (SOD) can reduce this potential damage causing species, the superoxide, to hydrogen peroxide. There are two major forms of SOD, which catalyze the following reaction:

$$2O_2^- + 2H^+ \rightarrow O_2 + H_2O_2$$

There are two isoforms of SOD—the copper plus zinc (CuZnSOD) or manganese (MnSOD) in the active sites, with CuZnSOD being the more common. The mitochondrial antioxidant enzyme manganese superoxide dismutase (MnSOD) acts as the chief ROS scavenging enzyme in the cell (Holley et al. 2011). The CuZnSODs are the relatively stable metalloenzymes and can withstand exposure to harsh treatments (Halliwell and Gutteridge 2007). SOD serves not only as a protective enzyme, but also has a central role in determining the basic biology of cells and tissues (Buettner et al. 2006).

Hydrogen peroxide is a non-radical species and is not a potent oxidant, but it can be readily reduced by metal catalysis or UV light to the highly reactive $^{\bullet}OH$ radicals. The SOD reaction described above shows how superoxide turns into hydrogen peroxide in vivo. In food systems, hydrogen peroxide is produced non-enzymatically as a result of polyphenol oxidation (Long et al. 1999; Halliwell 2008). Catalase (CAT), the heme-containing enzyme present in many biological systems, catalyzes the reduction of hydrogen peroxide to water and is nature's answer to this problem. The reaction is:

$$2H_2O_2 \rightarrow 2H_2O + O_2$$

Catalase activity correlates with the severity of oxidative stress. A few minutes after total tissue reperfusion, catalase activity was shown to increase (Domanski et al. 2006). In plants, hydrogen peroxide can be removed by the following mechanism involving ascorbate peroxidase:

$$2 \text{ ascorbate} + H_2O_2 \rightarrow 2 \text{ monodehydroascorbate} + 2H_2O$$

Most biological tissues also contain glutathione peroxidase (GSH-Px) an enzyme which is capable of deactivating both hydrogen and lipid peroxides. The enzyme GSH-Px contains a selenium ion within its active site and reduced glutathione (GSH) to reduce hydrogen peroxide or lipid hydroperoxide to water:

$$H_2O_2 + 2GSH \rightarrow 2H_2O + GSSG$$

or

$$\mathrm{LOOH} + 2\mathrm{GSH} \rightarrow \mathrm{LOH} + \mathrm{H_2O} + \mathrm{GSSG}$$

where GSSG is oxidized glutathione, and LOH is a fatty acid alcohol.

Elevated levels of ROS within 48 h after transplantation resulted in high levels of glutathione reductase and a marked increase in plasma and erythrocyte glutathione peroxidase (De Vega et al. 2003).

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Chapter 4
Sources of Natural Antioxidants and Their Activities

There are several sources of natural antioxidants such as herbs and spices. However, there are other natural products such as cereals, nuts, oilseeds, legumes, vegetables, animal products, and microbial products which can serve as rich sources of natural antioxidants. The richest sources of polyphenols are various spices and dried herbs, cocoa products, some darkly colored berries, some seeds (flaxseed) and nuts (chestnut, hazelnut), and some vegetables, including olive and globe artichoke heads with contents varying from 15,000 mg/100 g in cloves to 10 mg/100 mL in rose wine (Perez-Jimenez et al. 2010). Banana, custard apple, orange, lemon, guava, and papaya were found to be very rich in ascorbic acid. Among vegetables, capsicum (green sweet pepper), cauliflower, bittergourd, roundgourd, beetroot, spinach, cabbage, and radish contained high concentrations of ascorbic acid (Iqbal et al. 2006). Recently, popcorn was reported to contain more of the healthful antioxidant substances called "polyphenols" than fruits and vegetables (ACS National Meeting, 2012). Several antioxidant capacity methods have been developed and reported (Gulcin 2012). Eleven foods from three categories, including fruits (raspberry, blackberry, and apple), vegetables (broccoli, tomato, mushroom, and purple cauliflower), and legumes (soybean, adzuki bean, red kidney bean, and black bean) were combined in pairs either within the same food category or across food categories and analyzed for total antioxidant capacities. They found synergistic, additive, and antagonistic effects of these food mixtures and suggest the importance of strategically selecting foods or diets to maximum synergisms as well as to minimum antagonisms in antioxidant activity (Wang et al. 2011b). The following pages describe the antioxidant properties of different food categories. The antioxidant content, ORAC values, active constituents, and contents of different antioxidants present in different sources are presented in Tables 4.1, 4.2, 4.3, 4.4, 4.5, 4.6, 4.7, 4.8, 4.9, 4.10, 4.11, 4.12, 4.13, 4.14, and 4.15. The antioxidant capacity of some commons foods in the USA was reported by Wu et al. (2004) and is presented in Table 4.15.

D.J. Charles, *Antioxidant Properties of Spices, Herbs and Other Sources*,
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Table 4.1 Excerpt of the analyses of nuts, legumes, and grain products in the Antioxidant Food Table

	Antioxidant content mmol/100 g[a]
Barley, pearl and flour	1.0
Beans	0.8
Bread, with fiber/whole meal	0.5
Buckwheat, white flour	1.4
Buckwheat, whole meal flour	2.0
Chestnuts, with pellicle	4.7
Crisp bread, brown	1.1
Maize, white flour	0.6
Millet	1.3
Peanuts, roasted, with pellicle	2.0
Pecans, with pellicle	8.5
Pistachios	1.7
Sunflower seeds	6.4
Walnuts, with pellicle	21.9
Wheat bread, toasted	0.6
Whole wheat bread, toasted	1.0

Source: Carlsen et al. (2010)
[a]Mean value when $n > 1$

Table 4.2 Excerpt of the berries, fruit, and vegetable analyses in the Antioxidant Food Table

	Antioxidant content mmol/100 g[a]
Amla (Indian gooseberry), dried	261.5
Apples	0.4
Apples, dried	3.8
Apricots, dried	3.1
Artichoke	3.5
Bilberries, dried	48.3
Black olives	1.7
Blueberry jam	3.5
Broccoli, cooked	0.5
Chili, red and green	2.4
Curly kale	2.8
Dates, dried	1.7
Dog rose, products of dried hip	69.4
Fruit from the African baobab tree	10.8
Mango, dried	1.7
Moringa stenopetala, dried leaves, stem	11.9
Okra/gumbo from Mali, dry, flour	4.2
Oranges	0.9
Papaya	0.6
Plums, dried	3.2
Pomegranate	1.8
Prunes	2.4
Strawberries	2.1
Zereshk, red sour berries	27.3

Source: Carlsen et al. (2010)
[a]Mean value when $n > 1$

Table 4.3 Total phenol, flavonoid, flavanol, and ORAC values in selected vegetables

Vegetable	Total phenols (mg/100 g)	Flavonoids (mg/100 g)	Flavanols (mg/100 g)	ORAC (μmol TE/100 g)
Aubergine Violetta lunga	64.8	25.7	0.73	1,414
Aubergine Black beauty	57.4	28.4	0.35	1,194
Artichoke	330.4	285.2	0.88	6,552
Asparagus	64.0	24.6	0.77	1,288
Beet green	53.0	47.0	2.41	2,724
Beetroot Tonda sanguigna	154.1	92.8	2.21	3,632
Cabbage	105.2	45.7	0.66	2,050
Broccoli	109.5	60.1	0.64	3,529
Carrot	14.6	12.8	0.53	107
Celery	13.5	6.1	0.51	343
Cauliflower	62.3	32.0	0.72	925
Courgette	26.4	9.0	0.58	180
Cucumber	18.9	4.7	0.41	182
Fennel	27.5	11.0	0.22	361
Garlic	81.2	12.4	1.69	5,346
Green pepper	44.6	9.9	0.56	1,059
Green chili	101.1	8.9	0.42	534
Leek Atal	41.6	10.1	1.01	490
Leek Rossa di Trento	88.2	28.0	0.53	3,323
Leek Romana	54.7	38.7	0.98	910
Lettuce Catalogna	55.6	47.6	1.26	1,053
Lettuce Cocarde	66.2	25.9	0.54	2,127
Onion Bianca di maggio	23.6	6.4	0.28	342
Onion Rossa di tropea	42.8	3.6	0.21	1,521
Radish Tondo	61.4	10.9	1.25	3,602
Radish Jolly	30.0	10.8	1.26	1,240
Red chicory	129.5	89.1	1.13	3,537
Red chili	158.1	15.3	0.66	509
Red pepper	76.5	7.9	0.42	842
Spinach	89.4	32.5	1.34	2,732
Squash Butternut	23.2	9.2	0.33	396
Squash Miroo a grappolo	50.7	6.2	0.26	934
Tomato S. Marzano	32.3	6.1	0.48	697
Tomato Sarom	31.3	7.0	0.15	395
Yellow pepper	113.7	7.0	0.91	950

Source: Ninfali et al. (2005)

Table 4.4 Color code groups of fruits and vegetables

Color	Phytochemical	Fruits and vegetables
Red	Lycopene	Tomatoes and tomato products such as juice, soups, and pasta sauces
Red-purple	Anthocyanins and polyphenols	Grapes, blackberries, red wine, raspberries, blueberries
Orange	α- and β-Carotene	Carrots, mangos, pumpkin
Orange-yellow	β-Cryptoxanthin and flavonoids	Cantaloupe, peaches, tangerines, papaya, oranges
Yellow-green	Lutein and zeaxanthin	Spinach, avocado, honeydew melon
Green	Glucosinolates and indoles	Broccoli, bok choi, kale
White-green	Allyl sulfides	Leeks, garlic, onion, chives

Source: Heber and Bowerman (2001)

Table 4.5 Excerpt of the analyses of beverages in the Antioxidant Food Table

	Antioxidant content mmol/100 g [a]
Apple juice	0.27
Black tea, prepared	1.0
Green tea, prepared	1.5
Coffee, prepared filter and boiled	2.5
Espresso, prepared	14.2
Cocoa with milk	0.37
Cranberry juice	0.92
Grape juice	1.2
Orange juice	0.64
Pomegranate juice	2.1
Prune juice	1.0
Tomato juice	0.48
Red wine	2.5

Source: Carlsen et al. (2010)
[a]Mean value when $n > 1$

Table 4.6 ORAC values of tea

Tea	ORAC value (μmol TE/100 g)	
Tea, black, ready-to-drink, plain and flavored	H-ORAC	313
	Total-ORAC	313
Tea, brewed, prepared with tap water	H-ORAC	1,128
	Total-ORAC	1,128
Tea, green, brewed	H-ORAC	1,253
	Total-ORAC	1,253
Tea, green, ready-to-drink	H-ORAC	520
	Total-ORAC	520
Tea, white, ready-to-drink	H-ORAC	264
	Total-ORAC	264

Source: USDA (2010a, b)

Table 4.7 Total phenolic and ORAC values of herbs and spices

Herbs and spices	Total phenolic content (mg GAE/100 g)	ORAC (μmol TE/100 g)
Basil fresh	264	4,805
Basil dried	4,489	61,063
Dill weed fresh	243	4,392
Marjoram fresh	964	27,297
Oregano fresh	491	13,970
Peppermint fresh	690	13,978
Sage fresh	901	32,004
Savory fresh	227	9,465
Cardamom	167	2,764
Chili powder	1,713	23,636
Cinnamon ground	4,533	131,420
Cloves ground	16,550	290,283
Cumin seed	849	50,372
Curry powder	1,075	48,504
Garlic powder	42	6,665
Ginger ground	669	39,041
Mustard seed yellow	1,844	29,256
Nutmeg ground	567	69,640
Onion powder	861	4,289
Oregano dried	3,789	175,295
Paprika	1,643	21,932
Parsley dried	2,244	73,670
Pepper black	287	34,053
Pepper red or cayenne	1,130	19,671
Poppy seed	20	481
Rosemary dried	4,980	165,280
Sage ground	4,520	119,929
Thyme dried	4,470	157,380
Turmeric ground	2,754	127,068
Tarragon fresh	643	15,542
Thyme fresh	1,734	27,426
Vanilla beans dried	–	122,400

Source: USDA (2010a, b)

Table 4.8 Total phenolic and flavonoid content of spices

Spices	Total phenolic content (μg CE/g)	Total flavonoid content (μg QE/g)
Basil	20.25	131.60
Oregano	23.36	156.93
Rosemary	42.58	269.84
Savory	48.07	35.19
Thyme	7.78	14.25
Turmeric	58.28	324.08
Cumin	10.17	101.34
Caraway	9.92	45.01
Coriander	9.22	3.38
Fennel	9.36	44.76
Clove	108.28	75.97
Marjoram	20.44	157.73

Source: Kim et al. (2011)

Table 4.9 Phenolic, flavonoid, and ORAC values in selected spices

Spices	Total phenols (mg/100 g)	Flavonoids (mg/100 g)	ORAC (μmol TE/100 g)
Cumin	750	740	76,800
Cardamom	148	19	2,764
Coriander	134	94	5,141
Ginger fresh	200	117	14,840
Seasoned salt 1	274	255	1,897
Seasoned salt 2	110	91	897

Source: Ninfali et al. (2005)

Table 4.10 Antioxidant activity and polyphenol content of medicinal plants. Comparison between 80% acetone (ac) and water (w) extraction

Medicinal plant	$ORAC_{(ac)}$ (μmol TE/g)	$ORAC_{(w)}$ (μmol TE/g)	$Polyphenol_{(ac)}$ (mg/100 g)	$Polyphenol_{(w)}$ (mg/100 g)
Peppermint	2,917	1,409	20,216	9,356
Thyme	1,637	1,434	11,409	8,583
Basil	402	271	2,391	1,816
Wild basil	1,437	844	9,468	4,645
Birch	1,185	142	5,542	1,197
Balm	1,121	996	11,885	8,240
Lime	1,020	97	9,296	787
Sage	966	609	5,295	3,845
Yarrow	842	394	5,728	1,968
Laurel leaf	837	170	7,081	1,766
Chamomile	814	469	4,665	1,790
Hop	749	260	5,728	1,697
Spearmint	748	598	4,522	3,713
Liquorice	670	213	3,452	1,548
Marigold	407	247	2,141	1,537
Fenugreek	327	320	1,692	1,445

Source: Kratchanova et al. (2010)

Table 4.11 Phenolic, flavonoid, flavanol, and ORAC values in selected herbs

Herb	Total phenols (mg/100 g)	Flavonoids (mg/100 g)	Flavanols (mg/100 g)	ORAC (μmol TE/100 g)
Chive	74.9	35.3	1.10	2,094.2
Dill	215.2	93.2	0.73	4,392.1
Sage	798.0	749.5	1.61	32,004.1
Savory	201.2	67.5	1.13	9,645.2
Thyme	1,537.0	1,165.3	0.22	27.425
Hyssop	214.5	176.0	2.65	6,050.2
Lemon balm	434.0	289.0	1.91	5,996.5
Marjoram	854.2	812.6	2.71	27,297.4
Oregano	435.1	361.0	1.14	13,970.2
Parsley	67.9	52.2	0.90	1,301.8
Peppermint	611.2	592.5	4.33	13,978.1
Rocket	136.4	46.0	1.42	2,373.3
Sweet basil	234.0	230	0.93	4,805.2
Tarragon	570.0	537.0	0.11	15,542.2

Source: Ninfali et al. (2005)

Table 4.12 Excerpt of the spices and herbs analyzed in the Antioxidant Food Table

	Antioxidant content mmol/100 g[a]
Allspice, dried ground	100.4
Basil, dried	19.9
Bay leaves, dried	27.8
Cinnamon sticks and whole bark	26.5
Cinnamon, dried ground	77.0
Clove, dried, whole and ground	277.3
Dill, dried ground	20.2
Estragon, dried ground	43.8
Ginger, dried	20.3
Mint leaves, dried	116.4
Nutmeg, dried ground	26.4
Oregano, dried ground	63.2
Rosemary, dried ground	44.8
Saffron, dried ground	44.5
Saffron, dried whole stigma	17.5
Sage, dried ground	44.3
Thyme, dried ground	56.3

Source: Carlsen et al. (2010)
[a]Mean value when $n > 1$

Table 4.13 Scavenging rate of herbs by ESR measurement

Herbs	Relative scavenging rate (%)
Marjoram	63.1
Basil	83.5
Oregano	45.5
Rosemary	60.7
Summer savory	53.0
Sage	65.1
Thyme	68.5
Tarragon	24.5
Gardenia	13.0
Cinnamon	58.5
Bay leaf	46.5
Black pepper	41.5
White pepper	18.0
Turmeric	22.5
Ginger	11.0
Cardamom	11.0
Cumin	37.5
Caraway	25.5
Coriander	25.0
Dill Seed	17.5
Celery	12.5
Fennel	39.0
Anise seed	44.0
Red pepper	8.5
Nutmeg	19.0
Mace	25.5
Clove	88.6
Allspice	91.7
Fenugreek	45.5
Garlic	15.5
Mandarin	27.0
Star anise	27.0

Source: Yun et al. (2003)

Table 4.14 Active constituents in herbs and spices

Herb/spice	Active constituents
Ajowan	Carvacrol, thymol, limonene, α-terpinene
Allspice	Eugenol, gallic acid, pimentol, pedunculagin, quercetin
Angelica	Z-ligustilide, coniferyl ferulate, ferulic acid, limonene
Anise seed	Quercetin-3-glucuronide, rutin, luteolin-7-glucoside, isoorientin, isovitexin, apigenin-7-glucoside
Anise star	Limonene, flavonoids, lignans
Asafoetida	Sodium ferulate, phenols, flavonoids
Basil	Eugenol, apigenin, limonene, ursolic acid, methyl cinnamate, 1,8-cineole, α-terpinene, anthocyanins, β-sitosterol, carvacrol, Citronellol, farnesol, geraniol, kaempferol, menthol, *p*- coumaric acid, quercetin, rosmarinic acid, rutin, safrole, tannin, catechin
Bay leaf	1,8-cineole, cinnamtannin B-1
Caraway	Carvone, limonene, α-pinene, kaempferol, quercetin-3-glucuronides, isoquercitrin, quercetin 3-0 caffeylglucoside, kaempferol 3-glucoside, umbelliferone and scopoletin
Cardamom	Limonene, 1,8-cineole, caffeic acid
Celery	limonene, caffeic acid, *p*-coumaric acid, ferulic acid, apigenin, luteolin, kaempferol
Chervil	Apiin, luteolin-7-glucoside
Chives	Lutein, zeaxanthin, β-carotene, quercetin glucoside, isorhamnetin glucoside, kaempferol glucoside
Cinnamon	Cinnamic aldehyde, 2-hydroxycinnamaldehyde, eugenol, myristicin, cinnamate, phenolics
Cloves	Eugenol, isoeugenol, gallic acid, flavonoids, phenolic acids
Coriander	Quercetin, caffeic acid, cineole, geraniol, borneol, 1,8-cineole, α-terpinene, β-carotene, α-pinene, β-pinene, β-sitosterol, cinnamic acid, ferrulic acid, γ-terpinene, kaempferol, limonene, myrcene, *p*-coumaric acid, *p*-cymene, quercetin, rutin, vanillic acid, tocopherols, pyrogallol, glycitin
Cumin	α-Pinene, β-pinene, γ-terpinene, *p*-cymene, cuminaldehyde, carvone, 1,8-cineole, β-carotene, β-sitosterol, caffeic acid, ferulic acid, chlorogenic acid, carvacrol, geranial, kaempferol, limonene, *p*-coumaric acid, quercetin, tannin, thymol
Curry leaf	α-Pinene, β-pinene, alkaloids, phenolics
Dill	Carvone, limonene, isorhamnetin, kaempferol, myricetin, quercetin, catechin, falcarindiol
Fennel	α-Pinene, limonene, 1,8-cineole, β-carotene, quercetin, benzoic acid, β-sitosterol, caffeic acid, cinnamic acid, ferulic acid, fumaric acid, kaempferol, myristicin, *p*-coumaric acid, quercetin, rutin, vanillic acid, vanillin, umbelliferone, stigmasterol
Fenugreek	Limonene, trigonelline, choline, gentianne, carpaine, flavonoids
Garlic	Allicin, diallyl sulfide, diallyl disulfide, diallyl trisulfide allyl isothiocyanate, *S*-allylcysteine
Geranium	1,2,3,4,6-penta-*O*-galloyl-beta-D-glucose, geraniol, flavonoids
Ginger	Zingiberone, zingiberene, ar-curcumene, gingerol, paradol, shogaols, zingerone, curcumin, zerumbone
Horseradish	Phenylethyl isothiocyanate and allyl isothiocyanate, sinigrin, asparagines
Hyssop	Diosmin, rosmarinic acid, β-pinene, apigenin, luteolin
Juniper	Imbricatolic acid, longifolene, totarol, α-pinene, β-pinene, limonene, phenolics, flavonoids

(continued)

Table 4.14 (continued)

Herb/spice	Active constituents
Lavender	1,8-Cineole, limonene, ferulic acid, rosmarinic acid, *p*-coumaric acid, caffeic acid, quercetin, apigenin, and kaempferol glucosides
Lemon balm	Geraniol, eugenol, rosmarinic acid, caffeic acid, protocatechuic acid, luteolin
Lemongrass	Limonene, geraniol, citral, farnesol, elimicin, catechol, chlorogenic acid, caffeic acid, hydroquinone, luteolin, isoorientin 2′-*O*-rhamnoside, quercetin, kaempferol and apigenin
Licorice	Glycyrrhizin, Isoliquiritigenin, glycyrrhetinic acid, glabridin, licoagrodin, licoagrochalcones, licoagroaurone, licochalcone C, kanzonol Y, glyinflanin B, glycyrdione A
Marjoram	Sinapic acid, ferulic acid, coumarinic acid, caffeic acid, syringic acid, vanillic acid, 4-hydroxybenzoic acid, limonene, ursolic acid, α-pinene, α-terpinene, *p*-cymene, rosmarinic acid, sterols, apigenin
Mustard	Allyl isothiocyanate, β-carotene, isorhamnetin 7-*O*-glucoside, isorhamnetin, kaempferol glycosides
Myrtle	α-Pinene, 1,8-cineole, limonene, gallic acid, ellagic acids, anthocyanin pigments, myrtucommulone A and semimyrtucommulone, myricetin-3-*o*-galactoside, myricetin-3-*o*-rhamnoside
Nigella	*p*-Cymene, α-pinene, β-pinene, β-elemene, thymoquinone, thymohydroquinone, dithymoquinone, thymol, carvacrol, nigellimine-N-oxide, nigellicine, nigellidine and alpha-hederin
Nutmeg	Caffeic acid, argenteane, myristicin, lignans, catechin
Onion	Quercetin, caffeic acid, apigenin, dipropyl disulfides, rutin, quercetin-4′-glucoside, quercetin-3′-*O*-beta-D-glucoside
Oregano	Apigenin, rosmarinic acid, luteolin, quercetin, myricetin, caffeic acid, *p*-coumaric acid, diosmetin, protocatechuic acid, eriodictyol, carvacrol, thymol
Paprika	α-Tocopherol, capsaicin, dihydrocapsaicin, lutein, β-carotene, ascorbic acid, Vitamin E
Parsley	Apigenin, luteolin, kaempferol, myricetin, quercetin, caffeic acid
Black pepper	Piperidine, piperine, limonene, α-pinene, β- pinene, sarmentine, guineesine, isoquercetin,
Red pepper	Capsaicin, α-tocopherol, lutein, β-carotene, capsanthin, quercetin, ascorbic acid, vitamin E
Peppermint	Limonene, menthol, menthone, isomenthone, eriocitrin, eriodictyol, hesperidin, apigenin, luteolin, rutin, caffeic acid, rosmarinic acid, chlorogenic acid, α- and β-carotene, tocopherols
Pomegranate	Punicalagins, punicalins, gallagic acid, and ellagic acid, isoquercetin, sitosterol, gallic acid
Poppy	Sitosterol, campestrol, avenasterol, cholestanol, stigmasterol
Rosemary	Carnosol, carnosic acid, rosmanol, ursolic acid, 1,8-cineole, geraniol, α-pinene, limonene, β-carotene, apigenin, naringin, luteolin, caffeic acid, rosmarinic acid, rosmanol, vanillic acid, diosmetin
Saffron	Crocin, crocetin, picrocrocin, β-carotene, safranal, stigmasterol, catechol, vanillin, salicylic acid, cinnamic acid, *p*-hydroxybenzoic acid, gentisic acid, syringic acid, *p*-coumaric acid, gallic acid, *t*-ferulic acid, caffeic acid, all trans retinoic acid
Sage	α-Pinene, β-pinene, geraniol, limonene, 1,8-cineole, perillyl alcohol, citral, β-sitosterol, farnesol, ferulic acid, gallic acid, β-carotene, catechin, apigenin, luteolin, saponin, ursolic acid, rosmarinic acid, carnosic acid, vanillic acid, caffeic acid, carnosol

(continued)

Table 4.14 (continued)

Herb/spice	Active constituents
Savory	Carvacrol, β-pinene, limonene, 1,8-cineole, ursolic acid, beta sitosterol, rosmarinic acid
Spearmint	Diosmin, diosmetin, limonene, α-pinene, caffeic acid, eriocitrin, luteolin, rosmarinic acid
Tarragon	Luteolin, isorhamnetin, kaempferol, rutin, quercetin, caffeic acid
Tea green	(−)-Epigallocatechin gallate, (−)-epigallocatechin, (−) – (+)-catechin, theophylline, gallic acid, theanine
Thyme	Thymol, carvacrol, 1,8-cineole, α-pinene, limonene, apigenin, β-carotene, ursolic acid, luteolin, gallic acid, caffeic acid, rosmarinic acid, carnosic acid, hispidulin, cismaritin, diosmetin, naringenin, kaempferol, quercetin, hesperidin
Turmeric	Curcumin, curcuminoids, β-turmerin
Vanilla	Vanillin, ethyl vanillin, vanillic acid, *p*-hydroxybenzoic acid, *p*-hydroxybenzaldehyde

Table 4.15 Total antioxidant capacity of common food in the USA

Rank	Food item	Serving size	Total antioxidant capacity per serving size
1	Small red bean (dried)	Half cup	13,727
2	Wild blueberry	1 Cup	13,427
3	Red kidney bean (dried)	Half cup	13,259
4	Pinto bean	Half cup	11,864
5	Blueberry (cultivated)	1 Cup	9,019
6	Cranberry	1 Cup (whole)	8,983
7	Artichoke (cooked)	1 Cup (hearts)	7,904
8	Blackberry	1 Cup	7,701
9	Prune	Half cup	7,291
10	Raspberry	1 Cup	6,058
11	Strawberry	1 Cup	5,938
12	Red Delicious apple	1 Whole	5,900
13	Granny Smith apple	1 Whole	5,381
14	Pecan	1 Ounce	5,095
15	Sweet cherry	1 Cup	4,873
16	Black plum	1 Whole	4,844
17	Russet potato (cooked)	1 Whole	4,649
18	Black bean (dried)	Half cup	4,181
19	Plum	1 Whole	4,118

Source: Wu et al. (2004)

Nuts

Nuts are rich sources of antioxidants with the seed coat having the most and the cotyledons with lower amounts. Results showed that nuts (pecan, pine, pistachio, and cashew) are a good dietary source of unsaturated fatty acids, tocopherols, squalene, and phytosterols (Ryan et al. 2006). The antioxidant content of nuts, legumes, and grain products is presented in Table 4.1. Total phenolic content and the individual phenolics, with the exception of gallic acid, were highest in whole unroasted hazelnuts and was significantly lowered after skin removal (Schmitzer et al. 2011). Oils of olive, sunflower, safflower, rapeseed, soybean, linseed, corn, hazelnut, walnut, sesame, almond, mixture of oils for salad, "dietetic" oil, and peanut had antioxidant activity (Espín et al. 2000).

Macadamia nut oil obtained from the cotyledons had significantly lower phenolic content than the oil from the shell (Quinn and Tang 1996). Cold pressed macadamia nut oil has been shown to have more phenolics than the refined oils (Quinn and Tang 1996). Hazelnut oil, which is rich in monounsaturated fatty acids and antioxidants, reduced oxidative stress and cholesterol accumulation in the aortas of rabbits fed a high cholesterol diet (Hatipoglu et al. 2004). Aqueous extract of different hazelnut cultivars presented antioxidant activity in a concentration-dependent manner (Oliveira et al. 2008). The ethanolic extracts of hazelnut by-products (skin, hard shell, green leafy cover, and tree leaf) exhibited stronger activities than hazelnut kernel at all concentrations tested. Hazelnut extracts examined showed different antioxidative efficacies, expected to be related to the presence of phenolic compounds. Extracts of hazelnut skin, in general, showed superior antioxidative efficacy and higher phenolic content as compared to other extracts. Five phenolic acids (gallic acid, caffeic acid, *p*-coumaric acid, ferulic acid, and sinapic acid) were identified and quantified (both free and esterified forms). The extracts also contained different levels of phenolic acids (Shahidi et al. 2007). The phenolics confirmed in hazelnuts were seven flavan-3-ols (catechin, epicatechin, two procyanidin dimers, and three procyanidin trimers), three flavonols (quercetin pentoside, quercetin-3-*O*-rhamnoside, and myricetin-3-*O*-rhamnoside), two hydroxybenzoic acids (gallic acid, protocatechuic acid), and one dihydrochalcone (phloretin-2′-*O*-glucoside). Flavonols were only detected in whole hazelnut kernels. Roasting had a significant negative effect on individual phenolics but not on the total phenolic content and antioxidative potential of kernels. From a health promoting phytochemical composition of hazelnuts the consumption of whole unroasted kernels with skins should be preferential to peeled kernels either roasted or unroasted. A significant reduction in the antioxidative potential and total phenolic content was detected after hazelnut skin removal but not after roasting, suggesting that hazelnut kernels should be consumed whole (Schmitzer et al. 2011). The stability of hazelnuts has been correlated to the α-tocopherol content (Pershern et al. 1995). The raw kernels of hazelnuts were reported to be a good source of the natural antioxidants gallic acid and epicatechin (Solar and Stampar 2011). The Turkish extra virgin olive oil was found to have higher antioxidant activity than the refined oils of olive, hazelnut, and canola

(Karaosmanoglu et al. 2010). Roasted peanut and hazelnut skins had similar total phenolic contents, much higher than that of almond skins, but their flavan-3-ol profiles differed considerably. The antioxidant capacity as determined by various methods (i.e., total antioxidant capacity, ORAC, DPPH test, and reducing power) was higher for whole extracts from roasted hazelnut and peanut skins than for almond skins (Monagas et al. 2009). Different fractions prepared from hazelnut skin, kernel, and green leafy cover had different levels of phenolics, tannins, and antioxidant activity (Alasalvar et al. 2006, 2009). The bioactive nut constituents in the non-lipophilic extracts were shown to be more effective than lipophilic extracts for cytoprotection against hydroperoxide-induced oxidative stress (Banach et al. 2009).

Pecan nuts are good sources of phenolics and have been shown to have antioxidant activities (Morgan and Clayshulte 2000; Villarreal-Lozoya et al. 2009; Benvegnu et al. 2010). High concentrations of total extractable phenolics, flavonoids, and proanthocyanidins were found in pecan kernels, and 5–20-fold higher concentrations were found in shells. Five phenolic compounds identified in kernels were ellagic, gallic, protocatechuic, and *p*-hydroxybenzoic acids and catechin, while only ellagic and gallic acids could be identified in shells. Antioxidant activity was strongly correlated with the concentrations of phenolic compounds (de la Rosa et al. 2011). Aqueous extract of pecan nut shells was shown to prevent oxidative damage and increase antioxidant defenses of mice exposed to cigarette smoke. In addition, aqueous extract reduced the locomotor activity and anxiety symptoms induced by smoking withdrawal, and these behavioral parameters showed a positive correlation with RBC lipid peroxidation (Reckziegel et al. 2011). Bioactive constituents of pecan nuts (γ-tocopherol, flavan-3-ol monomers) were found to be absorbable and contribute to postprandial antioxidant defenses (Hudthagosol et al. 2011).

The major antioxidants in cashew reported include the phenolic acids like syringic (predominant), gallic and *p*-coumaric acids, and flavonoids (+)-catechin, (−)-epicatechin, and epigallocatechin (Chandrasekara and Shahidi 2011b). The methanolic extract of walnut showed the higher antioxidant activity based on lipid peroxidation assay. The higher phenolic content was found in walnuts followed by almonds, cashew nut, chironji, and least phenolic content was found in raisins. Walnut revealed the best antioxidant properties, presenting lower EC(50) values in all assays except in antioxidant enzymatic activity (Mishra et al. 2010). Anacardic acid, cardanol, and cardol, the main constituents of natural cashew nut shell liquid, showed antioxidant activity (Oliveira et al. 2011). Anacardic acids from cashew nut afforded gastroprotection principally through an antioxidant mechanism (Morais et al. 2010).

Walnuts (*Juglans sregia* L.) are an excellent source of α-linolenic acid (plant-based omega-3 fatty acid), have a high content of antioxidants such as flavonoids, phenolic acid (ellagic acid), melatonin, gamma tocopherol and selenium, and exhibit antioxidant activity (Jurd 1956; Reiter et al. 2005; Ros 2009; Torabian et al. 2009). In terms of antioxidant contents, walnuts ranked second among 1,113 different food items tested (Halvorsen et al. 2006). Dietary supplementation with fruit or vegetable extracts high in antioxidants (e.g., blueberries, strawberries, walnuts, and Concord grape juice) was shown to decrease the enhanced vulnerability to oxidative stress that occurred in aging and that these reductions are expressed as improvements in

behavior (Joseph et al. 2009). Walnuts constitute an excellent source of effective natural antioxidants and chemopreventive agents (Carvalho et al. 2010). While most nuts contain monounsaturated fats, walnuts comprise primarily polyunsaturated fat (13 g of 18 g total fat in one ounce of walnuts), of which α-linolenic acid is 2.5 g. Walnut extract offered protection against Aβ-mediated cell death by reducing the generation of free radicals, inhibiting membrane damage, and attenuating DNA damage (Muthaiyah et al. 2011). The chloroform and ethyl acetate fractions of walnut exhibited a high level of antiproliferation against HepG-2, liver cancer cell line (IC(50) = 9 and 15 μg mL^{-1}, respectively). By exhibiting high phenolic content, antioxidant activity, and potent antiproliferative activity, walnut may act as a cancer chemopreventive agent (Negi et al. 2011). In a recent study, walnuts had the highest free and total polyphenols in both the combined raw and roasted samples. Total polyphenols in the nuts were significantly higher than free polyphenols. Roasting had little effect on either free or total polyphenols in nuts. Raw and roasted walnuts had the highest total polyphenols. The efficacy of raw and roasted nut antioxidants was assessed by measuring the ability of the free polyphenol nut extracts to inhibit the oxidation of lower density lipoproteins (LDL + VLDL). A nut polyphenol, catechin, was measured after binding of three nut extracts to lower density lipoproteins. Walnut polyphenols had the best efficacy among the nuts and also the highest lipoprotein-bound antioxidant activity (Vinson and Cai 2012).

Oilseeds

Numerous micronutrients naturally abundant in oilseeds prevent the risk of cardiovascular diseases by reducing cholesterolemia and oxidative stress. These micronutrients include phytosterols and various antioxidants such as polyphenols, tocopherols, and coenzyme Q10/Q9. These could be lost during refining (Gladine et al. 2011). Camelina meal was found to be effective in inhibiting lipid oxidation and enhancing antioxidant capacity (Aziza et al. 2010). The sunflower is one of the four most important oilseed crops in the world, and the nutritional quality of its edible oil ranks among the best vegetable oils in cultivation. Sunflower, flaxseed, canola, cottonseed, and soybean antioxidants are the important oilseeds. Sterols are the major antioxidants in oilseeds. Sterols have been shown to prevent thermal oxidative degradation of oils (Gordon and Magos 1983). Other common antioxidants in oilseeds are the tocopherols and tocotrienols. Sesame oil has sesamin, sesangolin, and samin as the natural antioxidants. Ansu apricot oil from China and apricots in general were found to be a good natural source of antioxidants (Tian and Zhan 2011; Yert and Celik 2011). A fraction of the antioxidant capacity of apricot (*Prunus armeniaca* L.) fruits was attributable to the apricot carotenoids (Hegedus et al. 2010).

Regular intake of optimized sunflower oils was shown to help improve lipid status and reduce lipid peroxidation in plasma (Di Benedetto et al. 2010). The antioxidants in sunflower oils are phenolic acids, tocopherols, and sterols, while the purple hulled varieties contain significant amounts of anthocyanins. An oil mix of sesame and sunflower was shown to provide good protection over blood pressure and lipid

peroxidation, and brought enzymatic and nonenzymatic antioxidants, lipid profile, and electrolytes towards normalcy in hypertensive patients (Sudhakar et al. 2011). Feeding enrichment with both high-oleic sunflower oil and vitamin E can be used as an appropriate supplementation strategy to produce pork meat with a suitable oxidative stability (Cardenia et al. 2011).

Flaxseed (FS) is a dietary supplement known for its antioxidant and anti-inflammatory properties (Matumoto-Pintro et al. 2011; Razi et al. 2011). Shahidi et al. (1995a) suggested that lignans present in flaxseed could be responsible for the antioxidant activity and this was supported by the radical scavenging property of secoisolariciresinol diglucoside (Prasad 1997). Dietary flaxseed was found to be protective against ischemia–reperfusion injury in an experimental murine model and that flaxseed affects ROS generation and ROS detoxification via pathways not limited to upregulation of antioxidant enzymes such as HO-1 (Lee et al. 2008). The active ingredient of flaxseed (lignan, secoisolariciresinol diglucoside (SDG)) has significant antioxidant effects by inhibiting DNA scissions and lipid peroxidation and decreasing ROS (Prasad 2000; Lee et al. 2008; Newairy and Abdou 2009). The study on flaxseed action weakly supports that decreased insulin resistance might have been secondary to antioxidant activity of flaxseed (Rhee and Brunt 2011).

Cottonseed protein is widely regarded as a potential source of nutrients for humans and animals. The hydrolysate derived from cottonseed protein, particularly fraction III, could be a natural antioxidant source suitable for use as a food additive (Gao et al. 2010).

Cottonseed oil was found to have a lowering effect on total cholesterol of rats of both sexes, but on HDL-C for male animals only (Radcliffe and Czajka-Narins 2006). Cottonseed meals were shown to be highly effective antioxidants in cooked meats, decreasing day-3 TBARS values by 77–91% with 3% addition. However, there was no significant correlation between the antioxidative efficacy of the meals and free or total gossypol levels (Rhee et al. 2001). Soluble phenolic acids were predominantly in the ester form and there was no significant difference between gland and glandless cottonseeds (Dabrowski and Sosulski 1984). Whittern et al. (1984) reported that quercetin and rutin were the major flavonoids in cottonseed and responsible for the antioxidant activity. Tocopherol content for cottonseed was around 800 ppm (Van Niekerk and Burger 1985).

Different cultivars of soybeans and from different origins have been shown to have good antioxidant capacity, and thus helping in different conditions (Lee et al. 2004; Sakthivelu et al. 2008; Xu and Chang 2008a; Xu and Chang 2008b; Darmawan et al. 2010; Byun et al. 2010; Tepavcevic et al. 2010). Genistein (4,5,7-trihydroxyisoflavone), the predominant isoflavone in soybean enriched foods, has been shown to inhibit prostate carcinogenesis in animal models. Genistein has antioxidant effects and was shown to protect cells against ROS by scavenging free radicals, inhibiting the expression of stress-response related genes (Fan et al. 2006). In addition, genistein was shown to be a powerful inhibitor of NF-κB, Akt, and PTK signaling pathways, all of which are important for cell survival (Banerjee et al. 2008). Cyclo(His-Pro) a naturally occurring, cyclic dipeptide obtained from soybean meal was found to protect the cells from apoptotic cell death induced by oxidative stress of streptozotocin by increasing the expression of an antiapoptotic

protein, Bcl-2 (Koo et al. 2011). Soy aqueous extracts and concentrates contain isoflavones and phenolic acids as the major antioxidants, while the organic solvent extracts contain tocopherols, sterols, phospholipids, and other flavonoids. Phenolics in black soybean seed coat (BSSC) are considered to be responsible for the health benefits of black soybean. BSSCs of 60 Chinese varieties were examined for phenolic contents, anthocyanin profiles, and antioxidant activity. Total phenolic and condensed tannin contents ranged from 512.2 to 6,057.9 mg gallic acid equivalents/100 g and from 137.2 to 1,741.1 mg (+)-catechin equivalents/100 g, respectively. Six anthocyanins (delphinidin-3-glucoside, cyanidin-3-galactoside, cyanidin-3-glucoside, petunidin-3-glucoside, peonidin-3-glucoside, and malvidin-3-glucoside) were detected. Total anthocyanin contents (TAC) were from 98.8 to 2,132.5 mg/100 g, and cyanidin-3-glucoside was the most abundant anthocyanin in all varieties, with a distribution of 48.8–94.1% of TAC. Antioxidant properties detected by DPPH, FRAP, and ORAC methods all showed wide variations ranging from 4.8 to 65.3 μg/100 mL (expressed as EC(50)), from 17.5 to 105.8 units/g, and from 42.5 to 1,834.6 μmol Trolox equivalent/g, respectively (Zhang et al. 2011b). Isoflavone genistein from soybeans was able to target endogenous copper leading to prooxidant signaling and consequent cell death, and this explains the anticancer effect of genistein as also its preferential cytotoxicity towards cancer cells (Ullah et al. 2011). Dietary soybean isoflavones were shown to have a positive effect on antioxidant status, enhancing antioxidant capacity of plasma and antioxidant enzymes in various tissues in male Wistar rats (Barbosa et al. 2011). Soyasaponin-rich extract from soybean showed good antioxidant activity (Yang et al. 2011). The soy isoflavones were found to protect hepatic-kidney functions in diabetic rats and this was shown by the significant increases in superoxide dismutase, catalase, and glutathione peroxidase activities and the decrease in thiobarbituric acid reactive substances (Hamden et al. 2011).

Canola or rapeseed oil ingestion shortens the life span of stroke-prone spontaneously hypertensive rats compared with soybean oil and leads to changes in oxidative status, despite an improvement in the plasma lipids. Canola oil ingestion significantly reduced the red blood cell superoxide dismutase, glutathione peroxidase and catalase activities, total cholesterol, and low-density lipoprotein cholesterol (Papazzo et al. 2011). Canola oil has high phenolics and significant antioxidant activity (Goffman and Möllers 2000; Velasco et al. 2011; Baardseth et al. 2010). Rapeseed peptide hydrolysate could be useful as a human food addition as a source of bioactive peptides with antioxidant properties (Xue et al. 2009). The high antioxidant activity in canola oil fractions with several groups of phenolics clearly demonstrates the protective effect through multiple mechanisms.

Legumes

Legumes are considered to have very beneficial health benefits and this has been shown to be related to the phytochemicals present. The antioxidant content of some legumes is presented in Table 4.1.

Legumes have been shown to be a rich source of antioxidants. In their study on legumes (Xu and Chang 2007) found that the 50% acetone extracts exhibited the highest TPC for yellow pea, green pea, chickpea, and yellow soybean. Additionally, the acidic 70% acetone (+0.5% acetic acid) extracts exhibited the highest TPC, TFC, and FRAP values for black bean, lentil, black soybean, and red kidney bean. The 80% acetone extracts exhibited the highest TFC, CTC, and DPPH-free radical scavenging activity for yellow pea, green pea, chickpea, and yellow soybean. The 70% ethanol extracts exhibited the greatest ORAC value for all selected legumes. There was a high correlation between the phenolic compositions and antioxidant activities of legume extracts.

Peanut (*Arachis hypogaea*) is native to South America and contains several active components including flavonoids, phenolic acids, phytosterols, alkaloids, and stilbenes. Resveratrol content in commercial peanut products was found to be similar to the resveratrol content of the raw peanut fractions routinely used for making them (Sobolev and Cole 1999). Several therapeutic effects have been reported for peanut seed extracts, and these include antioxidative, antibacterial, antifungal, and anti-inflammatory activities (Lopes et al. 2011; Chang et al. 2006). Peanut root extracts also have shown good antioxidant activity (Holland et al. 2011). Peanut phytoalexins may become a viable source of natural alternatives to synthetic antioxidants and antimicrobials. Stilbenes and other low-molecular-weight phenolic compounds from peanuts have been shown to have high antioxidant activity and antimicrobial properties (Holland and O'Keefe 2010). Stilbenoids, such as resveratrol, arachidin-1, and arachidin-3 from peanut hairy root cultures, demonstrated good antioxidant activity (Abbott et al. 2010). The antioxidant capacities were shown to be dependent on peanut type, cultivars, and harvest date. Their results also showed that thermal processing altered the composition of the peanut kernel antioxidants, though the TPC and radical scavenging activities were preserved (Craft et al. 2010). Cultivar differences were highly significant for alpha-, beta-, gamma-, and delta-tocopherols and total tocopherol contents, whereas production year effects were highly significant for alpha- and beta-tocopherol levels (Shin et al. 2009). Peanut skins were shown to be low in monomeric flavan-3-ols (19%) in comparison to hazelnut (90%) and almond (89%) skins. However, the polymeric flavan-3-ols in peanut and almond skins occurred as both A- and B-type proanthocyanidins, but in peanuts the A forms (up to DP12) were predominant, whereas in almonds the B forms (up to DP8) were more abundant. In contrast, hazelnuts were mainly constituted by B-type proanthocyanidins (up to DP9). The antioxidant capacity as determined by various methods was found to be higher for whole extracts from roasted hazelnut and peanut skins than for almond skins; however, the antioxidant capacities of the HMW fraction of the three types of nut skins were almost the same (Monagas et al. 2009). Methanol, ethanol, and acetone extracts of peanut hulls were found to be significantly better antioxidants than the chloroform and hexane extracts (Duh et al. 1992). Phenolics probably play a vital role in the antioxidant activity of dehusked legumes (Saxena et al. 2007).

Several other legumes like kidney bean, guar, and tamarind have been shown to have strong antioxidant activity while some others like black soybean, azuki cowpea, lentil, and faba had lower antioxidant activity when added at 1 mg mL^{-1}. Two new

phenolic compounds, 5-hydroxy-2-[2-(4-hydroxyphenyl) acetyl]-3-methoxylbenzoic acid and (2S,3S)-3,7,8,3′,4′-pentahydroxyflavane, were obtained from the aqueous extract of *Acacia catechu*, along with four known compounds identified as rhamnetin, 4-hydroxyphenyl ethanol, 3,3′,5,5′,7-pentahydroxyflavane, and fisetinidol and had antioxidant activities (Li et al. 2011c). Tannins and other compounds from tamarind were reported to have strong antioxidant activity (Sinchaiyakit et al. 2011; Paula et al. 2009; Lamien-Meda et al. 2008: Martinello et al. 2006; Sudjaroen et al. 2005; Komutarin et al. 2004).

Cereals

Antioxidant properties of cereals (durum wheat, bread wheat, rice, barley, oat, rye, corn, and triticale) and cereal-based products are based on the tocopherols (T), tocotrienols (T3), and carotenoids present (Irakli et al. 2011). The antioxidant content of nuts, legumes, and grain products is presented in Table 4.1. Multicereal mixtures of oat, rye, buckwheat, and common wheat flours provided higher source of antioxidants (Angioloni and Collar 2011). Studies in healthy rodents have shown that phenolic-rich cereals lowered oxidized lipids in blood, liver, and brain tissue and increased the activity of antioxidant enzymes in blood including glutathione peroxidase and superoxide dismutase activity (Zdunczyk et al. 2006; Mukoda et al. 2001). Cereals play a major role in human nutrition and are a good source of saccharides, proteins, selected micronutrients, and phenolics (Klepacka et al. 2011; Dimitrios 2006; Balasundram et al. 2006). The noteworthy cereals are barley (Yadav et al. 2000) and buckwheat (Takahama et al. 2010). Grains of barley and buckwheat are used to produce frequently consumed groats and flakes (Takahama et al. 2010; Yadav et al. 2000; Hernández-Borges et al. 2005). Phenolic acids are the most important and the largest group of antioxidants in terms of incidence in cereal grains (Naczk and Shahidi 2006; Yadav et al. 2000; Hernández-Borges et al. 2005). They consist of two subgroups, i.e., hydroxybenzoic and hydroxycinnamic acids (Balasundram et al. 2006). The forms of salicylic, *p*-hydroxybenzoic, vanillic, protocatechuic, *p*-coumaric, syringic, ferulic, and sinapic acids have been identified in barley grains (Yadav et al. 2000; Hernández-Borges et al. 2005). The bran-aleurone fraction of buckwheat contains bound syringic, *p*-hydroxybenzoic, vanillic, and *p*-coumaric acids (Naczk and Shahidi 2006).

Barley leaf powder was shown to significantly retard oxidation of ground pork after cooking (Choe et al. 2011). Green mass of young plants of spring barley are a significant source of vitamins C and E which are important antioxidants. Spring barley can be recommended for the preparation of natural dietary supplements and is preferred to synthetic vitamin preparations (Brezinová Belcredi et al. 2010). Phenolic compounds, *p*-hydroxyacetophenone, 5,7-dihydroxychromone, naringenin, quercetin, and iso-americanol A, were found first time in the barley tea, together with the known compounds, *p*-hydroxybenzaldehyde, 3,4-dihydroxybenzaldehyde, *p*-hydroxybenzoic acid, vanillic acid, and *p*-coumaric acid. The compounds, 3,4-dihydroxybenzaldehyde,

p-coumaric acid, quercetin, and isoamericanol A, were shown to have stronger antioxidative activities than that of butylated hydroxytoluene (BHT) at 400 μM (Etoh et al. 2004). 3,4-dihydroxybenzaldehyde isolated from barley was shown to exert the inhibitory effect on H_2O_2-induced tumor development by blocking H_2O_2-induced oxidative DNA damage, cell death, and apoptosis (Jeong et al. 2009). Different varieties of Chinese barley showed significant antioxidant activity (Zhao et al. 2006). The phenolic compounds (+)-catechin and ferulic acid in barley were found to change significantly during malting. Moreover, results from the Pearson correlation analysis showed that there were good correlations among DPPH radical scavenging activity, ABTS radical cation scavenging activity, reducing power, total phenolic content, and sum of individual phenolic contents during malting (Lu et al. 2007). The pearled barley fractions were shown to have strong antioxidant properties and the phenolic compounds identified were vanillic, caffeic, *p*-coumaric, ferulic, and sinapic acids (Madhujith et al. 2006). The antioxidant and hypolipidemic effects of barley leaf essence could be useful in the prevention of cardiovascular disease in which atherosclerosis is important (Yu et al. 2002b). Barley leaf extracts were shown to scavenge oxygen free radicals, save the LDL-vitamin E content, and inhibit LDL oxidation in type 2 diabetic patients (Yu et al. 2002a).

The common buckwheat (*Fagopyrum esculentum* Moench) and tartary buckwheat (*Fagopyrum tataricum* (L.) Gaertn.) were studied for the general composition, functional components, and antioxidant capacity. The results showed that ethanol extracts of tartary buckwheat sprouts (TBS) had higher reducing power, free radical scavenging activity, and superoxide anion scavenging activity than those of common buckwheat sprouts (CBS). As for the chelating effects on ferrous ions, CBS had higher values than TBS. Rutin was shown to be the major flavonoid found in these two types of buckwheat sprouts, but TBS had fivefold higher rutin than CBS. The antioxidant effects of buckwheat sprouts on human hepatoma HepG2 cells revealed that both the TBS and CBS could decrease the production of intracellular peroxide and remove the intracellular superoxide anions in HepG2 cells, but TBS reduced the cellular oxidative stress more effectively than CBS, possibly because of its higher rutin (and quercetin) content (Liu et al. 2008).

Nicotiflorin and rutin have been shown to have neuroprotective effects on hypoxia-, glutamate-, or oxidative stress-induced RGC death at concentrations of 1 nM or higher (Nakayama et al. 2011). Intake of tartary buckwheat cookies with high level of the antioxidant rutin was found to reduce levels of myeloperoxidase, an indicator of inflammation, while intake of both types of buckwheat cookies could lower cholesterol levels (Wieslander et al. 2011). Rutin is one of the flavonoids derived from plants such as buckwheat and is well known as a powerful antioxidant (Morimoto et al. 2011). The highest content of rutin was found in flowers of both kinds of buckwheat (*F. esculentum*, *F. tataricum*). The free quercetin was found in flowers and achenes of *F. esculentum*, whereas flowers and achenes of *F. tataricum* contained quercitrin (Dadakova and Kalinova 2010). Phenolic acids, procyanidins, and galloylated propelargonidins are the antioxidants in buckwheat (Verardo et al. 2011). Proanthocyanidins in buckwheat flour were found to contribute to the scavenging of reactive nitrogen oxide species generated from NO and nitrous acid

in the stomach (Takahama et al. 2010). Tartary buckwheat bran extract was shown to significantly reduce the total triglycerides and total cholesterol in the serum and liver of hyperlipemic rats, raise the serum antioxidant activity, and inhibit serum lipid peroxide formation (Wang et al. 2009). Buckwheat honey was found to be most effective in reducing ROS levels, and thus it was selected for use in wound-healing products. The major antioxidant properties in buckwheat honey derive from its phenolic constituents, which are present in relatively large amounts (van den Berg et al. 2008).

Grains are the major supply source of antioxidants in daily life. The antioxidant activity of corn, in particular, is relatively high (Adom and Liu 2002) and thus is a good source of antioxidants. Corn was shown to have the highest total phenolic content, followed by wheat, oats, and rice. The major portion of phenolics in grains existed in the bound form (85% in corn, 75% in oats and wheat, and 62% in rice). Ferulic acid was shown to be the major phenolic compound in the grains tested, with free, soluble-conjugated, and bound ferulic acids present in the ratio 0.1:1:100. Corn also had the highest total antioxidant activity, followed by wheat, oats, and rice. The bound phytochemicals were the major contributors to the total antioxidant activity and could also survive stomach and intestinal digestion to reach the colon. This could partly explain the mechanism of grain consumption in the prevention of colon cancer, other digestive cancers, breast cancer, and prostate cancer, which is supported by epidemiological studies (Adom and Liu 2002).

Corn oil showed significant effect on catalase in rat liver (Dauqan et al. 2011). In Bolivian purple corn (*Zea mays* L.) varieties, the ferulic acid values ranged from 132.9 to 298.4 mg/100 g, and *p*-coumaric acid contents varied between 251.8 and 607.5 mg/100 g dry weight (DW), respectively, and were identified as the main nonanthocyanin phenolics. The total content of phenolic compounds ranged from 311.0 to 817.6 mg gallic acid equivalents (GAE)/100 g DW, and the percentage contribution of bound to total phenolics varied from 62.1 to 86.6%. The total monomeric anthocyanin content ranged from 1.9 to 71.7 mg cyanidin-3-glucoside equivalents/100 g DW. Differences were observed only in the relative percentage of each anthocyanin. Cyanidin-3-glucoside and its malonated derivative were detected as major anthocyanins. Several dimalonylated monoglucosides of cyanidin, peonidin, and pelargonidin were present as minor constituents (Cuevas et al. 2011). Extracts of maize kernels were reported to scavenge nitric oxide ($^{\bullet}NO$) and superoxide ($^{\bullet}O_2^-$) (Lee et al. 2010). White, blue, red, and purple corns (*Zea mays* L.) were lime-cooked to obtain masa for tortillas. The highest concentration of total phenolics, anthocyanins, antioxidant index, and induction of QR-inducing activity was found in the Veracruz 42 (Ver 42) genotype. The nixtamalization process (masa) was shown to reduce the total phenolics, anthocyanins, and antioxidant activities and the ability for QR induction when compared to raw grain. Processing masa into tortillas was also shown to negatively affect total phenolics, anthocyanin concentration, antioxidant activities, and QR induction in the colored corn varieties. The blue variety and its corresponding masa and tortillas did not induce QR. Ver 42 genotype and their products (masa and tortilla) showed the greatest antioxidant activity and capacity to induce QR (Lopez-Martinez et al. 2011). The black waxy corn was found to

have the highest quantity of anthocyanins, phenolics, and the best antioxidant activity. The yellow corn had a relatively large amount of carotenoids, while the white corn had the lowest amounts of carotenoids, anthocyanins, phenolics, and antioxidant capacity (Hu and Xu 2011). The two compounds from supersweet corn powder, 7-(*O*-β-glucosyloxy)oxindole-3-acetic acid and 7-hydroxy-oxindole-3-acetic acid, showed strong (DPPH) radical scavenging activity and 7-hydroxy-oxindole-3-acetic acid also showed antioxidative activity in vivo (Midoh et al. 2010).

Total phenolic content was shown to contribute significantly to the AOA of Indian cereals and millets (Sreeramulu et al. 2009). Different millet varieties were shown to display effective radical and ROS inhibition activities, and this generally correlated with the phenolic contents, except for hydroxyl radical. Ferulic and *p*-coumaric acids were present as the major hydroxycinnamic acids in phenolic extract and were responsible for the observed effects (Chandrasekara and Shahidi 2011a). The soluble as well as bound fractions of millet grains were shown to be rich sources of phenolic compounds with antioxidant, metal chelating, and reducing power. Kodo millet had the highest total phenolic content, whereas proso millet possessed the least. All millet varieties showed high antioxidant activities; however, the bound fractions contained more ferulic and *p*-coumaric acids compared to their soluble counterparts (Chandrasekara and Shahidi 2010). Mattila et al. (2005) studied the contents of free and total phenolic acids and alk(en)ylresorcinols were analyzed in commercial products of eight grains: oat (*Avena sativa*), wheat (*Triticum* spp.), rye (*Secale cerale*), barley (*Hordeum vulgare*), buckwheat (*Fagopyrum esculentum*), millet (*Panicum miliaceum*), rice (*Oryza sativa*), and corn (*Zea mays*). The highest contents of total phenolic acids were in brans of wheat (4,527 mg kg^{-1}) and rye (4,190 mg kg^{-1}) and in whole-grain flours of these grains (1,342 and 1,366 mg kg^{-1}, respectively). In other products, the contents varied from 111 mg kg^{-1} (white wheat bread) to 765 mg kg^{-1} (whole-grain rye bread). Common phenolic acids found in the grain products were ferulic acid (most abundant), ferulic acid dehydrodimers, sinapic acid, and *p*-coumaric acid (Mattila et al. 2005).

Rice is known to contain antioxidants, and colored rice shows higher antioxidant activity than white rice. Anthocyanins from black rice were shown to suppress mitochondrial oxidative stress-induced apoptosis by preserving mitochondrial glutathione and inhibiting cardiolipin oxidation and mitochondrial fragmentation (Kelsey et al. 2011).Unpolished red rice infant cereals showed high total phenolic contents and peroxyl radical scavenging activity (Hirawan et al. 2011). Eight vitamin E isomers (α-, β-, γ-, and δ-tocopherols and α-, β-, γ-, and δ-tocotrienols) and γ-oryzanol were quantified in rice (Huang and Ng 2011).

Rice brans were shown to be good natural sources of hydrophilic and lipophilic phytochemicals with significant antioxidant activity (Min et al. 2011). Ferulic and *p*-coumaric acids were found to be the major phenolic acids in the free fraction of pigmented rice husks, whereas vanillic acid was the dominant phenolic acid in the free fraction of normal rice husks. However, *p*-coumaric acid was found in bound form of both pigmented and normal rice husks. The antioxidant activity of husk extracts was found to be positively correlated with the total free phenolic content and individual phenolic acids especially ferulic acid (Butsat and Siriamornpun

2010). Thai rice brans were shown to be potential antioxidant sources (Muntana and Prasong 2010). Pigmented rice (black and red rice) bran extracts were found to be highly effective in inhibiting linoleic acid peroxidation (60–85%). High-performance liquid chromatography (HPLC) analysis of antioxidants in rice bran found that γ-oryzanol (39–63%) and phenolic acids (33–43%) were the major antioxidants in all bran samples, and black rice bran also contained anthocyanins 18–26%. HPLC analysis of anthocyanins showed that pigmented bran was rich in cyanidin-3-glucoside (58–95%). Ferulic acid was the dominant phenolic acid in the rice bran samples. Black rice bran contained gallic, hydroxybenzoic, and protocatechuic acids in higher contents than red rice bran and normal rice bran (Laokuldilok et al. 2011). The lignins from rice husk were also found to have good antioxidant activity (Salanti et al. 2010). Black rice bran was found to have higher content of phenolics, flavonoids, and anthocyanins and also higher antioxidant activity when compared to white rice bran. Interestingly, the phenolics, flavonoids, and anthocyanins of black rice bran were shown to be mainly present in free form (Zhang et al. 2010).

Cereal grains contain phenolic acids, saponins, phytoestrogens, and flavonoids (Liyana-Pathirana and Shahidi 2007; Helmja et al. 2011). Whole grains, including wheat, contain several compounds that are capable of minimizing the damaging effects of oxidation reactions. These include phytate, proteins, polysaccharides, phenolics, lignans, and tocopherols. Phenolic antioxidants are one of the major antioxidants in wheat. Ferulic, vanillic, and *p*-coumaric acids are the most abundant free phenolic acids in wheat exhibiting antioxidant activities (Graf 1992; Kroon et al. 1997; Zielinski and Kozlowska 2000). Soluble phenolics extracted from durum wheat bran extracts were shown to be effective antioxidants in dispersed soybean oil (Onyeneho and Hettiarachchy 1992). When antioxidant activity is compared at the free phenolic acid concentrations found in wheat, effectiveness is in the order of ferulic acid > vanillic acid > *p*-coumaric acid. The antioxidant activity of wheat products depends on the nature of antioxidant species, wheat variety, extraction method, and type of antioxidant activity assay (Fardet et al. 2008; Serpen et al. 2008). Both genetic and environmental effects had a strong effect on the tocols in wheat genotypes (Lampi et al. 2010). Total tocopherol and tocotrienol contents in different wheat types showed large variation. There are other types of wheat with high proportions of tocotrienols (Lampi et al. 2008). Different growing conditions and varieties also had significant effect on the total phenolic acid content in 26 different wheat genotypes (Li et al. 2008; Fernandez-Orozco et al. 2010). Wheat bran was shown to protect against diquat toxicity by activating the hepatic antioxidant system, and selenium was found to be the key antioxidant in wheat bran (Higuchi et al. 2011). Durum wheat flour and its methanol extract lengthened the induction period for the oxidation of linoleic acid indicating that they showed antioxidative capacities. Three kinds of gluten from durum wheat gluten, hard red winter wheat gluten, and hard red spring wheat gluten also showed antioxidative capacities. However, wheat starch had no antioxidative capacity (Iwamoto et al. 2009). Wheat germ oils were rich in linoleic acid (omega-6) and linolenic acid (omega-3). The wheat germ oil had reasonable amounts of whole sterols, but very high amounts of total tocopherol and tocotrienol components (Hassanein and Abedel-Razek 2009). Wheat germ was found to be very effective to

improve the antioxidant defense status in tissues in rats (Leenhardt et al. 2008). Whole grain wheat flour diet was found to improve the redox and lipid status in rats (Fardet et al. 2007). Yi et al. (2011) suggested the possible detoxification effect of wheat sprouts on BPA-induced oxidative stress in young women. The tocopherol content in wheat germ oil ranged from 1,947 to 4,082 ppm, with γ-tocopherol being the highest (Dolde et al. 1999). Wheat germ had strong antioxidant activity and this was due to the polyphenols (Alvarez et al. 2006). Multigrain blends were found to be more nutritious and have better functional activity (including antioxidant activity) than common wheat in breadmaking (Angioloni and Collar 2011). Wheat durum and Kamut khorasan were shown to be good sources of antioxidants and produced a lower oxidative state in rats fed the cereal-based diets (Gianotti et al. 2011). Fermented wheat aleurone was able to act on primary prevention of H_2O_2-induced DNA damage by inducing mRNA expression and the activity of enzymes involved in detoxification of carcinogens and antioxidative defense in human colon cells (Stein et al. 2010). No correlation was found between the antiradical activity and polyphenol or flavonoid contents in durum (9 varieties) and soft (17 varieties) wheat grains (Heimler et al. 2010). Wheat grass supplementation with a high-fat diet resulted in improved lipid levels (decreased total cholesterol and increased HDL-C) together with significantly reduced MDA levels and increased GSH and vitamin C levels in rats. These results indicated the protective role of wheat grass in ameliorating hyperlipidemia and the associated oxidative stress (Sethi et al. 2010). Anthocyanin products and compounds from blue wheat were assessed against scavenging of 2,2-diphenyl-1-picryl-hydrazyl and 2,2′-azino-di-(3-ethylbenzthiazoline sulfonate) radicals and inhibition of human low-density lipoprotein cholesterol oxidation. They showed differences in antioxidant capacity, but exceeded that of BHT (Abdel-Aal et al. 2008). The fractions of wheat grains with the highest aleurone content had the highest antioxidant capacity. Ferulic acid was found to be the major contributor to the antioxidant capacity in fractions with higher antioxidant capacity (Mateo Anson et al. 2008). Water-soluble wheat antioxidant showed the strongest DPPH(*) scavenging capacity on a per grain weight basis and also had a much higher level of total phenolic acids (Cheng et al. 2008).

Bran fractions of wheat genotypes were found to have the greatest antioxidant activities with ferulic acid as the predominant phenolic acid. The highest contents of anthocyanins were in the shorts of blue and purple wheat (Siebenhandl et al. 2007).

Oats are known to be a healthy food for the heart and this is mainly due to their high beta-glucan content. In addition, oats also contain more than 20 unique polyphenols, avenanthramides, which have shown strong antioxidant activity in vitro and in vivo. Oats possess antioxidant capacity most of which is likely derived from polar phenolic compounds in the aleurone (Handelman et al. 1999). The polyphenols of oats have also recently been found to exhibit anti-inflammatory, antiproliferative, and anti-itching activity, which may provide additional protection against coronary heart disease, colon cancer, and skin irritation (Meydani 2009). Oats produce a group of phenolic antioxidants termed avenanthramides. These metabolites are a unique group of antioxidants found almost exclusively in oats and have shown, in experimental systems, certain desirable nutritional characteristics such as inhibiting atherosclerotic plaque formation and reducing inflammation. Avenanthramides have

been shown to exert antioxidant and antigenotoxic activities that were comparable to those of ascorbic acid (Lee-Manion et al. 2009; Chen et al. 2007). Oat phenolics, including avenanthramides, were found to be bioavailable in hamsters and interact synergistically with vitamin C to protect LDL during oxidation (Chen et al. 2004). Avenanthramides occur in both the leaves and grain of oat. They are predominantly conjugates in which 25 and 20 are exclusive to the groat and hull (Wise 2011). Oat leaves were shown to produce phytoalexins, avenanthramides, in response to infection by pathogens or treatment with elicitors (Okazaki et al. 2004). Oats also have the important phytochemicals like tocopherols, tocotrienols, and carotenoids (Irakli et al. 2011). Oat milling fractions, the methanolic extracts of pearling fractions, flour and aspirations from flaking, and trichomes had high, intermediate, and low antioxidant activities. The pearling fractions were also highest in total phenolics and tocols and had *p*-hydroxybenzoic acid, vanillic acid, caffeic acid, vanillin, *p*-coumaric acid, and ferulic acid. Three avenanthramides were also detected. Total phenolic content was found to be significantly correlated with antioxidant activity (Emmons et al. 1999). Avenanthramide-rich extract (ARE) from oat bran was rich in vanillic acid, caffeic acid, syringic acid, *p*-coumaric acid, ferulic acid, and sinapic acid. Administration of D-galactose markedly lowered not only the activity of superoxide dismutase (SOD) and glutathione peroxidase (GPx) but also the gene expression of manganese superoxide dismutase (SOD), copper–zinc SOD, glutathione peroxidase (GPx), and lipoprotein lipase (LPL) mRNA in mice. However, the inclusion of ARE was shown to significantly reverse the D-galactose-induced oxidative stress by increasing the activity of the antioxidant enzymes and upregulating their gene expression. This was also accompanied by a significant decrease in the malondialdehyde level in mice given ARE compared to the control. These results demonstrated that ARE possessed antioxidant activity and was effective against D-galactose-induced oxidative stress (Ren et al. 2011). Oat vinegar manifested antioxidant activity which was stronger than that of rice vinegar in vitro and the same as that of vitamin E in vivo (Qiu et al. 2010).

Fruits and Berries

The antioxidant activity of fruits and berries has been studied extensively and they vary due to the use of different oxidation systems and methods to analyze the antioxidant compounds. The antioxidant content of fruits and berries is presented in Table 4.2. Fruits are a significant part of the human diet, providing fiber, minerals, vitamins, and other beneficial compounds such as antioxidants. The beverages are potential sources of antioxidants (Table 4.5). Edible berries are a potential source of natural anthocyanin antioxidants and have demonstrated a broad spectrum of biomedical functions. These include cardiovascular disorders, advancing age-induced oxidative stress, inflammatory responses, and diverse degenerative diseases. Berry anthocyanins also improve neuronal and cognitive brain functions, ocular health, as well as protect genomic DNA integrity. Dietary intakes of polyphenolic flavonoids,

especially from bran, apples, pears, red wine, grapefruit, strawberries, and chocolate, have been significantly associated with decreased risks for cardiovascular disease (CVD) mortality (Mink et al. 2007). Apples and strawberries have also been reported to be the largest contributors of cellular antioxidant activity among all fruits consumed in the USA (Wolfe et al. 2008). Concord grape juice, blueberry, or strawberry extracts significantly attenuated age-related motor and cognitive deficits (Cavazzoni et al. 1999). Intake of high-antioxidant foods such as berries, Concord grapes, and walnuts may enhance cognitive and motor function in aging (Joseph et al. 2009; Willis et al. 2009). The anthocyanins were the major contributors to the antioxidant capacity of black currants and blueberries, whereas the lower antioxidant capacity of red currants and cranberries was due mainly to the reduced anthocyanin content. Raspberries had a lower anthocyanin content than black currants and blueberries, but only a slight decline in the antioxidant capacity, and this was because of the presence of the ellagitannins sanguin H-6 and lambertianin C (Borges et al. 2010). The antioxidant activities of the wild berries like crowberry, cloudberry, whortleberry, Lingonberry, aronia, rowanberry, and cranberry were higher than those of the cultivated berries such as strawberry, redcurrant, blackcurrant, and raspberry (Kahkonen et al. 1999). Crowberry extract (*Empetrum nigrum*) had higher total content of anthocyanins than the other nine major berry species studied and also exerted the strongest antioxidant activity (Ogawa et al. 2008). Antioxidant potency, ability to inhibit LDL oxidation, and total polyphenol content were shown to be consistent in classifying the antioxidant capacity of the polyphenol-rich beverages in the following order: pomegranate juice > red wine > Concord grape juice > blueberry juice > black cherry juice, acai juice, cranberry juice > orange juice, iced tea beverages, apple juice (Seeram et al. 2008). The antioxidant activity of anthocyanins from tart cherries, *Prunus cerasus* L. (Rosaceae) cv. Balaton and Montmorency; sweet cherries, *Prunus avium* L. (Rosaceae); bilberries, *Vaccinium myrtillus* L. (Ericaceae); blackberries, *Rubus* sp. (Rosaceae); blueberries var. Jersey, *Vaccinium corymbosum* L. (Ericaceae); cranberries var. Early Black, *Vaccinium macrocarpon* Ait. (Ericaceae); elderberries, *Sambucus canadensis* (Caprifoliaceae); raspberries, *Rubus idaeus* (Rosaceae); and strawberries var. Honeoye, *Fragaria* × *ananassa* Duch. (Rosaceae) was shown to be comparable to the commercial antioxidants, tert-butylhydroquinone, butylated hydroxytoluene, and butylated hydroxyanisole, and superior to vitamin E (Seeram et al. 2001). Consumption of berries and fruits such as blueberries, mixed grape, and kiwifruit was associated with an increase in the plasma antioxidant capacity in the postprandial state. However, consumption of an energy source of macronutrients containing no antioxidants was associated with a decline in plasma antioxidant capacity (Prior et al. 2007). Cranberry and blueberry constituents (flavonoids such as anthocyanins, flavonols, and proanthocyanidins; substituted cinnamic acids and stilbenes; and triterpenoids such as ursolic acid and its esters) were shown to more likely act by mechanisms that counteract oxidative stress, decrease inflammation, and modulate macromolecular interactions and expression of genes associated with disease processes (Neto 2007). Seed flours from black raspberry, red raspberry, blueberry, cranberry, pinot noir grape, and chardonnay grape had good antioxidant capacity

(Parry et al. 2006). Cherries, and in particular sweet cherries, are a nutritionally dense food rich in anthocyanins, quercetin, hydroxycinnamates, potassium, fiber, vitamin C, carotenoids, and melatonin and exhibit relatively high antioxidant activity (Ferretti et al. 2010; McCune et al. 2011). Tart cherries and juices have been reported to have novel antioxidants and exhibit antioxidant activity (Haibo et al. 1999; Wang et al. 1999a, b; Seeram et al. 2001; Howatson et al. 2010). Prunes, prune juice, plums, and peaches have been reported to have significant antioxidant activity (Wang et al. 1996; Plumb et al. 1996b; Donovan et al. 1998; Gil et al. 2002; Kayano et al. 2004; Kimura et al. 2008). The ingestion of prunes was shown to decrease the LDL cholesterol plasma level in humans with hypercholesterolemia (Tinker et al. 1991) as well as the plasma and liver cholesterol concentrations in hyperlipidemic rats (Tinker et al. 1994). A prune extract and juice have been reported to inhibit low-density lipoprotein (LDL) oxidation (Donovan et al. 1998). In vitro assays have also shown that prunes had the highest antioxidative capacity among dried fruits (Karakaya et al. 2001; Wu et al. 2004; Pellegrini et al. 2006).

Strawberries are an excellent source of phytochemicals, particularly anthocyanins and ellagic acid, which have potent antioxidant and anti-inflammatory functions (Hannum 2004). Strawberry juice extracts have been shown to significantly inhibit free radicals (Wang and Jiao 2000) and reduce ox-LDL-induced proliferation of rat aortic smooth muscle cells (Chang et al. 2008). Ellagic acid supplementation also reduced oxidative stress and atherosclerotic lesion formation in hyperlipidemic rabbits (Yu et al. 2005). In animal models, freeze-dried strawberry powder has been shown to reduce obesity and improve glycemic control in mice fed a high-fat diet (Prior et al. 2008), while mice fed anthocyanin extracts from strawberries demonstrated an upregulation of anti-inflammatory adiponectin gene (Tsuda et al. 2004). Strawberries have been reported to be potent antioxidants and reduce cardiovascular risk factors, such as elevated blood pressure, hyperglycemia, dyslipidemia, and inflammation in limited studies. Berries, such as strawberries (*Fragaria*×*ananassa*), are a good source of polyphenolic anthocyanins, fiber, and several micronutrients (Hannum 2004; Tulipani et al. 2008; Reber et al. 2011). Strawberries have been highly ranked as an excellent source of total polyphenols and antioxidant capacity among the fruits and vegetables in US diet (Halvorsen et al. 2006; Marques et al. 2010; Henning et al. 2010). Strawberry supplementation in healthy volunteers has been shown to increase serum antioxidant capacity, thereby indicating protection against oxidative damage (Cao et al. 1998). Strawberry supplementation was found to reduce the oxidative damage to LDL while maintaining reductions in blood lipids and enhancing diet palatability in hyperlipidemic subjects (Jenkins et al. 2008). In subjects with cardiovascular risk factors, supplementation of strawberry puree, in combination with other berries, was shown to increase HDL-cholesterol and decrease systolic blood pressure versus the control group (Erlund et al. 2008). Therapeutic roles of strawberries, blueberries, and cranberries in the metabolic syndrome, a prediabetic state characterized by several cardiovascular risk factors, have been shown. Interventional studies have demonstrated the following effects: strawberries lowering total and LDL-cholesterol, but not triglycerides, and decreasing surrogate biomarkers of atherosclerosis (malondialdehyde and adhesion molecules), blueberries

lowering systolic and diastolic blood pressure and lipid oxidation and improving insulin resistance, and low-calorie cranberry juice selectively decreasing biomarkers of lipid oxidation (oxidized LDL) and inflammation (adhesion molecules) in the metabolic syndrome. Mechanistic studies further explain these observations as upregulation of endothelial nitric oxide synthase activity, reduction in renal oxidative damage, and inhibition of the activity of carbohydrate digestive enzymes or angiotensin-converting enzyme by these berries. Strawberry antioxidants were found to show favorable effects on postprandial inflammation and insulin sensitivity (Edirisinghe et al. 2011). The over-ripe fruit of strawberries was shown to be an excellent source of natural antioxidants (Goulas and Manganaris 2011).

Zhang et al. (2008) isolated and identified the following phenolics: cyanidin-3-glucoside (1), pelargonidin (2), pelargonidin-3-glucoside (3), pelargonidin-3-rutinoside (4), kaempferol (5), quercetin (6), kaempferol-3-(6′-coumaroyl)glucoside) (7), 3,4,5-trihydroxyphenyl-acrylic acid (8), glucose ester of (E)-*p*-coumaric acid (9), and ellagic acid (10) from strawberry . Among the pure compounds, the anthocyanins 1 (7,156 μM Trolox/mg), 2 (4,922 μM Trolox/mg), and 4 (5,514 μM Trolox/mg) were the most potent antioxidants. Crude extracts (250 μg mL^{-1}) and pure compounds (100 μg mL^{-1}) inhibited the growth of human oral (CAL-27, KB), colon (HT29, HCT-116), and prostate (LNCaP, DU145) cancer cells with different sensitivities observed between cell lines (Zhang et al. 2008).

Blueberries (*Vaccinium* spp.) have the highest antioxidant capacities among the fruits and vegetables and contain polyphenols such as anthocyanins, proanthocyanidins, and phenolic acids, and flavanols (Prior et al. 2000; Smith et al. 2000; Wu et al. 2004; Burdulis et al. 2009). Blueberry had the highest cellular antioxidant activity value, followed by cranberry > apple = red grape > green grape (Wolfe and Liu 2007). Blueberry diet protected against atherosclerosis in the apoE(−/−) mouse model and this probably involved reduction in oxidative stress by both inhibition of lipid peroxidation and enhancement of antioxidant defense (Wu et al. 2010). Blueberry-enriched diets and extracts have been shown to attenuate and even improve age-related behavioral and neuronal deficits in rodents (Joseph et al. 1999, 2005; Bickford et al. 2000; Ramassamy 2006). There was a significant cognitive enhancement observed in adult mice after supplementation with blueberry extract concentrated in polyphenols, and this was closely related to the higher brain antioxidant properties and inhibition of acetylcholinesterase activity (Papandreou et al. 2009). Blueberry infusion had high total phenol contents and showed significant reducing capacity as well as radical scavenging potential (Piljac-Zegarac et al. 2009). Blueberry exhibited preventive and protective effects on CCl_4-induced hepatic fibrosis by reducing hepatocyte injury and lipid peroxidation (Wang et al. 2010b). Blueberry supplementation has also been shown to attenuate proinflammatory cytokine production in rat glial cells (Lau et al. 2007). Additionally, hypertensive rats on blueberry supplemented diets exhibited significantly lower systolic and mean arterial pressures and renal nitrite content (Shaughnessy et al. 2009). Blueberry fruits rich in malvidin glycosides were found to be beneficial in alleviating muscle damage caused by oxidative stress (Hurst et al. 2010). Highbush blueberry cultivars and their fermented beverages were reported to be good natural sources of antioxidants

and starch-degrading enzyme inhibitors important for type 2 diabetes (Johnson et al. 2011; Dastmalchi et al. 2011). Freeze-dried blueberries and fresh blueberries were found to have similar antioxidant activities (Reyes et al. 2011). Blueberry fruit grown from organic culture was shown to yield significantly higher total phenolics, total anthocyanins, and antioxidant activity (ORAC) than fruit from the conventional culture (Wang et al. 2008). The fruit, juice, and pulp of strawberry, Saskatoon berry, raspberry, wild blueberry, chokecherry, and seabuckthorn extracts showed good antioxidant capacity as measured by ORAC method (Hosseinian et al. 2007).

Apple is one of the major sources of dietary flavonoids and a good source of antioxidants. It contains appreciable amounts of vitamin C and various phenolic compounds (catechins, phenolics acids, quercetin, and phloretin), which also have protective effects (Bellion et al. 2010). Apples and pears are good sources of phenolic compounds and also show good antioxidant capacity (Huber and Rupasinghe 2009; Vieira et al. 2009; Kevers et al. 2011; Sivam et al. 2011). Procyanidins are major components of the apple (*Malus pumila* Mill., Rosaceae) polyphenols. Proanthocyanidins, Leucocyanidins, procyanidins, and condensed tannins account for approximately 65% of apple polyphenols (Sunagawa et al. 2011). Procyanidins are also found in a variety of fruits, berries, and several medicinal plants or plant components, such as grape (*Vitis vinifera*) seeds (Zanchi et al. 2009), bilberry (*Vaccinium myrtillus*) (Hokkanen et al. 2009), hawthorn (*Crataegus monogyna*) (Shahat et al. 2002), ginkgo (*Ginkgo biloba*) (Van Beek 2002), tormentil (genus *Potentilla*) (Vennat et al. 1994), and oak (genus *Quercus*) (Pallenbach et al. 1993). Epidemiological studies have linked the consumption of apples with reduced risk of some cancers, cardiovascular disease, asthma, and diabetes, lipid oxidation, cholesterol. Apple and grape pomace contain significant amounts of phenolic compounds (Sehm et al. 2007; Scalbert and Williamson 2000) and exert significant peroxyl radical (ORAC) and DPPH radical scavenging activities (Gonzalez-Paramas et al. 2004; Hogan et al. 2009, 2010; Rossle et al. 2011). Apple extract has been shown to protect against oxidatively induced DNA damage (Miene et al. 2009). Apple juice/cider was associated with lower non-Hodgkin's lymphoma risk and follicular lymphoma in particular (Thompson et al. 2010). Apple polyphenols had a significant protective effect against acute hepatotoxicity induced by $CCl_{(4)}$ in mice, which they suggest could be due to its free radical scavenging effect, inhibition of lipid peroxidation, and its ability to increase antioxidant activity (Yang et al. 2010). Apple peel polyphenol extract was found to protect against complex I inhibition and its downstream oxidative consequences in Caco-2 cells (Carrasco-Pozo et al. 2011a), and also protected the gastric, intestinal, and colonic mucosa from oxidative stress by preventing increased malondialdehyde concentrations and decreasing the GSH/GSSG ratio in rats (Carrasco-Pozo et al. 2011b). Six types of apple pomace extracts were shown to have strong relationship between radical scavenging activities and phenolic contents or flavonol glycosides (Cetkovic et al. 2011). Low doses of phloridzin, a major phenolic compound in apple, increased life span of yeasts by inhibiting ROS and increasing antioxidant defense of the yeast (Xiang et al. 2011). The antiaging activity of apple polyphenols in fruit flies was shown to be at least in part, mediated by its interaction with genes SOD, CAT, MTH, and Rpn11 (Peng et al.

2011b). The alcohol-insoluble solids of fruits (lignin and nonextractable procyanidins) of apple, Chinese quince, quince, hawthorn, pear, and blueberry fruits showed positive correlations with the bile acid binding and radical scavenging activities (Hamauzu and Mizuno 2011). Ursolic acid, a natural triterpenoid present in apples, was found to be effective in reducing the oxidative stress-mediated changes in liver of rats (Gayathri et al. 2009).

Citrus fruits and juices, as well as purified flavonoids, have been shown to have hypolipidemic and/or antidiabetic effects and antioxidant activities (Jung et al; 2003; Gorinstein et al. 2004, 2005, 2006; Kurowska and Manthey 2004; Roza et al. 2007; Guimaraes et al. 2010; Judy et al. 2010; Nichols et al. 2011). The peel-deriving polymethoxylated flavones, tangeretin, nobiletin, and sinensetin were found in higher concentrations in juice than in peeled tangerine fruit. In contrast, the concentrations of the flavanone glycosides, narirutin, hesperidin, and didymin were several fold higher in peeled fruit than in tangerine juice. The predominant carotenoid was β-cryptoxanthin followed by zeaxanthin, lutein, lycopene, and β-carotene in tangerine juice (Stuetz et al. 2010). Organic mandarin juice was shown to have higher antioxidant activity and total carotenoid concentrations than the conventional (Navarro et al. 2011). Mandarin and lemon juices had higher antioxidant activity than the bitter orange and blood orange juices (Tounsi et al. 2011). Essential oil of lemon (*C. limon*) treatment was found to significantly reduce the lipid peroxidation levels and nitrite content but increase the GSH levels and the SOD, catalase, and GPx activities in mice hippocampus (Campelo et al. 2011). The essential oil of sweet orange had significant antioxidant activity (Chalova et al. 2010; Singh et al. 2010). The antioxidant activity assessed in all the Clementine fruits (*Citrus clementina* Hort. Ex. Tan) cultivated in Italy was closely correlated with vitamin C and total polyphenols content, rather than with the flavonoid compounds (Milella et al. 2011). A good correlation was found between the total phenolic content and the total antioxidant activity in orange juice (Stella et al. 2011). Hesperetin, a citrus flavonone, was found to be a potent antioxidative agent against Cd-induced testicular toxicity in rats (Shagirtha and Pari 2011). Naringenin from grapefruits and other citrus fruits contributes to the hydroxyl radical scavenging activity of grapefruit (Turkkan et al. 2012). Both 5-demethylnobiletin and nobiletin from citrus fruits exhibited similar hypolipidemic activity and can enhance LDL receptor gene expression and activity and decrease acyl CoA:diacylglycerol acyltransferase 2 expression (Yen et al. 2011). The citrus flavanones, naringin and nobiletin, even at physiological concentrations, showed neuroprotective effects against H_2O_2-induced cytotoxicity in PC12 cells (Lu et al. 2010). The protective effect shown by naringin, a citrus flavanone, against DNA damage induced by daunorubicin in mouse hepatocytes and cardiocytes, probably is related with its capacity to trap free radicals (Carino-Cortes et al. 2010).

Kiwifruit is rich in vitamins and polyphenols and has strong antioxidant effects. Kiwifruit was shown to be rich in polyphenols compared with other fruits (Iwasawa et al. 2011). Gold kiwi and navel orange had the strongest inhibition rates of lipid oxidation followed by Green kiwi, mandarin orange, grapefruit, and apple (Iwasawa et al. 2011).

Green kiwi (Hayward) extracts were reported to contain a number of antioxidant constituents such as vitamin C and E, caffeic acid, naringenin, quercetin, and epicatechin (Fiorentino et al. 2009).

Grapes (*Vitis vinifera*) are a natural source of bioactive compounds, in particular antioxidants, with potential health promoting and disease protective qualities (Bagchi et al. 1997; Sato et al. 1999; Shi et al. 2003; Louli et al. 2004; Zhang et al. 2007; Choi et al. 2010a, b; El-Ashmawy et al. 2010; Ginjom et al. 2010; Jordao et al. 2010; Polovka et al. 2010; Radovanovic and Radovanovic 2010; Radovanovic et al. 2010; Wang et al. 2010a, b; Aguiar et al. 2011; Charradi et al. 2011; Ghanim et al. 2011; Hanausek et al. 2011; Li et al. 2011a–d; Ndiaye et al. 2011; Park et al. 2011; Jing Yu et al. 2011). Both fresh grapes and commercial grape juices are a significant source of phenolic antioxidants (Aguiar et al. 2011). Wines, grapes, and grape seed extracts are a major source of polyphenolic components such as anthocyanins, flavanols, flavonols, resveratol, catechins, and proanthocyanidins (Mazza 1995; Frankel and Meyer 1998; Munoz-Espada et al. 2004; Manach et al. 2004; Castillo-Munoz et al. 2007; Huntley 2007; Xia et al. 2010). Grape seed extract (GSE) is reported to have many pharmacological benefits, including antioxidant, anti-inflammatory, anticarcinogenic, and antimicrobial properties (Nassiri-Asl and Hosseinzadeh 2009; Yadav et al. 2009; Choi et al. 2010a, b; Feng et al. 2010; Yalcin et al. 2010; El-Mowafy et al. 2011; Jagetia and Reddy 2011). The antiatherosclerotic properties of GSE were concluded to depend on their powerful antioxidant potential (Ayub et al. 1999; Kim et al. 2007; Mohamed et al. 2010). The grape seed extract was shown to enhance the antioxidant defense against reactive oxygen species produced under hyperglycemic conditions, hence protecting the liver cells in Wistar rats (Chis et al. 2009). Jia et al. (2011) concluded that grape seed proanthocyanidin (GSPE) extract was useful in attenuation of H_2O_2-induced oxidative stress and the activation of NF- B and MAPK signaling in HLE-B3 cells, and thus this suggested that GSPE has a potential protective effect against cataractogenesis. The highest antioxidant capacity was found in grape seeds, followed by skin, while the flesh displayed the lowest antioxidant capacity (Pastrana-Bonilla et al. 2003). Wine-making affords grape pomace as a by-product in an estimated amount of 13% by weight of the grapes. This waste, consisting of peels, seed, and stems, has high levels of residual phenolic compounds (Amico et al. 2004). Thus, grape seed and peel are increasingly being used to obtain functional food ingredients such as natural antioxidants and dietary supplements (Goni et al. 2005). In red wine, anthocyanins and flavonoids are the major two groups of phenolic compounds and (+)-catechin is an abundant flavonoid (Bell et al. 2000). The in vitro antioxidant activity of the isolated total polyphenols extract from different winemaking stages was found to remain unchanged after alcoholic fermentation, and this was independent of the variation of phenolic composition and sensory properties (Sun et al. 2011). The antioxidant activity and phenolic compounds were reported to be similar in wine made with the three different wine making methods and showed a similar pattern even after 3 months storage (Mulero et al. 2011). Simonetti et al. (2002) reported that the ingestion of grape seed extract increased the levels of α-tocopherol in red blood cell membranes and suggested that grape seed extract exerts their

antioxidant protection by sparing liposoluble vitamin E in vivo. Vinson et al. (2000) reported that grape juice was a powerful in vivo antioxidant, and suggested that this property, in combination with its platelet aggregation inhibition ability, could potentially reduce the risk of heart disease. It has been reported that the intake of proanthocyanidins increases the resistance of plasma against oxidative stress and may contribute to physiological functions of plant food including wine through their in vivo antioxidant activities (Koga et al. 1999). It has also been suggested that proanthocyanidins, the major polyphenol in red wine, might trap reactive oxygen species in plasma and interstitial fluid of the arterial wall, thereby inhibiting the oxidation of LDL, and show an antiatherosclerotic activity (Yamakoshi et al. 1999). The grape peel is rich in anthocyanins, which are glycosidic-linked flavonoids responsible for the red, violet, purple, and blue colors of many plants (Wang et al. 1997). As with other plant polyphenols, many anthocyanins have marked antioxidant activity in vitro (Tsuda et al. 1996). The study by Pan et al. (2011) revealed that grape seed extract co-treatment significantly attenuated arsenic-induced low antioxidant defense, oxidative damage, proinflammatory cytokines, and fibrogenic genes. Grape seed proanthocyanidin (GSPE) extract was shown to enhance sperm motility by downregulating c-kit expression and offsetting the apoptosis and oxidative stress induced by nickel sulfate, by directly decreasing MDA and NO, scavenging H_2O_2, and downregulating Bax expression (Su et al. 2011). GSPE was also shown to decrease the free radical generation and this may lead to the upregulation of $Na^{(+)}/K^{(+)}$-ATPase alpha1 subunit in rats (Zhao et al. 2010). Fractions from grapes, rich in procyanidin oligomers and gallate esters, showed most protective effect against UV-induced oxidative damage in HaCaT human keratinocytes (Matito et al. 2011). Anter et al. (2011) reported that red table grapes were potent antimutagens that protected DNA from oxidative damage as well as being cytotoxic toward the HL60 tumor cell line.

Teas

There is a long history of tea as a beverage or a folk medicine. Tea originates from the plant *Camellia sinensis* and is cultivated around the world. The three major forms of tea are green tea (nonfermented), oolong tea (semifermented), and black tea (fermented). Tea, in the form of green or black tea, is one of the most widely consumed beverages in the world. The ORAC values of different teas are presented in Table 4.6. The flavonoids of tea have antioxidant effects via attenuation of the inflammatory process in atherosclerosis, reduction of thrombosis, promotion of normal endothelial function, and inhibition of the expression of cellular adhesion molecules (Kris-Etherton and Keen 2002). Numerous epidemiological studies have revealed that tea consumption may reduce the risk of several diseases such as cancer, cardiovascular, or neurodegenerative diseases (Keli et al. 1996; Commenges et al. 2000; Checkoway et al. 2002; Tan et al. 2003). Tea constituents exhibit various biological and pharmacological properties such as anti-inflammatory, anticarcinogenic,

antioxidative, antiallergic, antivirus, antihypertensive, antiatherosclerosis, antimutagenic, anticardiovascular disease, antihyperglycemic, and antihypercholesterolemic activities (Matsuzaki and Hara 1985; Muramatsu et al. 1986; Bors and Saran 1987; Chisaka et al. 1988; Shimizu et al. 1988; Kada et al. 1985; Sano et al. 1995; Sazuka et al. 1995; Janakun et al. 1997; Cao and Cao 1999; Hodgson et al. 1999; Benelli et al. 2002; Wang and Bachrach 2002; Lambert and Yang 2003; Hsu 2005; Chen et al. 2011a, b; Hu et al. 2011a, b; Zeng et al. 2011). The neuroprotective effect has been ascribed to tea's high content of polyphenolic compounds, mainly catechins and other flavanols (Stewart et al. 2005; Mandel et al. 2006; Tipoe et al. 2007; Khan and Mukhtar 2007; Almajano et al. 2008). During the last two decades, research both in vitro and in vivo has shown its therapeutic potential and beneficial effects on human health, such as preventing cancer (Bushman 1998; Blumberg 2003; Yang et al. 2009; Li et al. 2010, 2011a–d; Jagdeo and Brody 2011) and cardiovascular disease (Trevisanato and Kim 2000; Zhu et al. 2006). The basic protecting mechanism of tea has been linked to its strong antioxidative properties (Cao et al. 2012; Abib et al. 2011; Ankolekar et al. 2011; Baluchnejadmojarad and Roghani 2011; Finco et al. 2011; Hu et al. 2011a, b; Huvaere et al. 2011; Korany and Ezzat 2011; Kumar et al. 2011; Lopez de Dicastillo et al. 2011; Peng et al. 2011a; Thring et al. 2011; Wei et al. 2011; Wu et al. 2011; Zhong et al. 2011). Tea and its chemical compounds are regarded as natural antioxidants. Tea polyphenols are particularly good in vivo antioxidants, due to their bipolar properties. Antioxidative properties of catechins have already been shown to inhibit free radical generation, scavenge free radicals, and chelate transition metal ions. Although similar amounts of these polyphenolic compounds have been found in both green and black teas, green tea exhibits higher protective activity than black tea (Del Rio et al. 2004). Indeed, catechins are converted to theaflavins, thearubigins, and more complex polyphenols as green tea is processed into black teas. Since catechins exhibit higher antioxidant activity than theaflavins, it has been postulated that higher protection might be expected from teas that have undergone the minimal processing (Hernaez et al. 1998; Santana-Rios et al. 2001). White tea, the less processed tea (steamed and dried without a prior withering stage), has similar or even higher antioxidant activity than certain green teas (Santana-Rios et al. 2001; Thring et al. 2009; Muller et al. 2010; Unachukwu et al. 2010). White tea was recently reported to have high polyphenolic contents and to exhibit high activities in antioxidant assays, along with potential antiaging activity via inhibition of collagenase and elastase (Thring et al. 2009). It is often included in skin care products and usually advertised for their astringent and antioxidant properties. In the scientific literature, white tea is reported for topical treatment of skin disorders and has antiseptic and antioxidant properties (Van Wyk and Wink 2004). Almajano et al. (2011) reported that white tea extracts protected striatal cell lines against oxidative stress-mediated cell death and this protection of striatal cell cultures is likely associated with the antioxidant properties of white tea components. White tea extract was shown to protect PC12 cells against H_2O_2-induced toxicity, and this was due to the antioxidant mechanism through ROS scavenging and this may be in part responsible for cells neuroprotection (Lopez and Calvo 2011).

Recently, theaflavins (TFs) formed by the oxidation of a couple of epimerized catechins have been proposed to be prospective antioxidative agents. TFs are the orange pigments in brewed black tea and account for 2–6% of the dry weight of solids (Roberts 1958; Balentine et al. 1997). To date, more than 28 TF derivatives have been isolated, and the most abundant TFs in black tea are theaflavin (TF_1), theaflavin-3-gallate (TF_2A), theaflavin-3′-gallate (TF_2B), and theaflavin-3,3′-digallate (TF_3). TF complexes were generally believed to be the major antioxidant constituents of black tea, inhibiting free radical generation (Miller et al. 1996), inhibiting pro-oxidative enzyme activities (Lin et al. 1999, 2000; Yang et al. 2008), and chelating transition metal ions to prevent lipid peroxidation in vitro and in vivo (Rice-Evans et al. 1997). TF_3 has also been shown to possess a higher antioxidative activity than catechins, including (−)-epigallocatechin gallate (EGCG) in HL-60 cells (Lin et al. 2000; Yang et al. 2008). Theaflavins undergo further oxidation during the fermentation of black tea and pu-erh tea to form more polymerized thearubigins, and then condensed theabrownins (Lin et al. 1996; Yao et al. 2006; Yang et al. 2009; Gong et al. 2010; Xu et al. 2011). The postfermented pu-erh tea was shown to have the best effect on inhibiting the lipopolysaccharide (LPS)-induced production of NO (Xu et al. 2011).

Epidemiological data suggest that green tea (GT) consumption may protect against cardiovascular diseases and different types of cancer (Liu et al. 2011; Yuan 2011). This effect is attributed primarily to the antioxidant properties of flavanols from GT. GT consists of four different types of catechins: (−)-epigallocatechin-3-gallate (EGCG), (−)-epigallocatechin (EGC), (−)-epicatechin-3-gallate (ECG), and (−)-epicatechin (EC) (Balentine et al. 1997). The green tea catechins (EGC, EC, ECG, EGCG) exhibited good superoxide-, lipoxygenase-, as well as lipid oxidation-inhibition abilities, but all the theaflavins showed little effect on the inhibition of lipid peroxidation (Hara 1997). EGCG has been shown to have beneficial health effects, including prevention of cancer and heart disease, and it is also a potent antioxidant (Serafini et al. 1996; Peairs et al. 2010; Adhikary et al. 2011; Cavet et al. 2011; Chen et al. 2011a, b; Li et al. 2011a–d; Liu et al. 2011; Peng et al. 2011a; Tanaka et al. 2011; Tu et al. 2011; Van Aller et al. 2011; Wang et al. 2011a; Yang and Wang 2011; Cao et al. 2012). EGCG has a protective effect on I/R-associated hemodynamic alteration and injury by acting as an antioxidant and antiapoptotic agent in one (Piao et al. 2011).Green tea polyphenol (−)-epigallocatechin gallate and black tea polyphenol theaflavins (TF) inhibit the growth of cervical cancer cells by inducing apoptosis and regulating NF-kappaB and Akt (Singh et al. 2011). EGCG was found to have prophylactic effects on lupus nephritis in mice, and this was shown to be highly associated with its effects of enhancing the Nrf2 antioxidant signaling pathway, decreasing renal NLRP3 inflammasome activation, and increasing systemic Treg cell activity (Tsai et al. 2011). Zhong and Shahidi (2011) reported that EGCG derivatives exhibited greater antioxidant activity in scavenging the 1,1-diphenyl-2-picrylhydrazyl (DPPH) radical than EGCG, and thus may be used as potential lipophilic antioxidants in the food, cosmetic, and medicinal industries. Jowko et al. (2011) showed that in previously untrained men, dietary supplementation with green tea extract (in combination with strength training) enhanced the antioxidant defense

system in plasma at rest, and they suggest that it may give protection against oxidative damage induced by both short-term muscular endurance test and long-term strength training.

Vegetables

Consumption of fruits and vegetables is believed to be beneficial to human health. Fruits, vegetables, and some beverages, such as tea and coffee, are particularly rich in bioactive compounds with antioxidant activity, such as phenolic compounds, carotenoids, and vitamins, which can delay or inhibit the oxidation of biomolecules (DNA, proteins, and lipids). The antioxidant content of berries, fruits, and vegetables is presented in Table 4.2. The total phenol, flavonoid, flavanol, and ORAC values in selected vegetables are presented in Table 4.3. The fruits and vegetables have been divided into groups based on the color (Table 4.4). Fruits and vegetables have been identified as being high in antioxidant activity in the oxygen radical absorbance capacity assay (Wang et al. 1996). Consumption of strawberries, spinach, or red wine, which are rich in antioxidant phenolic compounds, can increase the serum antioxidant capacity in humans (Cao et al. 1998). The neutral and acidic flavonoids of red cabbage, red lettuce, black bean, mulberry, Gala apple peel, jambolao, acai fruit pulp, mulberry fruit pulp, and the acidic flavonoids of acerola fruit pulp showed high antioxidant activities (Hassimotto et al. 2005). Consumption of dietary polyphenols or fruits and vegetables (rich in carotenoids) and beverages such as red wine and tea has shown in epidemiological studies to protect against cardiovascular diseases, neurodegenerative diseases, and some forms of cancer (Verlangieri et al. 1985; Block et al. 1992; Renaud and de Lorgeril 1992; Vinson et al. 1995; Arts et al. 2001a, b; Di Castelnuovo et al. 2002; Hashimoto et al. 2002; Dauchet et al. 2006; He et al. 2006; Kuriyama et al. 2006; Kang et al. 2011; Kim and Kim 2011; Schini-Kerth et al. 2011). Several epidemiological studies have shown an association between the consumption of diets rich in fruits and vegetables and a lowered risk for chronic diseases such as cancer (Steinmetz and Potter 1996; Vainio and Weiderpass 2006; Mates et al. 2011), heart disease (Hertog et al. 1993; Joshipura et al. 2001; Nunez-Cordoba and Martinez-Gonzalez 2011), and stroke (Gillman et al. 1995; Joshipura et al. 1999).

Vegetables like green leafy vegetables (lettuce, spinach), tuberous crops (carrots, potatoes, red beets, sweet potatoes), cruciferous vegetables (Brussels sprouts, broccoli, cabbage, kale, collard), and others have been studied for their antioxidants and antioxidant activity using different methods (Cao et al. 1996; Vinson et al. 1998; Carlsen et al. 2010). The antioxidant score for kale was the highest while cucumber was lowest (Cao et al. 1996). The ORAC values of different vegetables and fruits are a good source of information (USDA 2010a, b). The top five contributors to the total antioxidative activity of the Japanese vegetables were onion, edible burdock, potato, eggplant, and cabbage (Takebayashi et al. 2010).

Carrot was found to exert antioxidant activity though it is not very strong compared to other vegetables (Cao et al. 1996; Vinson et al. 1998; El and Karakaya 2004; Shahar et al. 2011). Reactive oxygen species was shown to play a key role as a signaling molecule for the stress-induced accumulation of polyphenol content in carrots (Jacobo-Velázquez et al. 2011). Carrots dehydrated by ultrasound were found to retain more vitamin C and β-carotene compared to convective air drying (Frias et al. 2010). Carrot ingestion was found to decrease lipemia and improve the antioxidant status in mice (Nicolle et al. 2004a). Purple carrot juice was shown to attenuate or reverse all changes in high-carbohydrate, high-fat diet-fed rats, while β-carotene did not reduce oxidative stress, cardiac stiffness, or hepatic fat deposition. As the juice itself did not contain high concentrations of carotenoids, it is more likely that the anthocyanins were responsible for the antioxidant and anti-inflammatory properties of purple carrot juice to improve glucose tolerance as well as cardiovascular and hepatic structure and function (Poudyal et al. 2010). Chlorogenic acid was a major antioxidant in all seven colored carrots, but anthocyanins were the major antioxidants in purple-yellow and purple-orange carrots. Carotenoids were not found to contribute to the total antioxidant capacity, but correlated well with antioxidant capacity of hydrophobic extracts. Both the DPPH and ABTS assays showed that the hydrophilic extract had higher antioxidant capacity than the hydrophobic extract. Purple-yellow carrots had the highest antioxidant capacity, followed by purple-orange carrots, and the other carrots did not significantly differ (Sun et al. 2009). The white, yellow, and solid-colored purple carrot cultivars showed quite low contents of carotenoids, but the solid-colored purple contained most phenolic compounds. The red cultivar was the only one to contain lycopene. The α-carotene showed noteworthy differences in the orange cultivar and the purple cultivar with an orange core, with higher α-carotene content resulting in a higher antioxidative capacity. Also, the lycopene content in the red cultivar was higher in 2004 than in 2003, which again lead to an increased antioxidative capacity. Higher phenolics values were found for the purple-colored cultivars in 2004, which only in the case of the purple cultivar with an orange core, however, led to a higher antioxidative capacity (Grassmann et al. 2007).

Potato (*Solanum tuberosum* L.) tubers contain a wide range of carotenoid contents. Potato peel extract was found to have the highest antioxidant activity owing to its high content of phenolic compounds and flavonoids (Mohdaly et al. 2010). Potato peel extracts possess strong antioxidant activity in chemical and biological model systems in vitro, and this is attributable to its polyphenolic content. Singh and Rajini (2008) found that the potato peel extracts offered significant protection to human erythrocyte membrane proteins from oxidative damage induced by ferrous-ascorbate. Potato peel pretreatment was found to restore the $CCl_{(4)}$-induced altered antioxidant enzyme activities to control levels in rats. Their results demonstrated that potato peel pretreatment significantly offsets the $CCl_{(4)}$-induced liver injury in rats, and this could be attributable to the strong antioxidant properties of potato peel (Singh et al. 2008). Pigmented potatoes contain high concentrations of antioxidants, including phenolic acids, anthocyanins, and carotenoids. Potato protein hydrolysate

was found to exhibit strong antioxidant activity (Cheng et al. 2010). The soluble phenols as well as proteins present in tuber tissue of potatoes were found to substantially contribute to the total antioxidant capacity. Moreover, the quantities of soluble phenols, proteins, and antioxidants increased notably upon wounding the tubers (Wegener and Jansen 2010). The free fraction of extracts contributed 68, 64, and 88% to total phenolics, total antioxidant activity (ORAC value), and total flavonoids, respectively, in purple potato flour. Caffeic, *p*-coumaric, and ferulic acids were mostly observed in the bound extracts of raw formulations as in the extrudates, whereas chlorogenic acid was predominant in the free extracts. The extruded products had significantly higher content of total phenolics, ORAC antioxidant activity, and flavonoids, compared to the raw formulations (Nayak et al. 2011). Kaspar et al. (2011) studied the effects of pigmented potato consumption on oxidative stress and inflammation biomarkers in free-living healthy men (18–40 years; $n = 12$/group). They consumed 150 g of cooked white- (WP), yellow- (YP), or purple-flesh potatoes (PP) once per day for 6 weeks in a randomized study. The results showed that compared with the white potato group, the yellow potato group had higher concentrations of phenolic acids and carotenoids, whereas the purple flesh potato group had higher concentrations of phenolic acids and anthocyanins. Men who consumed YP and PP tended to have lower ($P < 0.08$) plasma IL-6 compared with those consuming WP. The PP group tended to have a lower plasma CRP concentration than the WP group ($P = 0.07$). Anthocyanins of the purple sweet potato exhibit antioxidant and hepatoprotective activities via a multitude of biochemical mechanisms. The anthocyanin fraction of purple sweet potato was shown to induce antioxidant defense via the Nrf2 pathway and reduce inflammation via NF-κB inhibition in the livers of DMN-intoxicated rats (Hwang et al. 2011). Consumption of a high-polyphenol diet (purple sweet potato leaves) for 7 days was shown to modulate antioxidative status and decrease exercise-induced oxidative damage and proinflammatory cytokine secretion (Chang et al. 2010). The radioprotective effect of purple sweet potato pigments in murine thymocytes was shown to be related to ROS scavenging, the enhancement of the activity of antioxidant enzymes, the maintenance of mitochondrial transmembrane potential, and the sequential inhibition of cytochrome c release and downstream caspase and PARP cleavage (Xie et al. 2010). The ethanol and water extracts of purple sweet potato (PSP) can be used as putative antiatherosclerotic and antidiabetic agents with strong antioxidant functions. This was the first report to report the biological functions of PSP extract to treat hyperlipidemic and hyperglycemic disorders (Park et al. 2010). PSP anthocyanins were found to protect the PC-12 cell from Abeta-induced injury through the inhibition of oxidative damage, intracellular calcium influx, mitochondria dysfunction, and ultimately inhibition of cell apoptosis (Ye et al. 2010). Anthocyanins from PSP were also found to protect against APAP-induced hepatotoxicity by blocking CYP2E1-mediated APAP bioactivation, by upregulating hepatic GSH levels, and by acting as a free radical scavenger (Choi et al. 2009). Sweet potato anthocyanin was shown to have effective in situ and in vitro antioxidant activity (Philpott et al. 2004).

Beetroot (*Beta vulgaris var. rubra*) is a food ingredient containing betalain pigments that show antioxidant activity (Wettasinghe et al. 2002; Kahkonen et al. 1999).

Beetroot products have been shown to inhibit neutrophil oxidative metabolism in a concentration-dependent manner (Zieli ska-Przyjemska et al., 2009). They also have high vitamin C content. Georgiev et al. (2010) reported that betalain extracts obtained from hairy root cultures of the red beetroot had higher antioxidant activity than extracts obtained from mature beetroots. This high antioxidant activity of the hairy root extracts was associated with increased concentrations (more than 20-fold) of total phenolic concomitant compounds, which may have synergistic effects with betalains. They also reported the presence of 4-hydroxybenzoic acid, caffeic acid, catechin hydrate, and epicatechin in both types of extract, but at different concentrations. Rutin was only present at high concentration in betalain extracts from the hairy root cultures, whereas chlorogenic acid was only detected at measurable concentrations in extracts from intact plants. Beetroot juice was among the European vegetable juices to have good antioxidant activity (Lichtenthaler and Marx 2005). Beet ranked eighth among the 23 vegetables used for the inhibition of LDL oxidation (Vinson et al. 1998).

Green leafy vegetables offer a cheap but rich source of a number of micronutrients and other phytochemicals having antioxidant properties. Antioxidant-rich leafy vegetable mix diet (beet leaf, angelica, red leaf lettuce, dandelion, green cos lettuce, lollo rosso, romaine lettuce) (12.5%, respectively), scotch kale, and red kale (6.25%, respectively) improved the antioxidants (glutathione and β-carotene) and antioxidant enzyme activities (glutathione peroxidase, glutathione reductase, and superoxide dismutase) in mice. It also showed a beneficial effect on the resistance of hepatocytes and lymphocytes DNA to oxidative damage. The mix may be useful for protecting cells from lipid peroxidation and oxidative DNA damage (Kim et al. 2009). Lettuce may provide relatively low levels of antioxidative phytochemicals that contribute to human health, but lettuce leaf extracts do contain compounds with high specific peroxyl radical scavenging activities (Caldwell 2003). Extract of lettuce showed an antioxidant activity comparable with those of DL-alpha-tocopherol and quercetin (Souri et al. 2004). The association of lettuce with arbuscular mycorrhizal fungi was found to result in higher concentrations of anthocyanins, carotenoids, and, to a lesser extent, phenolics in lettuce plants (Baslam et al. 2011). The ethanolic extract of lettuce (*Lactuca sativa*) was shown to be effective in protecting membranes against oxidative stress induced by D-galactose in midgut tissue of silkworm larvae (Gaikwad et al. 2010). The phenolic extract of romaine lettuce protected PC-12 cells against oxidative stress caused by H_2O_2 in a dose-dependent manner. Isochlorogenic acid, one of the phenolics, showed stronger neuroprotection than the other three caffeic acid derivatives found in lettuce (Im et al. 2010). Acetone extracts of lettuce showed strong inhibition of NO generation in murine macrophage cell line, RAW 264.7 (Lee et al. 2009a). The red lettuce extract was found to reduce the endogenous DNA damage in HT-29 colon cancer cells (Philpott et al. 2009). Lee et al. (2009b) reported that the supplementation of a high-cholesterol high-fat diet with 8% red-pigmented leafy lettuce resulted in an improvement of plasma cholesterol and lipid levels, prevention of lipid peroxidation, and an increase of the antioxidant defense system and, therefore, could contribute to reduce the risk factors of CVD. Lettuce (head) ranked 22nd among the 23 vegetables assayed for inhibition of LDL (Vinson et al. 1998). Dietary consumption of lettuce in rats increased the

total cholesterol end-products excretion and improved the antioxidant status due to the richness in antioxidants (vitamins C, E and carotenoids). In their model, lettuce clearly showed a beneficial effect on lipid metabolism and on tissue oxidation (Nicolle et al. 2004a, b). Lettuce (baby, romaine, and iceberg cultivars) and chicory had strong antioxidants and antioxidant capacity. There was good correlation between the phenolic content and antioxidant capacity (Llorach et al. 2004).

Spinach leaves are eaten as vegetable and have been reported to be a good source of minerals, vitamin B complex, vitamin K, ascorbic acid, carotene (β-carotene, lutein, zeaxanthin), protein content (2.0% per 100 g of edible protein), and flavonoids, all which possess antioxidant properties (Ferreres et al. 1997). Studies have reported the presence of a series of water soluble natural antioxidants in spinach leaves extract and their biological activities (Zurovsky et al. 1994; Zurovsky and Gispann 1995; Nyska et al. 2003; Joseph et al. 2005). Glycolipid extracts from spinach have been shown to have antioxidative and anti-inflammatory effects, and the extract may be useful for prevention of drug-induced mucosal injury and other inflammatory diseases (Shiota et al. 2010). Scavenging activity correlated well with the total phenolic content (Okada et al. 2010). Results of the FRAP and the TEAC assays showed that spinach was the vegetable with the greatest antioxidant capacity, followed by peppers (red bell for TEAC and chili pepper for FRAP assay), whereas cucumber and endive exhibited the lowest TAC values for the FRAP and TEAC assays, respectively. In the case of the TRAP assay, the highest TAC value was found for asparagus, whereas the TAC values of zucchini and cucumber were not detectable (Pellegrini et al. 2003). Similar results for spinach were reported earlier (Proteggente et al. 2002). The high antioxidant capacity of spinach is due to both the water- and lipid-soluble fractions; the former contains glucuronic acid derivates of flavonoids and derivates and isomers of *p*-coumaric acid (Bergman et al. 2001), and the latter is rich in lutein and chlorophylls (Buratti et al. 2001).

Cruciferous vegetables like cabbage, broccoli, brussel sprouts, kale, collard, mustard, and turnip leaves are a great source of antioxidants and are known for their antioxidant and anticarcinogenic effects. York cabbage extract had the highest total phenolic content (33.5), followed by broccoli, Brussels sprouts, and white cabbage (23.6, 20.4, and 18.4 mg GAE/g of dried weight) extracts. All the vegetable extracts had high flavonoid contents in the order of 21.7, 17.5, 15.4, and 8.75 mg QE/g of extract dry weight for York cabbage, broccoli, Brussels sprouts, and white cabbage, respectively. The extracts showed a rapid and concentration-dependent antioxidant capacity in diverse antioxidant systems. There was a good correlation between the total phenolic content obtained by spectrophotometric analysis and the sum of the individual polyphenols monitored by HPLC-DAD (Jaiswal et al. 2011). Climate was shown to have an effect on the natural antioxidants and antioxidant activity of six different Brassica vegetables. Broccoli inflorescences and Portuguese kale showed high antioxidant activity in Spring–Summer while turnip leaves did so in Summer–Winter. The antioxidant activity could be correlated to the high levels of L-ascorbic acid, total phenolics, and total flavonoids of each sample (Aires et al. 2011). Five white cabbage cultivars with the highest total phenolic content showed the highest antioxidant capacity (Penas et al. 2011). Cabbage and rape, the two traditional cultivated vegetables highly consumed

among Northern Portuguese regions, were rich in tocopherols, lycopene, phenolics, flavonoids, and high in antioxidant properties (Batista et al. 2011). Different glucosinolates and phenolic antioxidants were identified in kale, cabbage, and leaf rape (Velasco et al. 2011). Dietary treatment with broccoli sprouts was shown to strongly protect the heart against oxidative stress and cell death caused by ischemia–reperfusion in rats (Akhlaghi and Bandy 2010). According to Plumb et al. (1996a, b) extracts from broccoli, Brussels sprouts, red cabbage, white cabbage, and cauliflower show significant antioxidant properties against lipid peroxidation. Indole-3-carbinol (I3C), from cruciferous vegetables, has been associated with a reduced risk of several tumor types, such as breast cancer. This is hydrolyzed to a number of products, including a dimeric product, 3,3′-diindolylmethane (DIM), its major active metabolite, in the acidic environment of the stomach (Fan et al. 2009). Both these phytochemicals have been shown to stimulate BRCA1 in breast and prostate cancer cells and to protect cells against oxidative stress mediated by H_2O_2 and γ-radiation (Fan et al. 2006, 2009).

There are other vegetables like asparagus, artichoke, cauliflower, cucumber, celery, corn, cucumber, eggplant, pea, radish, tomato, and zucchini that have been shown to have good antioxidant activities. Tomato fruits are an important dietary source of antioxidants for humans due both to the fact that they have a high content of these compounds and the high consumption of this crop by the western population. The main nonenzymatic antioxidants found in tomato fruits are ascorbic acid, lycopene and carotenoids, phenolics, and vitamin E (Abushita et al. 1997; Frusciante et al. 2007). Recent studies have reinforced the hypothesis of beneficial effects of vitamin E on human health, mainly in the prevention of coronary heart disease, breast cancer, and protection against nicotine-induced oxidative stress in the brain (Das et al. 2009a; Ros 2009; Zhang et al. 2009). Several reports link vitamin E to the protection of pigments, proteins, and polyunsaturated fatty acids of the photosynthetic apparatus against reactive oxygen species generated during photosynthesis (Semchuk et al. 2009). It has additionally been proposed that vitamin E interacts with other antioxidant mechanisms in order to maintain cellular redox homeostasis (Foyer and Noctor 2005; Almeida et al. 2011). Dietary intakes of tomatoes and tomato products containing lycopene have been shown to be associated with decreased risk of chronic diseases, such as cancer (van Breemen et al. 2011). Evidence is accumulating to suggest that lycopene may act as a modulator of intracellular reactive oxygen species (ROS) and, therefore, control ROS-mediated cell growth (Palozza et al. 2011). Vallverdu-Queralt et al. (2011) reported that phenolic compounds and hydrophilic antioxidant capacity were responsible for the differences among tomato samples according to variety. Tomato lycopene complex has been shown to have protective effects against cisplatin-induced nephrotoxicity and lipid peroxidation in rats (Dogukan et al. 2011). The renal reducing ability of lycopene-treated rats was shown to be significantly greater than that of the control and is the first verification of in vivo antioxidant enhancement via dietary lycopene administration (Yoshida et al. 2011).

Asparagus (*A. officinalis*) is a vegetable with high antioxidant activity (Rodríguez et al. 2005; Pellegrini et al. 2003; Makris and Rossiter 2001). Asparagus and other vegetable extracts were found to exert antioxidant, neuroprotective and cholinergic

properties (Sharma et al. 2010). Extracts (*A. racemosus*) have been found to exert hepatoprotective activity by inhibiting the production of free radicals and acts as a scavenger, reducing the free radical generation via inhibition of hepatic CYP2E1 activity, increasing the removal of free radicals through the induction of antioxidant enzymes, and improving nonenzymatic thiol antioxidant GSH. Extracts (aqueous and ethanol) of asparagus increased the superoxide dismutase activity and total antioxidant capacity while the malondialdehyde level and the distribution of lipid droplets decreased in liver cells of mice (Zhu et al. 2010). Two major anthocyanins, cyanidin 3-[3″-(*O*-beta-D-glucopyranosyl)-6″-(*O*-alpha-L-rhamnopyranosyl)-*O*-beta-D-glucopyranoside] and cyanidin 3-rutinoside, were isolated from purple asparagus and the asparagus was found to have high antioxidant activities (Sakaguchi et al. 2008). The carotenoids, capsanthin, capsorubin, capsanthin 5,6-epoxide, antheraxanthin, violaxanthin, neoxanthin, mutatoxanthin epimers, zeaxanthin, lutein, beta-cryptoxanthin, beta-carotene, and some cis isomers were found in the ripe and unripe fruits of asparagus (Deli et al. 2000).

The antioxidant activities of five varieties of eggplant were correlated with the total amounts of phenolic and flavonoid. There was significant correlation between the hepatoprotective activities and total phenolic/flavonoid content and antioxidant activities, indicating the contribution of the phenolic antioxidants present in eggplant to its hepatoprotective effect on t-BuOOH-induced toxicity (Akanitapichat et al. 2010). Different genotypes of eggplant had nutraceutical and antioxidant properties (Mennella et al. 2010). Thermal treatment commonly used before consumption was found to increase the content and biological activity of antioxidant compounds of eggplants (Lo Scalzo et al. 2010). Extracts from purple color small size eggplant fruit demonstrated better antioxidant activities than the other samples (long green, purple-colored big size, purple-colored moderate size) and this was attributed to the higher phenolic and anthocyanin content since a linear relation was observed between the TPC and the antioxidant parameters (Nisha et al. 2009). Anthocyanins from the peels of different accessions of eggplant showed significant antioxidant activities (Azuma et al. 2008; Sadilova et al. 2006; Matsubara et al. 2005; Noda et al. 1998, 2000). Eggplant and pea sprout extracts contained high total phenolic compounds, anthocyanins, and ascorbic acids which appeared to be responsible for their antioxidant activities and scavenging effects on NO derived from sodium nitroprusside in RAW 264.7 macrophage (Bor et al. 2006). Tomato, guava, squash, tangerine, wax gourd, pineapple, chayote, and eggplant showed antioxidant activity which was different with different assays (Huang et al. 2004). Flavonoids isolated from brinjal (*Solanum melongena*) showed potent antioxidant activity (Sudheesh et al. 1999).

Herbs and Spices

Humans have a long history of using herbs and spices in their daily life. Herbs and spices have been used as medicines in ancient Egypt and Asia and as food preservatives in ancient Rome and Greece. Herbs and spices continued to be used during the middle ages for flavoring, food preservation, and/or medicinal purposes. Culinary

herbs and spices have been widely used for their hypoglycemic, lipid-lowering, and anti-inflammatory activities. These herbs and spices have very low calorie content and are reliable sources of antioxidants and other potential bioactive compounds in diet. The total phenolic content and ORAC values of selected herbs and spices are presented in Table 4.7. The early work on the antioxidant activities of herbs and spices (Chipault et al. 1952, 1956) has led to renewed interest about these compounds and the mechanism of action. They have many phytochemicals which are a potential source of natural antioxidant, e.g., phenolic diterpenes, flavonoids, alkaloids, tannins, and phenolic acids (Moure et al. 2001; Amro et al. 2002; Cai et al. 2004; Kim et al. 2011). The total phenolic and flavonoid content of spices is presented in Table 4.8. Spices and herbs have been described to possess antithrombotic, antiatherosclerotic, hypolipidemic, hypoglycemic, anti-inflammatory, and antiarthritic properties. It has been experimentally demonstrated that spices, herbs, and their extracts possess antimicrobial, anti-inflammatory, antirheumatic, lipid-lowering, hepatoprotective, nephroprotective, antimutagenic, and anticancer activities, besides their gastroprotective and antiulcer activities. Herbs and spices are rich in phytochemical antioxidants (Carlsen et al. 2010) and research indicates that these bioactive components may act alone or in concert to reduce disease risk through their antimicrobial (Lai and Roy 2004; Suppakul et al. 2003; Shelef 1984), antioxidant (Zheng and Wang 2001; Capecka et al. 2005; Huang et al. 2010; Loizzo et al. 2010; Ranilla et al. 2010; Vasanthi and Parameswari 2010; Jin et al. 2011; Viuda-Martos et al. 2011), and antitumorigenic properties (Yi and Wetzstein 2011; Kaefer and Milner 2008; Lai and Roy 2004; Kris-Etherton et al. 2002). Cumin, cardamom, coriander, and ginger were found to have strong antioxidant activity (Table 4.9). The antioxidative activity of ground clove, ginger, oregano, sage, and thyme in meat lipids was found to be concentration dependent, and clove was most effective, followed by sage and rosemary (Shahidi et al. 1995a, b). High antioxidant activity was reported for the ethanol extracts of *Gaultheria shallon*, *Sambucus cerulea*, and *Prunus americana* and one extracted rhizome, *Acorus calamus* (Acuna et al. 2002). Halvorsen et al. (2006) in their study found that among the top 50 foods with antioxidants, the top five antioxidants were dried spices (ground cloves, dried oregano, ground ginger, ground cinnamon, turmeric powder). Compared to other categories of food products within this study, the herbs and spices displayed the largest range in antioxidant capacity (0.803–125.549 mmol/100 g). The herbs, spices, and medicinal plants are rich sources of phenolic compounds, flavonoids, and flavanols with good antioxidant activity (Tables 4.10, 4.11, and 4.12). Dragland et al. (2003) in their study utilized the FRAP method to assess the antioxidant capacity of 18 fresh herbs and 38 commercially available dried spices in Norway. They found oregano, sage, peppermint, and thyme to contain the greatest antioxidant capacity for fresh herbs, while cloves, allspice, and cinnamon contained the highest levels of antioxidant activity among dried spices. Dragland et al. (2003) considered herbs or spices to be high in antioxidants if they contained >75 mmol/100 g, whereas Halvorsen et al. (2006) considered >10 mmol/100 g to be a high antioxidant content in their study. There has been found a positive linear correlation between phenolic compounds, primarily phenolic acids and flavonoids, and the antioxidant capacity of herbs and spices (Zheng and Wang 2001). Thyme, sage,

rosemary, and marjoram contained the greatest antioxidant capacity (ORAC scores) among the herbs, while cumin and ginger had the highest among the spices (Ninfali et al. 2005). The herbs with the highest reported antioxidant capacity in Zheng and Wang (2001) study were for Mexican and Greek oregano, marjoram, and dill. Wu et al. (2004) measured the antioxidant capacity of hydrophilic and lipophilic fractions of 16 dried spices and found that the lipophilic ORAC values for four spices (clove, ginger, black pepper, and turmeric) were higher than the hydrophilic ORAC values, which indicated the essential oils in these spices contained a substantial amount of antioxidants. The aqueous extracts of five umbelliferous fruits—caraway (*Carum carvi*), coriander (*Coriandrum sativum*), cumin (*Cuminum cyminum*), dill (*Anethum graveolens*), and fennel (*Foeniculum vulgare*) showed strong antioxidant activity that was superior to the known antioxidant ascorbic acid (Satyanarayana et al. 2004). Yun et al. (2003) studied the scavenging rate of herbs by ESR measurement and found clove and allspice to be highest among the herbs tested (Table 4.13). The list of some active constituents in herbs and spices is presented in Table 4.14.

Curcumin, a diferuloylmethane, derived from the rhizomes of turmeric has been shown to target the Nrf2-ARE signaling pathway to induce phase II detoxifying enzymes on an event of oxidative stress (Kang et al. 2006; Hatcher et al. 2008). Saffron, clove, cardamom, and cinnamon are highly aromatic spices and have been shown to have several anticarcinogenic activities against several cancers by upregulating several phase II detoxification enzymes, antioxidants, and reducing the lipid peroxides in the cells (Salim and Fukushima 2003; Das et al. 2004, 2009b; Bhattacharjee et al. 2007; Kaefer and Milner 2008; Das and Saha 2009). Clove, cinnamon, and oregano had the highest antioxidant capacity among the 26 spices tested (Shan et al. 2005). They also found a highly positive linear relationship between the total equivalent antioxidant capacity and total phenolic content (phenolic acids, phenolic diterpenes, flavonoids, and volatile oils). The aqueous extracts of 30 plants were investigated for their antioxidant properties using DPPH and ABTS radical scavenging capacity assay, oxygen radical absorbance capacity (ORAC) assay, superoxide dismutase (SOD) assay, and ferric reducing antioxidant potential (FRAP) assay. Total phenolic content was determined by the Folin–Ciocalteu method (Dudonne et al. 2009). They reported that oak (*Quercus robur*), pine (*Pinus maritima*), and cinnamon (*Cinnamomum zeylanicum*) aqueous extracts possessed the highest antioxidant capacities in most of the methods used and could be potential sources of natural antioxidants. These extracts also had the highest phenolic content (300–400 mg GAE/g). Mate (*Ilex paraguariensis*) and clove (*Eugenia caryophyllus* clovis) aqueous extracts also showed strong antioxidant properties and a high phenolic content (about 200 mg GAE/g). They reported a significant relationship between antioxidant capacity and total phenolic content, indicating that phenolic compounds are the major contributors to the antioxidant properties of these plants (Dudonne et al. 2009). Garlic extracts inhibited the oxidative modification of lipids induced by DMBA, thus protecting cells from injury by the oxidized molecules (Das and Saha 2009). Oral administration with aqueous infusion of garlic and cardamom in addition to the DMBA treatment to the Swiss albino mice demonstrated downregulation of COX2 and p53 (tumor suppressor) expression when compared to the DMBA treated mice only. This indicated the reduction of inflammation related abnormalities in the

phytocompounds treated mice. These phytocompounds delayed the formation of skin papillomas in animals and simultaneously decreased the size and number of papillomas demonstrating their beneficial effects (Das et al. 2009b; Das and Saha 2009). Leaves from thyme, sage, spearmint, and peppermint grown in the greenhouse showed significantly higher total phenol content and antioxidant capacity than those grown under field conditions, with a threefold difference being observed in peppermint. They all had high total phenolic content and antioxidant capacity. Rosemary, spearmint, and peppermint extracts showed stronger inhibition of cyclooxygenase COX-2 than of COX-1 (Yi and Wetzstein 2010). The aqueous extracts of rosemary and sage were the richest in phenolic compounds and showed the highest ability in binding iron and inhibiting DPPH, superoxide radicals and advanced glycation end-product production, lipid peroxidation, and the activity of α-glucosidase and α-amylase, while the methanol extracts of both rosemary and sage were less efficient than those of garlic, onion, parsley, and chili in scavenging hydroxyl radicals (Cazzola et al. 2011). Oregano exhibited the highest AC among the herbs tested (basil, chili, cilantro, dill, garlic, ginger, lemongrass, oregano, and parsley) in dry and fresh forms. The AC in dry form was decreased in garlic, chili, dill, oregano, and parsley and paste form of oregano and basil. With the exception of dried garlic and lemongrass in fresh and paste form, all herbs in dry, paste, and fresh form contained significant AC. The AC was shown to be correlated significantly to the total phenolic content in both dry and fresh form (Henning et al. 2011). Kim et al. (2011) studied the antioxidant activities of 13 spices and found the DPPH radical scavenging ability of the spice extracts to be in the order clove > thyme > rosemary > savory > oregano. The values for superoxide anion radical scavenging activities were in the order of marjoram > rosemary > oregano > cumin > savory > basil > thyme > fennel > coriander. Clove had the highest total phenolic content (108.28 μg (CE)/g). The total flavonoid content of the spices varied from 324.08 μg (QE)/g for thyme to 3.38 μg QE/g for coriander. Their results indicated that hot water extracts of several spices had a high antioxidant activity which was partly due to the phenolic and flavonoid compounds. The total phenolics, flavonoids, and antioxidant activities were assayed in leaves and stem bark of *Azadirachta indica*, *Butea monosperma*, *Cassia fistula*, *Mangifera indica*, *Syzygium cumini*, and *Tamarindus indica* using the 2,2-diphenyl-1-picrylhydrazyl (DPPH) and superoxide radical scavenging method. The DPPH radical scavenging activity positively correlated with the total phenolic content in both stem bark and leaf. Superoxide radical scavenging activity increased with increasing flavonoid contents (Choudhary and Swarnkar 2011). Parsley has been reported to have strong antioxidant properties (Pizzorno and Murray 1985; Fejes et al. 1998, 2000; Campanella et al. 2003; Gomez-Coronado et al. 2004; Meyer et al. 2006; Wei and Shibamoto 2007; Yildiz et al. 2008; Vora et al. 2009). The samples of parsley rich in flavonoids were shown to have good correlation between the chemical property and the antioxidant effect. Chohan et al. (2008) reported that simmering, soup making, and stewing significantly increased the antioxidant capacity of parsley extracts, while grilling and stir frying decreased it. Several extracts of parsley were found to be good scavengers of DPPH and OH radicals and reduced the intensity of lipid peroxidation. The in vivo effects were evaluated on some antioxidant systems (activities of LPx, GSH-Px, Px, CAT and XOD, and GSH content) in mice liver and

blood after treatment with parsley extracts, or in combination with CCl_4. The examined extracts exhibited a protective effect (Popovic et al. 2007). Vora et al. (2009) reported the ethanolic extract of parsley to have a protective effect against mitochondrial oxidative damage in the mouse brain. They reported a significant decrease in the activity of superoxide dismutase and glutathione and an increase in catalase activity in D-galactose-stressed mice. However, the treatment with an ethanolic extract of parsley of the D-galactose-stressed mice showed protection against the induced oxidative stress in brain regions. The concentration of thiobarbituric acid-reactive product was greatly elevated in D-galactose stress-induced mice, but was significantly reduced in the brain regions of the mice on treatment with parsley (Vora et al. 2009). The essential oils of parsley were also found to play a significant role in the scavenging effect (Fejes et al. 1998). It was reported that the antioxidant activity of parsley in food systems was related to their total phenolic content and radical scavenging capacity but not to their ability to chelate iron in vitro (Jimenez-Alvarez et al. 2008). Zhang et al. (2011a, b) studied the antioxidant and anti-inflammatory activities of 14 Chinese medicinal plants and found some of them to be good sources of antioxidants. They reported a positive linear correlation between the antioxidant activity and the total phenolics and flavonoid contents. Ramesh et al. (2012) found that administration of the fermented Panax ginseng extract (GINST) to aged rats resulted in increased activities of SOD, CAT, GPx, GR, and GST as well as elevation in GSH, ascorbic acid, and α-tocopherol levels. Besides, the level of MDA, AST, ALT, urea, and creatinine were also reduced on administration of GINST to aged rats. Their results suggested that treatment with GINST could improve the antioxidant status during aging, thereby minimizing the oxidative stress and occurrence of age-related disorders associated with free radicals. The commonly used dietary agents such as *Allium sativum* (garlic), *Camellia sinensis* (tea), *Curcuma longa* (turmeric), *Emblica officinalis* (Indian gooseberry), *Ferula asafoetida* (asafoetida), *Garcinia cambogia* (Malabar tamarind), *Glycine max* (soyabean), *Murraya koenigii* (curry leaves), *Piper betle* (beetle leaf), *Prunus armeniaca* (apricot), *Ocimum gratissimum* (wild basil), *Theobroma cacao* (cocoa), *Trigonella foenum-graecum* (fenugreek), and *Vitis vinifera* (grapes) have been shown in recent preclinical studies to protect against ethanol-induced hepatotoxicity. The beneficial effects of these phytochemicals in preventing the ethanol-induced hepatotoxicity were found in these studies to be mediated by the antioxidant, free radical scavenging, anti-inflammatory, and antifibrotic effects (Shivashankara et al. 2012).

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Part II

Chapter 5
Ajowan

Botanical Name:	*Trachyspermum ammi* (L.) Sprague ex Turill.
Synonyms:	*Trachyspermum copticum* Linn; *Carum copticum* Benth and Hook; *Ammi copticum* Linn.; *Ptychotis coptica* DC; *Lingusticum ajowain* Roxb.
Family:	Apiaceae (Umbelliferae)—Parsley family.
Common Names:	**French**: ajowan; **German**: Ajowan; **Italian**: ajowan; **Spanish**: ajowan; **Hindi**: ajwain, ajvini, ajavani; **Bengali**: jowan; **English**: Bishop's weed; **Farsi**: Nanava; **Arabic**: Taleb el Koub.

Introduction

History

Ajowan seed has been popular from ancient times for its use in folk medicines. It is known as bishop's weed, carum seed, or carum ajowan. In addition, it has many uses for flavoring, culinary, household, and cosmetic purposes. The entire plant has its herbal value in medicinal industry, but commercially it is valued for its seed. It is a small, caraway-like seed used whole or ground. Sometimes it is mislabeled as lovage seeds. It is a popular spice in Indian, Pakistani, Iranian, and Ethiopian cooking. They are used in India as a traditional spice in many foods, including curries. It reached Central Europe in 1549.

Producing Regions

Ajowan is widely produced and is indigenous to India and Egypt. It is also cultivated in the Mediterranean region and Southwest Asian countries of Iran, Iraq, Afghanistan, and Pakistan, Egypt, and also Europe. It is predominant in India, in the

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states of Gujarat and Rajasthan and also on a smaller scale in Uttar Pradesh, Bihar, Madhya Pradesh, Tamil Nadu, Punjab, and Andhra Pradesh.

Botanical Description

Ajowan is similar to caraway, dill, and cumin. It is an annual, herbaceous aromatic plant profusely branched with a height of 90 cm (1–3 ft). It has many branched leafy stems with feathery leaves 2–3 pinnately divided with flowers which are terminal, compound, and red. The fruits are small, oval muricate with grayish-brown compressed mericarps having five ridges and tubercular surface.

Parts Used

Seeds, volatile oil, and oleoresins. Seeds are used whole or ground.

Flavor and Aroma

The seeds have a strong aromatic odor which resembles thyme/cumin with a very pungent aromatic taste. The ajowan seeds when crushed slightly leave a more intense flavor which is slightly spicy and bitter and at the same time leaving a milder, pleasant aftertaste. It has piney, phenol like, and slight lemony notes.

Active Constituents

Ajowan seeds contain moisture 9%, protein 15.4%, fat 18.1%, crude fiber 11.9%, carbohydrates 38.6%, mineral matter 7.1%, calcium 1.42%, phosphorous 0.3%, and iron 14.6 mg/100 g, with 2–5% essential oil, mainly thymol (35–60%), along with carvacrol, α-pinene, *p*-cymene, limonene, and α-terpinene (Pruthi 2001).

Preparation and Consumption

In countries like India, Pakistan, Egypt, and Iran, ajowan is used whole or ground. It combines well with starchy foods like pastries, snacks, breads, and also with root vegetables like legumes and beans. Ajowan is also an essential ingredient of curry powder. It makes starch and meals easier to digest and is also added to legumes to prevent flatulence. Whole ajowan seed, powder, and oil are used as adjuncts for

flavoring foods. The oleoresin from seeds gives a warm, aromatic, and pleasing flavor to food products. It is used in processed foods, snacks, sauces, and various vegetable preparations.

Medicinal Uses and Functional Properties

Ajowan is highly valued in countries like India as a medicine for digestive complaints, mild cramp like pain in the abdomen, flatulence, colic, and diarrhea. The essential oil is also used for relief in rheumatic and neuralgic pain. It is also used as a stimulant, carminative, and expectorant. It is also a strong antiseptic and is used in toothpastes and mouthwash. Traditionally, ajowan seeds have been used in India as a folk remedy for arthritis, asthma, coughs, indigestion, influenza, and rheumatism (Sayre 2001). It is a strong antioxidant. The essential oil of ajowan was found to have high antimicrobial activity with minimum inhibitory concentration against 64 bacteria strains (Mayaud et al. 2008). Pandey et al. (2009) showed that the essential oil and thymol had excellent larvicidal, oviposition-deterrent, vapor toxicity, and repellent activity against malarial vector, *Anopheles stephensi*. An ethereal extract of ajowan was found to inhibit platelet aggregation induced by arachidonic acid, epinephrine, and collagen, and in this respect it was most effective against arachidonic acid-induced aggregation (Srivastava 1988). A crude extract and an active principle (phenolic monoterpene) isolated from the fruits of ajowan fruits showed macrofilaricidal activity and female worm sterility against *Brugia malayi* (Matthew et al. 2008). The essential oil of ajowan displayed great degree of selectivity, inhibiting the growth of potential pathogens at concentrations that had no effect on the beneficial bacteria examined (Hawrelak et al. 2009).

Antioxidant Properties

The methanolic extracts of ajowan seeds have been shown to possess antioxidant properties. Recently, Nickavar and Abolhasani (2009) studied the antioxidant activity of ethanol extract of ajowan and found it to be promising. Singh and Kale (2010) studied the chemopreventive effect of different doses (2%, 4%, and 6%) of test diets of Trachyspermum seeds. They examined the effect on DMBA-induced skin and B(a)P-induced forestomach papillomagenesis, inducibility of drug metabolizing phase I and phase II enzymes, antioxidant enzymes (catalase, superoxide dismutase, glutathione peroxidase, glyoxalase I), reduced glutathione content, and peroxidative damage. A concomitant increase in the activities of phase II enzymes and antioxidant enzymes was observed in *Trachyspermum ammi* treated groups. Patil et al. (2011) showed that regular use of ajowan may prevent postprandial rise in glucose levels through inhibition of intestinal alpha-glucosidase and may maintain blood glucose level through insulin secretagogue action. Ajowan essential oil was shown to

have strong antioxidant activity (Huang et al. 2011). They reported that of the 25 essential oils they studied, ajowan essential oil was the best. They also found a positive correlation between the phenolic compounds and the DPPH activity, TEAC activity, ferric thiocyanate activity.

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Chapter 6
Allspice

Scientific Name:	*Pimenta dioica* (L.) Merr.
Synonyms:	*Eugenia pimenta* DC; *Pimenta officinalis* Lindl; Jamaica pepper; myrtle pepper, pimenta, pimento berry.
Family:	Myrtaceae (Myrtle family).
Common Names:	**French**: pimento, tout-epice; **German**: Jamikapfefer; **Italian**: pimento; **Spanish**: pimento de Jamaica; **Hindi**: kabab cheene, seetful.

Introduction

History

Allspice was discovered by Christopher Columbus around 1494 in the Caribbean islands. Jamaica has been producing allspice since 1509 and the Spanish explorers and settlers in Jamaica used the berries and leaves. In the sixteenth century, it was brought to the European regions by the Spaniards. According to Clusius in his *Liber Exoticorum*, the berries reached London in 1601, and the plants were first cultivated in England in 1732. The English derived the name allspice because it has the flavors of cinnamon, clove, nutmeg, and black pepper combined in it. Spanish explorers named it pimiento or pepper because of its resemblance to black peppercorns. Pimienta eventually became pimento. An interesting fact about the species name *dioica* (Greek di- from *dyo* means two and *oikos* meaning house) suggests the functional male and female flowers growing on different plants. Central Americans not only used allspice to season meat, fish, or to flavor chocolate, but also used it to embalm the bodies of important leaders. Allspice was used by Aztecs to sweeten and flavor their chocolate drink. The allspice cured meat was known in Arawak as *boucan* and so later Europeans who cured meat this way came to be known as boucaniers, which ultimately became "buccaneers."

D.J. Charles, *Antioxidant Properties of Spices, Herbs and Other Sources*,
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Producing Regions

Whole allspice is indigenous to the West Indies and South America. It is now extensively cultivated in Cuba, Jamaica, and Central America. The main exporting country is Jamaica which prides in the highest quality of allspice in the world. India, Sri Lanka, Malaysia, Reunion, and Singapore do cultivate allspice, but it has not succeeded fully.

Botanical Description

It is a small, dioecious evergreen tree, reaching up to 10-m (15–30 ft) high. The leaves are leather like approximately 15 cm in length and 4 cm in width, borne in clusters at the end of branches. The foliage leaves appear to be dark green above and pale green below loaded with aroma. The bark is shiny, silvery pale and the wood is pinkish and strong. The inflorescence is axillary, compound, paniculate, separately branched, and composed of many flowered cymes. The flowers are white, small on many stalked cymes in the axils of upper leaves, heavily fragrant, and having stamens and ovaries to function as male on one tree and female on the other. The fruit is produced in the third year and each fruit has two kidney-shaped green seeds, which turn black when ripe. The seed is globular and is rough on the surface being 4–5 mm in diameter. The berries are collected in the unripe stage, dried in the sun till they turn dark, reddish brown in color, maintaining the full aroma of the fruit.

Parts Used

The berries of allspice are used whole or ground. Sometimes the bark or leaf is used for culinary purposes. Essential oil of allspice is obtained from the berry and leaf. Berry oleoresin is also used. The oleoresin is brownish green in color. The berries are used for essential oil and oleoresin production. The aromatic leaves and bark can also be used to provide an allspice-type flavor to foods, especially smoked meats and beverages.

Flavor and Aroma

The aroma is very fragrant, similar to clove. Allspice has a pungent but warm aroma which is reminiscent of a combination of clove, nutmeg, pepper, and cinnamon. Warm and sweetly pungent with peppery overtones. Jamaican allspice is the most aromatic. It has a warm pungent taste.

Table 6.1 Nutrient composition of allspice ground

Nutrient	Units	Value per 100 g
Water	g	8.46
Energy	kcal	263
Protein	g	6.09
Total lipid (fat)	g	8.69
Carbohydrate, by difference	g	72.12
Fiber, total dietary	g	21.6
Calcium, Ca	mg	661
Vitamin C, total ascorbic acid	mg	39.2
Vitamin B-6	mg	0.210
Vitamin B-12	mcg	0.00
Vitamin A, RAE	mcg_RAE	27
Vitamin A, IU	IU	540
Vitamin D	IU	0
Fatty acids, total saturated	g	2.550
Fatty acids, total monounsaturated	g	0.660
Fatty acids, total polyunsaturated	g	2.360

Source: USDA National Nutrient Database for Standard Reference, Release 24 (2011)

Active Constituents

Moisture 8.5%, protein 6.1%, carbohydrate 72.1%, fat 8.7%, fiber 21.6%, ash 4.6%, minerals (calcium, iron, magnesium, phosphorous, potassium, sodium, zinc, copper, manganese), vitamins (vitamin C, Thiamin B1, riboflavin B2, Niacin, vitamin B6, folate, vitamin E), phenolic acids, flavonoids, catechins and phenyl propanoids, volatile oil (3–4.5%). The major constituents of the oil are eugenol (65–90%), methyl eugenol, β-caryophyllene, humulene, and terpinen-4-ol (Pino et al. 1989; Vosgen et al. 1980; Kikuzaki et al. 1999). The nutritional constituents of ground allspice are given in Table 6.1.

Preparation and Consumption

Allspice berry is mainly used as a flavoring and curing agent in processed meat and bakery products. In Sweden and Finland it is mostly used to flavor fish, while in the USA it is used to enhance the flavor of desserts, pickles, ketchup, and also soups and sauces. Whole or ground allspice is used to flavor vegetables. Allspice is also an essential component of the liqueurs Chartreuse and Benedictine together with the all famous local Jamaican drink *Pimento Dram*. Some cosmetic industries use it for their soaps and perfume products. The oleoresin is also used in the meat processing and canning industries in the same way as the ground spice. The Pimenta leaf oil is used commercially in ice creams, ices, confections, pickles, baked goods, puddings, gelatins, liqueurs, perfumery, and medicines. Walking sticks and even umbrella rods are manufactured from the upright trunk and branches of the tree.

Medicinal Uses and Functional Properties

It is used in traditional medicine to treat indigestion, flatulence, and diarrhea and also to stimulate appetite. Allspice has a soothing effect on nerves and is said to relieve depression, nervous exhaustion, tension, neuralgia, and stress. It is also helpful in rheumatism, arthritis, stiffness, chills, congested coughs, bronchitis, and neuralgia. It also has anesthetic, analgesic, antiseptic, carminative, muscle relaxant, rubefacient, stimulant, and purgative properties (Rema and Krishnamoorthy 1989). It is useful in halitosis. It also has bactericidal, fungicidal, and antioxidant properties (Friedman et al. 2002; Leela and Ramana 2000; Bhargava and Meena 2001). Allspice had strong bactericidal effect against *Yersinia enterocolitica* (Bara and Vanetti 1995). Allspice was shown to suppress the growth of *E. coli*, *S. enterica*, and *Listeria monocytogenes* (Friedman et al. 2002). The essential oil and the major constituent of the oil, eugenol, showed nematicidal activity (Leela and Ramana 2000). The essential oil of allspice berries was also found to have strong acaricidal effects against the cattle tick (Martinez-Velazquez et al. 2011).

Antioxidant Properties

Oya et al. (1997) showed that the methanolic extract of allspice and Pimentol from allspice effectively inhibited the formation of pentosidine in a model system of *N* alpha-*t*-butoxycarbonyl-fructoselysine and *N* alpha-*t*-butoxycarbonyl-arginine. These revealed strong activity as hydroxyl radical scavengers at a concentration of 2.0 μM. Nakatani (2000) isolated 25 compounds from the berries of allspice which had high antioxidant activity. Three new galloylglucosides were isolated from the berries of allspice along with gallic acid, pimentol, and eugenol 4-*O*-beta-D-(6-*O*-galloyl)glucopyranoside, and all showed radical scavenging activity nearly equivalent to that of gallic acid against 1,1-diphenyl-2-picrylhydrazyl radical (Kikuzaki et al. 2000). Dragland et al. (2003) showed that allspice contained very high concentration of antioxidants (>75 mmol/100 g). Allspice water extracts were found to reduce the amount of superoxide anion radical ($O_2^{\bullet -}$) by inhibition of the formation of ($O_2^{\bullet -}$) (Yun et al. 2003). Ramos et al. (2003) showed that allspice prevented DNA damage by ter-butyl hydroperoxide (TBH) to the test bacteria *E. coli* and also eugenol, the main constituent of allspice essential oil also inhibited mutagenesis by TBH in *E. coli*, at concentrations ranging from 150 to 400 mg/plate. Blomhoff (2004) also reported very high levels of antioxidants in allspice. The ethyl acetate-soluble fraction of allspice showed strong antioxidant activity and radical scavenging activity against 1,1diphenyl-2-picrylhydrazyl (DPPH) radical. Quercetin and its glycoside plus two new compounds also showed remarkable activity for scavenging DPPH and inhibiting peroxidation of liposome (Miyajima et al. 2004). Shyamala et al. (2005) in their study found the antihyperlipidemic as well as the antioxidant activity of an aqueous extract of allspice. Pedunculagin isolated from the leaves of allspice was the most toxic compound against solid tumor cancer cells, the most

potent scavenger against the artificial radical DPPH, and strongly inhibited the NO generation (Marzouk et al. 2007). Kikuzaki et al. (2008) isolated four new phenolic glycosides from the berries of allspice and found them to possess strong radical scavenging activity against DPPH radicals. Padmakumari et al. (2011) reported that essential oils obtained from pimento berry possessed very high radical scavenging activities. The metal chelating capacities and reducing power were also found to be very high, thus suggesting its use as a natural antioxidant. Eugenol, which is the most abundant ingredient in clove and allspice extract, showed the most potent antioxidative activity [ORAC value of 39,270 μmol TE (trolox equivalent)/g] (Yoshimura et al. 2011).

Regulatory Status

GRAS 182.10 and GRAS 182.20.

Standard

ISO 973 (Specification), ISO 3043 (Oil berry), ISO 4729 (Oil leaf).

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Chapter 7
Angelica

Botanical Name: *Angelica archangelica* L.
Family: Apiaceae (Umbelliferae).
Synonyms: *Angelica officinalis* Moench; *Archangelica officinalis* (Moench) Hoffm.; archangel, European angelica, chanda.
Common Names: **French**: Archangelique; **German**: EchtEngerwurz; **Spanish**: Arcangelica; **Italian**: Angelica.

Introduction

History

Angelica (*Angelica archangelica*) has a long-standing reputation as a medicinal herb and has been recommended by European herbalists since the fifteenth century. Angelica is used to reduce muscular spasms in asthma and bronchitis, and the oil has been shown to ease rheumatic inflammation, regulate menstrual flow, and act as an appetite stimulant. The stems are candied for culinary use. The folklore of North European countries merits it as a protection against communicable diseases, for purifying blood, and for curing every conceivable problem. The herb is associated with Hermes and the archangel Michael. As the botanical name implies, it was always considered an "Angel's Herb." According to one Western legend, *Angelica* was revealed in a dream by an angel as a gift of Mother Angel to cure the plague. Another explanation for the name is that it blooms on the day of Michael the Archangel and is on that account an additive against evil spirits and witchcraft. Originating in Spain, angelica root was one of the few spices that were actually exported from Europe to the Orient. It was used as a common flavoring and apothecary drug, and, referred to as the "Root of the Holy Ghost," was considered to contain magical powers. It is also a flavoring for Cointreau liqueur. In "The History of Plants," angelica was described as an antidote for all poisons, dog and snake bites, asthma, coughs, and all manner of ailments; it would stimulate digestion,

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regular peristalsis, increase the appetite, and aid in the secretion of gastric juices; it was prescribed for reducing lust in teenagers and for reducing one's desire for alcoholic beverages.

Producing Regions

It is believed that angelica was brought to Europe from Asia around the sixteenth century. It is native to northern and eastern Europe, Asia, and Siberia. It is cultivated mainly in Belgium, France, Hungary, and Germany and in small northern areas of the United States.

Botanical Description

It is a large hairy plant about 2 m (6 ft) high, with fern-like leaves and umbels of white flowers. The flowers are numerous and small, greenish-white or yellowish in color. The stems are hollow, round, smooth, and purplish in color. Rosettes of large, green basal leaves arise from the stem. The fruits are pale yellow and oblong. The rhizome is large and very aromatic. The spindle-like roots are long and fleshy with many long, descending rootlets. It flowers every 2 years.

Parts Used

All parts of the bushy plant (flowers, fruits, stems, rhizomes, and roots) are useful. The seeds, rhizomes, and essential oils are used in flavorings. The leaves are used fresh in salads.

Flavor and Aroma

The essential oil has a light, delicate peppery-sweet top note. Body note is rich, herbaceous, earthy, woody, and spicy. Dry out is musky, spicy, with good tenacity. Overall volatility is low with good diffusiveness. All plant parts have strong spicy aroma and sharp bitter taste resembling that of juniper berries.

Active Constituents

Essential oil is obtained by steam distillation of the dried root and rhizome. The oil is a colorless to pale yellow to amber (brown if old) slightly viscous liquid.

Yield 0.3–1.9 %. The major constituents of the oil are α-pinene, α- and β-phellandrene, limonene, sabinene, δ-3-carene, and myrcene. The main constituents that comprised A. archangelica oil were monoterpene hydrocarbons such as 24.5 % alpha-pinene, 13.8 % delta-3-carene, 10.1 % beta-phellandrene, 8.8 % *p*-cymene, 8.4 % limonene, and 6.3 % sabinene (Wedge et al. 2009). The roots contain furocoumarins namely archangelin, prangolarin, ostsathol, and osthol.

Preparation and Consumption

Angelica is a favorite flavoring herb in Western culinary preparations. It is used to decorate cakes and pastry and to flavor jams. Angelica jams and jellies are very good and favorites. It is a popular flavoring for confectionery and liqueurs. The aromatic seeds are employed in alcoholic distillates, especially in the preparation of vermouth. Angelica root is the main flavoring ingredient of gin. It is used in liqueurs like Benedictine, chartreuse, cointreau, and vermouth. Chopped leaves are added to fruit salads, fish dishes, and cottage cheese. Fresh or preserved roots have been added to snuff and used by Laplanders and North American Indians as tobacco (Clevely and Richmond 1999).

Medicinal Uses and Functional Properties

The leaves, roots, and seeds of angelica are used for medicinal purposes. The herb and extracts of the herb are considered to be antispasmodic, aphrodisiac, anticoagulant, bactericidal, carminative, diaphoretic, digestive, diuretic, emmenagogue, expectorant, febrifuge, hepatic, nervine, stimulant, stomachic, and tonic. Angelica herb promotes perspiration, stimulates appetite, and is also used for chest ailments and digestion (Westland 1987).

The antimutagenic effect of angelica against thio-TEPA mutagenicity in murine bone marrow cells was greater with pretreatment than simultaneous treatment (Salikhova and Poroshenko 1995). The cytoprotective activity of STW 5 (an extract of angelica and eight other plants) was assigned to the flavonoid content and free radical scavenging properties (Khayyal et al. 2001). Angelica has significant importance in improving defense function of peritoneal macrophages (Li et al. 2002). It has been found to relax both endothelium-dependent and -independent isolated rat aorta (Rhyu et al. 2005). Water-soluble components of angelica were reported to have protective effects against lethal endotoxemia and experimental sepsis in part by attenuating systematic accumulation of a late proinflammatory cytokine, HMGB1 (Wang et al. 2006). The furanocoumarins from the fruit accounted for most of the antiproliferative activity of the tincture of angelica (Sigurdsson et al. 2004). Sigurdsson et al. (2005) demonstrated the antiproliferative activity in vitro and antitumor activity in vivo of a leaf extract from *A. archangelica* in mice. Ferulic

acid an important component of angelica has been shown to bind to cytochrome c, and this binding inhibits cytochrome c-induced apoptosis of human hepatoma cell line SMMC-7721 (Yang et al. 2007a). Ethyl acetate extracts of angelica exerted significant NF-kappaB inhibitory activity and acted in a cell type-dependent fashion (Chao et al. 2009). Angelica inhibited COX-2 expression at both protein and mRNA levels, but at much lesser extents as compared with that for iNOS expression (Chu et al. 2009a, b). The essential oil exhibited antiseizure effect and this antiseizure effect may be attributed to the presence of terpenes in the essential oil (Pathak et al. 2010). The extracts of roots and fruits of angelica were found to be strong inhibitors of butyrylcholinesterase (Wszelaki et al. 2011). Angelica extract was shown to be effective and valuable for treating the behavioral and psychological symptoms of dementia in frontotemporal lobar degeneration and dementia with Lewy bodies (Kimura et al. 2011).

Antioxidant Properties

Angelica and its essential oil have been shown to have strong antioxidative properties (Wu et al. 2004; Wei and Shibamoto 2007; Li et al. 2007; Luo et al. 2007; Meng et al. 2007; Xin et al. 2007; Wojcikowski et al. 2009; Cheng et al. 2008; Chu et al. 2009a, b; Kim et al. 2009; Thring et al. 2009). Angelica processed products were efficient in clearing superoxide radical generated through hypoxanthine–xanthine oxidase system and hydroxyl radical generated through Fenton action, and inhibiting lipid peroxidation of supernatant hepatic homogenate in mice induced by free radical generation system (Wu et al. 1996). A traditional Chinese herb mixture of seven herbal components including angelica improved the antioxidant status of D-galactose-induced mimetic aging mice (Liu et al. 2003a, b). Liu et al. (2003a, b) studied the effect of angelica polysaccharide (ASP) on immunological colon injury and its mechanism in rats. Their results showed that ASP at doses of 400 and 800 mg kg^{-1} had a protective effect on immunological colon injury induced by 2,4,6-trinitrobenzene sulfonic acid and ethanol enema in rats, and this was probably due to the mechanism of antioxidation, immunomodulation, and promotion of wound repair. A mixture of *Ligusticum chuanxiong* and *Angelica sinensis* protected human umbilical vein endothelial cells against hydrogen peroxide damage by enhancing the antioxidative ability, activating ERK and eNOS signaling pathway (Hou et al. 2004). Angelica is a cytoprotective agent effective against chronic ethanol-induced hepatotoxicity, and this is possibly through inhibition of the production of oxygen free radicals that cause lipid peroxidation, and hence indirectly protects the liver from oxidative stress (Yeh et al. 2003). A decoction of Astragali and Angelica roots enhanced myocardial mitochondrial and red blood cell glutathione status, thus increasing their resistance to oxidative stress-induced injury in rats (Mak et al. 2006). The essential oil of angelica was shown to have concentration-dependent antioxidant activity, and this was attributed to the component, coniferyl ferulate (Li et al. 2007). Z-ligustilide, a primary compound from angelica, has a profound

protective effect against H_2O_2-induced cytotoxicity, and this is partly by improving cellular antioxidant defense and inhibiting the mitochondrial apoptotic pathway (Yu et al. 2008). Dietz et al. (2008) observed that angelica extracts and Z-ligustilide induced the detoxification enzymes and thus have potential as chemopreventive agents. Polysaccharides from angelica roots were found to effectively inhibit H_2O_2-induced decrease of cell viability, lactate dehydrogenase (LDH) leakage, and malondialdehyde (MDA) formation. They also reduced decline of superoxide dismutase (SOD) activity and glutathione depletion, and protected macrophages by inhibiting release of excess NO and reactive oxygen species induced by H_2O_2. They significantly enhanced t-BHP-decreased cell survival, intracellular glutathione content, and SOD activity, also inhibiting t-BHP-increased LDH leakage and MDA formation (Yang et al. 2007b, c). Yang et al. (2009) studied the antioxidant activities of six herbs including angelica and found a strong correlation between the rate of enhancement in antioxidant capacity and the rate of increase in flavonoid content.

Regulatory Status

GRAS 182.10 and GRAS 182.20.

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Chapter 8
Anise

Scientific Name:	*Pimpinella anisum* L.
Synonyms:	*Anisum vulgare* Gaertn; *Pimpinella magna* L.; Anise, Anis seed, Anis, Sweet cumin.
Family:	Apiaceae (Umbelliferae) (Carrot family).
Common Names:	**French**: anis vert; **German**: Anis; **Italian**: anice verde; **Spanish**: anis; **Hindi**: saunf, sompf, souf; **Arabic**: Yansoon; **Dutch**: anijs; **Hebrew**: anison; **Japanese**: anisu; **Malaysian**: Jintan manis; **Portuguese**: erva doce.

Introduction

History

It is said that the Egyptian used anise as a spice as early as 1500 BC and eventually by the Greeks, Hebrews, and Romans. In the Bible, in the book of Matthew, there is mention of paying tithe with anise. In the first century AD, the Romans used anise seed to flavor the small cakes baked in bay leaves, known as *mustaceum*. On the island of Majorca, cakes of minced figs flavored with anise seed and wrapped in fig leaves were served at Christmas. Both Pliny of Rome and the Greek Dioscorides wrote about anise in the first century. Anise seed was cultivated throughout Europe during the seventh through twelfth centuries, though rarely in Britain. In the year 1305, during the reign of King Edward I taxes and tolls on anise seed helped to pay for repairs to London Bridge. King Edward IV scented his clothes with anise seeds. Anise seed was also tucked under pillows to avoid disagreeable dreams. Pythagoras believed that the herb would prevent indigestion and could be used for stomach disorders. Anise seed has been known for its amazing historical background

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surrounded by legends and folklore. In the year 1619, the Virginia Assembly decreed that each household should plant at least six anise seeds that year and repeat the plantings the following year from the seeds produced that year.

Producing Regions

Anise seed is indigenous to Eastern Mediterranean (Greece, Egypt) and western Asia. It is also widely cultivated in the southern parts of Russian Federation, Lebanon, South America, Japan, and India. The main exporting country is Turkey. Egypt, Hungary, Spain, and Lebanon also export anise seed.

Botanical Description

Anise seed is an annual, herbaceous plant, erect with a height reaching up to 0.5-m (2 ft) high. Fine hairs seem to cover the whole plant. It has an erect cylindrical stalk with deep penetrating, thin spindle-shaped root. The plant has two distinctive, bright green leaf patterns which alternate with yellowish-white flowers in typical umbrella-shaped clusters. The flowers are bisexual with the inconspicuous calyx and the corolla with five obovate-cordate petals. It is a cross pollinating species and is genetically heterogeneous. When the flowers turn into seed-like fruits, they appear to be oval-pear shaped, compressed at the side, almost lens shaped. These seeds are 3–5 mm long and 1–2 mm wide with pedicles attached. They appear to be grayish-green to dull yellowish-brown in color.

Parts Used

Ripe dry seeds, essential oil, oleoresin, and the fresh leaves which are full of aroma like the seeds. Anise is sold whole, cracked, or ground.

Flavor and Aroma

Anise has a warm fruity note, sweet licorice like, and a hint of mint and camphor. Its aroma is similar to fennel, but is light and delicate with a sweet fragrance. Mild, sweet licorice taste, almost similar to fennel and anise star. The feathery leaves are also aromatic.

Table 8.1 Nutrient composition of anise seed

Nutrient	Units	Value per 100 g
Water	g	9.54
Energy	kcal	337
Protein	g	17.60
Total lipid (fat)	g	15.90
Carbohydrate, by difference	g	50.02
Fiber, total dietary	g	14.6
Calcium, Ca	mg	646
Vitamin C, total ascorbic acid	mg	21.0
Vitamin B-6	mg	0.650
Vitamin B-12	mcg	0.00
Vitamin A, RAE	mcg_RAE	16
Vitamin A, IU	IU	311
Vitamin D	IU	0
Fatty acids, total saturated	g	0.586
Fatty acids, total monounsaturated	g	9.780
Fatty acids, total polyunsaturated	g	0.211

Source: USDA National Nutrient Database for Standard Reference, Release 24 (2011)

Active Constituents

The anise fruits contain moisture 9%, protein 18%, fat 16%, carbohydrates 35%, fiber 15%, ash 7%, flavonoid glycosides (rutin), and 4% volatile oil. Major constituent of oil is trans (E)-anethole (up to 90%). The major coumarins are bergapten, umbelliprenine, umbelliferone, and scopoletin. The major flavonoid glycosides are quercetin-3-glucuronide, rutin, luteolin-7-glucoside, isoorientin, isovitexin, and apigenin-7-glucoside. The nutritional constituents of anise seed are presented in Table 8.1.

Preparation and Consumption

Anise seed is used widely to flavor food in different regions of the world. The Europeans use it mostly to flavor cookies, pretzels, bread, fruit salads, juice drinks, and teas. Further anise is also used by the French, Germans, and Italians to flavor cakes, sweet rolls, apple sauces, sausages, fish, and luncheon meats. On the other hand, in Asia it is widely used to flavor spicy pungent curries and baked snacks. It is also a favorite flavoring for various types of alcoholic beverages such as French *Pastis*, *Pernod*, *Anisette*, *Ricard*, Egyptian *kibib*, Greek *Ouzo*, Turkish *Raki*, *Arabian Arak*, South American *Aguardiente*, Russian *Allasch*, and Puerto Rican *Tres Castillos*. Syrians use it in a beverage called miglee and in their popular fig jams.

Anise and anise oils are used in Italian sausage, pepperoni, pizza topping, and other meat items, which give it its unique flavor and stir up the appetite. The essential oil is also used to flavor toothpastes, mouthwashes, perfume creams, and lotion.

Medicinal Uses and Functional Properties

Anise is often used to aid digestion, improve appetite, and decrease cramp and colic in infants. It is also a mild expectorant used to ease coughing and is used in lozenges and cough syrups. It is also used to promote lactation and decrease catarrh, often used in bronchitis. In India and Europe, it is chewed to freshen breath, but can also be used to induce sleep. If few seeds are taken with water it will cure hiccups.

Anise powder and aqueous extract are used as carminatives, antiseptics, diuretics, digestives, aphrodisiacs, and as a remedy for insomnia and constipation (Kreydiyyeh et al. 2003). In Unani and Arabian traditional medicine, anise fruit and its essential oils have been used for the treatment of conditions like dyspepsia, abdominal colic, nausea, epilepsy, and seizures (Said et al. 1996). Anise essential oil has been reported to be highly effective as both larvicidal and ovicidal agents (Prajapati et al. 2005). Besharati-Seidani et al. (2005) reported that anise has digestive, carminative, diuretic, and expectorant actions. The relaxant effects of hydroalcoholic extract of anise involved the participation of NO and subsequent activation of the NO-cGMP pathway (Tirapelli et al. 2007). This relaxant action justifies its use as an antispasmodic agent. Anise was shown to have antimicrobial properties (Robles-Zepeda et al. 2011). Three antiviral and immunostimulating substances were isolated from anise seeds. These lignin–carbohydrate complexes showed antiviral activities against herpes simplex virus types 1 and 2, human cytomegalovirus, and against measles virus. Furthermore, they enhanced nitric oxide (NO) production by inducing iNOS mRNA and protein expression in RAW 264.7 murine macrophage cells. The induced mRNA expression of cytokines including IL-1β and IL-10 was also apparent. These results suggest that the lignin–carbohydrate–protein complexes from *P. anisum* possessed potency as functional food ingredients against infectious diseases (Lee et al. 2011). The essential oil of anise showed strong nematicidal activity against *M. incognita* (Ntalli et al. 2011).

Antioxidant Properties

Anise has been identified as free radicals or active oxygen scavengers (Gulcin et al. 2003). Farag and el-Khawas (1998) evaluated the antioxidant property of anise essential oils extracted from untreated, gamma-irradiated, and microwaved fruits against sunflower oil oxidative rancidity. They showed that the irradiated and microwaved essential oil exhibited a stronger antioxidant activity than the mixture of BHT and BHA (200 ppm). They also reported that the gamma-irradiated fruit essential

oils were more effective than the microwaved fruit oils. Studies by Mofleh et al. (2007) found that aqueous suspension of anise seed protects rats against chemically induced gastric ulcers. They found that anise significantly inhibited gastric mucosal damage induced by necrotizing agents and indomethacin. In pylorus-ligated Shay rats, anise suspension was found to significantly reduce the basal gastric acid secretion, acidity, and completely inhibit the rumenal ulceration. The suspension also significantly replenished ethanol-induced depleted levels of gastric mucosal NP-SH and gastric wall mucus concentration. They concluded that this antiulcer effect of anise was possibly prostaglandin mediated and/or through its antisecretory and antioxidative properties. The essential oils of anise were reported to have strong antioxidants and antioxidant activity (Topal et al. 2008). Nickavar and Abolhasani (2009) found that the ethyl acetate fraction of anise seed exhibited the highest antioxidant activity and flavonoid content of the different fractions. They also found a positive correlation between the antioxidant potency and flavonoid content of the fractions.

Regulatory Status

GRAS 182.10 and GRAS 182.20.

Standard

ISO 7386 (Specification), ISO 3475 (Oil).

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Chapter 9
Anise Star

Scientific Name:	*Illicium verum* Hook. f.
Synonyms:	star anise; Chinese star anise; takkola.
Family:	Illiciaceae (Magnoliaceae).
Common Names:	**French**: badanier de Chine; **German**: stern-anis-e; **Italian**: anice stellato; **Spanish**: badian; **Chinese**: ba chio, bart gok, pa-chiao, peh kah; **Arabic**: albadyan; **Dutch**: sternanijis; **Hindi**: chakriphool; **Indonesian**: bunga lawang.

Introduction

History

Star anise is known to be a native spice of China and has been used as a spice and medicine for well over 3,000 years. The Chinese believe that star anise with its normal "eight" arms intact brings good luck. The English navigator, Sir Thomas Cavendish, in 1578 brought the first fruits to Europe via the Philippines, and thus Europe believed that star anise originated from Philippines. In Russia, it was used since the seventeenth century and was brought in use in Germany as late as the eighteenth century. The aroma of star anise gives its genus name believed to be derived from the Latin *illicium*, meaning allurement, alluding to the fruits sweet aroma.

Producing Regions

It is indigenous to the southern and southwestern provinces of China and North Vietnam. China and northeastern Vietnam are the main producing regions known for commercial production and export. Star anise is now widely cultivated in Spain, France, Italy, Morocco, China, India, and the Philippines.

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Botanical Description

The star anise is an evergreen tree up to 12-m (36 ft) high. The plant has a very aromatic, whitish trunk with short stemmed, dark green simple leaves up to 12 cm long, 3–4 cm wide, and appear to be leathery along the margin. The single flowers are bisexual and composed of 10–20 yellow or reddish white petals with 10–20 stamina. The fruit is an etaerio. These distinctive star-shaped fruits are made up of eight separate carpels that develop into a small capsule-like follicles with a single pale, brown, shiny seed inside. After ripening these brownish very much like cork capsules burst open revealing the seed inside. The seeds are small, smooth, and shiny ovoids. The odor of the fruit is anise like, and the carpels taste sweet and aromatic.

Parts Used

Whole, ground, or crushed seeds (fruit), essential oil from seeds.

Flavor and Aroma

Star anise has a powerful licorice-like, sweet, and more pungent aroma than fennel seed or anise seed but very similar. It often leaves a bitter aftertaste if a high level use of it is made. A spicy sweet flavor similar to anise seed but slightly harsher, becoming more intense with cooking. The pods have more flavor than the seeds, but the broken pieces are less aromatic.

Active Constituents

The fruit contains fixed oil, minerals, catechins, pro-anthocyanidin, and 5–9% essential oil in the pericarp and in the seeds. Numerous compounds including volatiles, seco-prezizaane-type sesquiterpenes, phenylpropanoids, lignans, flavonoids, and other constituents have been identified from *I. verum* (Wang et al. 2011). Decorticated seeds contain 55% fatty oil, including oleic acid, linoleic acid, myristic acid, and stearic acid. The major constituent in essential oil is trans-(E)-anethole (up to 95%), α-pinene, phellandrene, *p*-cymene, 1,4-cineole, limonene, and D-terpineol.

Preparation and Consumption

Star anise is used both in the East and West. Mostly used in Chinese style cooking in stocks and soups. In Asia often used in marinades, roast, stews, barbecue, and soups. The flavor is enhanced when simmered for a period of time. It is used in

sweeteners and confectionery, in meat and poultry dishes, especially well with pork and duck. The Chinese "five-spice powder mix" is very common. Star anise finds application in Indian, Persian, and Pakistani cuisine also. In Malaysia and Singapore it is used to flavor curries, soups, and sauces. In India it is a popular spice used in Kashmiri, south Indian, and Goan recipes. It is also used in spice blends for its unique flavor and aroma. In the West it is used in to flavor jams, confectionaries, liqueurs like the anisette and also marmalades, fruit soups, bonbons, and cookies.

Medicinal Uses and Functional Properties

The fruit being antibacterial, carminative, stomachic, diuretic, and mildly expectorant is taken to relieve congestion of phlegm in the respiratory tract. In addition it is also taken for relief of colic and stomach pains. The essential oil and the fruit are sometimes used to increase production of breast milk, facilitate childbirth, and promote menstruation. It is often used in cough syrups and lozenges to cure sore throat and cough.

Bhadra et al. (2011) reported that *I. verum* can be a good lead as anticholinesterase agent from natural resources because of its strong anticholinesterase activity. Both the essential oil and trans-anethole exhibited strong inhibitory effect against all fungi indicating that most of the observed antifungal properties were due to the presence of trans-anethole in the oil, which could be developed as natural fungicides for plant disease control in fruit and vegetable preservation (Huang et al. 2010). The supercritical CO_2 and ethanol extracts of *I. verum* showed substantial antibacterial activity against 67 clinical drug-resistant isolates, including 27 *Acinetobacter baumannii*, 20 *Pseudomonas aeruginosa*, and 20 methicillin-resistant *Staphylococcus aureus* (Yang et al. 2010). The essential oil of ajowan displayed great degree of selectivity, inhibiting the growth of potential pathogens at concentrations that had no effect on the beneficial bacteria examined (Hawrelak et al. 2009).

Antioxidant Properties

Modern pharmacology studies demonstrated that crude extracts of star anise fruit and active compounds possess wide pharmacological actions, especially in antimicrobial, antioxidant, insecticidal, analgesic, sedative, and convulsive activities (Wang et al. 2011). Recently, Yadav and Bhatnagar (2007) assessed star anise for its anticarcinogenic potential in *N*-nitrosodiethylamine (NDEA)-initiated and phenobarbital (PB)-promoted hepato-carcinogenesis. Their results indicated that treatment with star anise reduced the tumor burden, lowered oxidative stress, and increased the level of phase II enzymes, which may contribute to its anticarcinogenic potential. The liver and erythrocyte glutathione-S-transferase (GST) activity increased in all the groups treated with NDEA and PB. The star anise treatment significantly reduced the GST level. The extracts of star anise were found to

significantly stop the initiation of lipid peroxidation in rat liver (Yadav and Bhatnagar 2010). The star anise showed insulin secretagogue, alpha-glucosidase, and strong antioxidant activity in streptozotocin-induced diabetic rats. The authors suggest that the regular use of this spice may prevent postprandial rise in glucose levels through inhibition of intestinal alpha-glucosidase and may maintain blood glucose level through insulin secretagogue action (Patil et al. 2011).

Regulatory Status

GRAS 182.20 and GRAS 182.10.

Standard

ISO 11178 (Specification), ISO 11016 (Oil).

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Chapter 10
Asafoetida

Botanical Name: *Ferula assa-foetida* L.
Synonyms: Asafetida, devil's dung, food of the gods.
Family: Apiaceae (Umbelliferae).
Common Names: **French**: ferule persique, ase fetide; **German**: Stinkasant, Teufellsdreck; **Italian**: assafetida; **Spanish**: asafetida; **Hindi**: Hing, Hingra.

Introduction

History

The name asafoetida comes from the Persian *aza*, for mastic or resin, and the Latin *foetidus*, for stinking. Ancient records mention that Alexander the Great carried this product "stink finger" west in 4 BC. It was known to early Persians as "the food of the Gods" and to the Romans as Persian sylphium. The Europeans equated its smell to truffles and called asafoetida, the devil's dung. Asafoetida was believed to enhance singers' voices, and during the Mughal Dynasty in India, the court singers would eat a spoonful of asafoetida with butter and practice on the banks of the river Yamuna. In ancient Rome it was used as a spice and has been used in Indian cooking for ages. In ancient India and Iran, asafoetida was used as a condiment and as a medicine.

Producing Regions

Asafoetida is indigenous to Iran and Asian deserts. It is also found in China and Russia. The various Apiaceae gums are produced from wild plants in a large area that stretches from Iran to Afghanistan, Pakistan, and India. In India it is cultivated

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in Kashmir. Central Asia is the main source of asafoetida and Afghanistan and Iran are the major producers in this region.

Botanical Description

An erect perennial herb up to 3 m (9 ft) high, with a fleshy taproot, deeply dissected leaves, and inconspicuous yellow flowers borne in compound umbels. The plant has a perennial fusiform root with a coarse, hairy summit, either simple like parsnip. The bark is wrinkled and black and contains large amounts of thick alliaceous juice. The leaves are shiny whose lobes are oblong and obtuse. They are few in number and appear in autumn. The stem is herbaceous, solid, smooth, and clothed with membranous sheaths. The fruits are thin, flat, foliaceous, and reddish brown with vittae. Asafoetida or similar oleogum resins are obtained from *F. assa-foetida*, *F. foetida*, and *F. narthex*; gum galbanum from *F. galbaniflua* (=*F. gummosa*) and *F. rubicaulis* (see also *Dorema ammoniacum*).

Parts Used

Oleogum resin (devil's dung—*asafoetida*) is obtained as secretions of the upper parts of the roots of the plants by incision. It is dark brown to black resin-like gum obtained from the juice of the rhizome. After drying, it becomes darker brown, resin-like mass. Different grades of resins, dried granules, chunks, or powders are sold. It is marketed in three forms—tears, mass, and paste.

Flavor and Aroma

Pungent smell of sulfur or rotting onions. The smell dissipates with cooking. An extremely unpleasant, like rotten garlic. It adds an onion-like flavor in cooked foods.

Active Constituents

Asafoetida contains 62% resin, 25% gum, and 7% oil. These oleoresin gums have a complex composition; they contain sesquiterpene-coumarin ethers (such as asacoumarin B and farnesiferol A-C), and a volatile oil (6–17%) rich in sulfurous compounds, with which the smell and medicinal activity of asafetida and galbanum are associated: disulfides and polysulfanes in asafetida; propenyldisulfides with various

other compounds in galbanum. Coumarins, sesquiterpenoid coumarin, phenolic compounds, flavonoids, and various sulfur derivatives have been reported (Rastogi and Mehrotra 1995; Duan et al. 2002; Nabavi et al. 2011).

Preparation and Consumption

It is reported to be an ingredient in Worcestershire sauce. It is reportedly used in nonalcoholic beverages, frozen dairy desserts, candy, baked goods, gelatins, puddings, meat, meat products, and condiments. It is used in Indian vegetarian cooking, especially those of Jain and Brahmin castes where onion and garlic are prohibited. It is used in lentils, vegetarian soups, and pickles and also suited in many fish dishes. It is a well used spice in Persian cuisine. Afghans and Persians eat the stem and leaves as vegetables, the odor disappearing once boiled.

Medicinal Uses and Functional Properties

The gum resin is antispasmodic, anthelmintic, aphrodisiac, diuretic, expectorant, mildly laxative, and a nerve tonic. The leaves have anthelmintic, carminative, and diaphoretic properties. Asafoetida is used to treat dyspepsia with flatulent colic, but also to treat bronchitis, coughs, and nervous disorders. Externally it is counterirritant. Despite being considered the most foul smelling of all natural substances, it is widely used as a natural food flavoring. Asafoetida is an effective carminative against intestinal flatulence and gas formation. It is also useful for asthma, bronchitis, flatulence, colic pain, and for spasmodic movement of the bowels and infantile convulsions (Duke 2003).

Asafoetida has been shown to possess antifungal, antidiabetic, anti-inflammatory, antimutagenic, and antiviral activities (Iranshahy and Iranshahi 2011). Ferulic acid and umbelliferone from asafetida have been reported to be active molluscicidal components that inhibit the activity of alkaline phosphatase and acetylcholinesterase both in in vivo and in vitro (Kumar et al. 2009). The hemocompatibilty of silk fibroin (SF) has been shown to be improved with ferulic acid (FA) from asafoetida by graft polymerization (Wang et al. 2008). Dried root latex powder of asafoetida was found to be potent molluscicides (Kumar and Singh 2006). Asafoetida extracts inhibited the aflatoxin production by *Aspergillus parasiticus* considerably (Soni et al. 1992).

Antioxidant Properties

Antioxidants isolated from asafoetida inhibited peroxidation and scavenged the DPPH radical (Kogure et al. 2004). Phenolics which have medicinal properties have been reported in asafoetida (Singh et al. 2004). The pretreatment of carcinoma-induced

animals with asafoetida was found to recover the antioxidant level and reverse the induced ODC activity and DNA synthesis (Saleem et al. 2001). Lu et al. (1998) found that oxidative stress can induce apoptosis in lymphocytes, and this induction could be partly prevented by sodium ferulate from asafoetida. Asafoetida extracts were found to show remarkable antioxidant and antihemolytic activities, and this could be attributed to the presence of phenols and flavonoids in the extract (Nabavi et al. 2011).

Regulatory Status

GRAS 182.20.

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Chapter 11
Basil

Botanical Name:	*Ocimum basilicum* L.
Synonyms:	*Ocimum canum* Sims; *Ocimum americanum* ssp. *americanum*; Reunion basil, Comoran basil, sweet basil.
Family:	Lamiaceae (Labiatae).
Common Names:	**French**: basilic; **German**: basilikum; **Italian**: basilico; **Spanish**: alba laca; **Russian**: basilik.

Introduction

History

The French call basil "herbe royale." Basil is well known for its wonderful "royal" fragrance. Dioscorides (40–90 AD) warned not to use lot of basil as it dulleth the eyesight, breedeth wind, provoketh urine, drieth up milk, and is difficult to digest. In Italy, basil has been a sign of love—if a woman puts a pot of basil on her balcony, it means she is ready to receive her suitor. Another tradition has it that when a man gives a woman a sprig of basil, she will fall in love and never leave him. It is also believed that the name is a derivative of *basileus*, Greek for king. The Greek called it basilisk, because it was supposed to provide protection from a half-lizard, half-dragon monster of the same name. Early Africans claimed that only those who had eaten basil could be immune to pain from the bites of scorpions. In Romania, a young man was considered engaged if he accepted a sprig of basil from a young lady. In India, basil is considered very holy and worshipped more than kings. This basil is known as Tulsi basil and is woven into a garland to grace the Hindu God, Vishnu. Early Roman and Greek physicians believed that to have a good crop of basil, one had to shout and curse during the sowing of seeds. Based on this was born the French idiom "*semer le basilica*," "sowing the basil," for raving. Basil was found growing around Christ's tomb after the resurrection. There are many species and varieties of basil. Sweet basil is the most popular type being used.

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Producing Regions

Annual herbaceous plant native to Asia and Africa. It is cultivated throughout Europe as a culinary herb. They are also cultivated in Africa, Iran, Seychelles, Egypt, and the USA.

Botanical Description

It is a robust, aromatic annual plant up to 60-cm (6–25 in.) high with an erect stem and very green, ovate leaves, grayish-green beneath, and white, greenish, or purplish pinky-white flowers. The whole plant has a very powerful aromatic scent.

Parts Used

Leaves, essential oil. Fresh basil is used whole, chopped, or pureed. Dried basil is used as ground or particulate of varying sizes. Basil comes as fresh, dried, or as paste.

Flavor and Aroma

Fragrantly sweet and spicy, with grassy green, hay-like, and minty notes. Has a rich spicy, mildly peppery flavor with a trace of mint and clove. Its taste is fresh and delicate with slight minty notes. Holy basil has a strong anise-like, musky, and lemony taste with slightly camphoraceous aroma. The Thai basil has somewhat sweet anise aroma and licorice-like notes with a little spicy flavor. Cinnamon basil has the overtones of cinnamon, while the Lemon basil has a spicy, lemony taste with fruity aroma.

Active Constituents

Tannins and flavonoids, essential oil (up to 1%). Major constituents of the oil are linalool, methyl chavicol, eugenol, 1,8-cineole. Protein 14%, carbohydrates 61%, vitamin A and C, and rosmarinic acid. Aqueous extract of basil had reducing sugars, cardiac glycosides, tannins, saponins, glycosides, flavonoids, and steroids (El-Beshbishy and Bahashwan 2012). The nutritional constituents and ORAC values of dried basil are given in Table 11.1.

Table 11.1 Nutrient composition and ORAC values of basil dried

Nutrient	Units	Value per 100 g
Water	g	10.35
Energy	kcal	233
Protein	g	22.98
Total lipid (fat)	g	4.07
Carbohydrate, by difference	g	47.75
Fiber, total dietary	g	37.7
Sugars, total	g	1.71
Calcium, Ca	mg	2,240
Vitamin C, total ascorbic acid	mg	0.8
Vitamin B-6	mg	1.340
Vitamin B-12	mcg	0.00
Vitamin A, RAE	mcg_RAE	37
Vitamin A, IU	IU	744
Vitamin D	IU	0
Vitamin E (alpha-tocopherol)	mg	10.70
Fatty acids, total saturated	g	2.157
Fatty acids, total monounsaturated	g	1.238
Fatty acids, total polyunsaturated	g	0.498
H-ORAC	μmol TE/100 g	56,685
L-ORAC	μmol TE/100 g	4,378
Total-ORAC	μmol TE/100 g	61,063
TP	mg GAE/100 g	4,489

Source: USDA National Nutrient Database for Standard Reference, Release 24 (2011)

Preparation and Consumption

It has a warm spicy flavor and is sprinkled over salads and sliced tomatoes and its pungent flavor complements garlic. Sweet basil is used in seasonings for canned spaghetti sauces, meatballs, and salad croutons. It is great in pesto sauce and many Mediterranean dishes, and is used to flavor blended vinegars. The French use sweet basil in their pesto called pistou which is served in soups, sauces or stews, and omelets. Basil makes a wonderfully aromatic garnish. Traditional in Italian, Mediterranean, and Thai cookery, basil is superb with veal, lamb, fish, poultry, beans, pasta, rice, tomatoes, cheese, and eggs. It adds snap to vegetables like zucchini, eggplant, cabbage, potato, carrots, cauliflower, and spinach and to vegetable soups, stews, and sauces. Basil is one of the ingredients in the liqueur Chartreuse.

Medicinal Uses and Functional Properties

It is recommended for digestive purposes. An after-dinner cup of basil tea helps digestion. Good for stomach cramps, vomiting, and constipation. It has slight sedative action and is recommended for nervous headaches and anxiety. It has been used

to treat colds and flus to reduce fever, congestion, and joint pain. Various basils are used for the treatment of inflammation, stress, diarrhea, and as an antioxidant drug in the Indian ethnic system of medicine.

Antibacterial, anti-ulcerogenic, and anthelmintic activities have been reported (Suppakul et al. 2003). Makino et al. (2000) reported rosmarinic acid as a promising agent for preventing mesangioproliferative glomerular diseases. The holy basil (*O. sanctum*) has been reported to have radioprotective, cardioprotective, anticarcinogenic, and antioxidant properties (Uma Devi 2001; Vrinda and Uma Devi 2001; Sharma et al. 2001; Geetha and Vasudevan 2004; Manikandan et al. 2007; Hakkim et al. 2007). The essential oil of Amazonian basil (*O. micranthum*) was shown to possess antioxidant capacity, antibacterial activity, and antifungal activity (Sacchetti et al. 2004). The essential oils of *O. basilicum* exhibited antioxidant, antimicrobial, and antifungal activities (Bozin et al. 2006; Trevisan et al. 2006; De Almeida et al. 2007; Blum and Didyk 2007).

Antioxidant Properties

Basils are a source of antioxidants and antioxidant activity (Devi and Ganasoundari 1999; Kelm et al. 2000; Lee and Shibamoto 2002; Calucci et al. 2003; Jayasinghe et al. 2003; Dasgupta et al. 2004; Ray et al. 2006; Apak et al. 2006; Gülçin et al. 2007; Agbor et al. 2007; Kivilompolo and Hyötyläinen 2007; Drăgan et al. 2007; Nguyen and Niemeyer 2008; Tuntipopipat et al. 2009; Hossain et al. 2010; Dorman and Hiltunen 2010; Kaurinovic et al. 2011; Kim et al. 2011: Sgherri et al. 2011: Monga et al. 2011; Cazzola et al. 2011; Checker et al. 2012). Essential oils of different species of *Ocimum* exhibited strong antioxidant capacity (Trevisan et al. 2006; Chaturvedi et al. 2007; Wei and Shibamoto 2010). The antioxidant activity in basil has also been attributed to the flavonoids in green basils and anthocyanins in purple basil. The phenolic activity of basil was found to be higher than rose hips, but similar to red and black raspberry (Juliani and Simon 2002). Rosmarinic acid from sweet basil and other Lamiaceae herbs was reported to be the major antioxidant compound with cytoprotective effect (Jayasinghe et al. 2003; Renzulli et al. 2004). Rosmarinic acid and extracts of basil inhibited NO production and inducible nitric oxide synthase (iNOS) protein synthesis induced by lipopolysaccharide and suppressed phorbol 12-myristate 13-acetate (PMA)-induced superoxide production in RAW264.7 macrophages (Qiao et al. 2005; Tsai et al. 2007). Aqueous extract of *O. basilicum* exerted a hypolipidemic effect which was markedly stronger than the effect induced by fenofibrate treatments, and it also displayed a high antioxidant power (Amrani et al. 2006). Tincture of *O. basilicum* has been reported to possess anti-inflammatory effects on bone marrow acute phase response and a reduced one on NO synthesis (Benedec et al. 2007). The antigenotoxic potential of basil derivatives could be attributed to their antioxidant properties (Beric et al. 2008). Ethanolic extracts of basil (*O. basilicum*) showed significant hepatoprotective effects against liver damage induced by H_2O_2 and CCl_4. It decreased the levels of antioxidant

enzymes (enzymatic and nonenzymatic) and showed significant antilipid peroxidation effects in vitro (Meera et al. 2009). The extract also exhibited significant activity in superoxide radical and NO radical scavenging, indicating potent antioxidant effects. Aqueous extract of basil was shown to have strong antioxidant activity and this correlated well with the total polyphenol and flavonoid content. They suggested that the basil aqueous extract via antioxidant and α-glucosidase and α-amylase activities offered positive benefits to diabetes control (El-Beshbishy and Bahashwan 2012). Monga et al. (2011) found that the 50% alcoholic aqueous extract of different species of *Ocimum* administered orally resulted in significant reduction in tumor volume, increase in average body weight, and survival rate of mice. The various extracts showed modulatory influence against lethal irradiation doses of gamma radiation in terms of radiation-induced chromosomal damage, while at the same time induced an increase in reduced glutathione level and GST activity. These results demonstrated that *Ocimum* species have antimelanoma and radioprotective activity against B(16)F(10) metastatic melanoma cell line-induced metastasis.

Regulatory Status

GRAS 182.10 and GRAS 182.20.

Standard

ISO 11163 (Specification), ISO 11043 (Oil).

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Chapter 12
Bay

Botanical Name:	*Laurus nobilis* L.
Synonyms:	*Laurus persea* L.; *Laurus winteriana* L.; bay laurel; Grecian laurel; sweet bay; true bay; true laurel.
Family:	Lauraceae.
Common Names:	**French**: laurier; **German**: lorbeer; **Italian**: allauro, lauro; **Spanish**: laurel; **Arabic**: ghar; **Turkish**: defne, defne yapragi; **Greek**: dhafni.

Introduction

History

In biblical times, bay was symbolic of wealth and wickedness. The Delphi oracle chewed bay leaves or sniffed the smoke of burning leaves to promote her visionary trances. In classical Greece, *L. nobilis* was sacred to the god Apollo, and as legend goes, when Daphne, the nymph daughter of the earth goddess Gaia, was pursued by Apollo, the slayer of her bridegroom, she prayed to the Gods to help her, so they changed her into a laurel tree. So Apollo crowned himself with a wreath of laurel leaves and declared the tree sacred to his divinity. In ancient Rome, a garland of woven laurel leaves was awarded as a symbol of victory or honor. But Julius Caesar preferred a crown of Alexandrian laurel (*Ruscus racemosus*), as its broader leaves covered more of his bald head. In the Middle Ages, distinguished men were crowned with a wreath of berried laurel and hence the English title of Poet Laureate. University graduates were known as Bachelors from the Latin baccalaureus (bacco, a berry and laureus, of laurel) and were forbidden to marry as this would distract them from their studies and hence the general designation in Europe of unmarried men as bachelors. A dying laurel tree in a garden predicted a disaster. Dioscorides claimed that bay leaves were useful in treating diseases of the bladder, wasp and bee

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stings, and general inflammation. In Shakespeare's play Richard II, an actor says, "Tis thought the King is dead; we will not stay/The bay trees in our country are all withered." The Emperor Tiberius always wore a laurel wreath during thunderstorms. Mentioned in Grete Herbal (1526) by Peter Travis, "A paste of powdered bay berries mixed with honey applied to the face, will treat against all manner of red things that come in young folks faces." Legend has it that bay leaf is supposed to mean "I change but in death."

Producing Regions

Bay leaf is native to the Mediterranean region and Asia. It has been cultivated especially for its berries, in France, Spain, Italy, Morocco, Yugoslavia, China, Israel, Turkey, and Russia. The oil is produced mainly in Yugoslavia.

Botanical Description

It is a small evergreen tree up to 20-m (66 ft) high, with dark green, shiny, and leathery leaves. The bay leaf from Mediterranean area is shiny, leathery, and grayish-green. Male and female flowers are borne on separate trees. The bark is smooth with olive green or reddish hue. Yellowish-white flowers in the case of female trees develop into black fruits or berries. The fruits (berries) are cherry like, succulent, and purple to black in color. They are ovoid, coarsely wrinkled containing a single seed with loose kernel.

Parts Used

Leaves (should be whole, flat, of a uniform light green with a brownish tinge, but not brown) and essential oil. The oleoresin is a dark green viscous extract.

Flavor and Aroma

Has a pleasant sweetly aromatic, camphoraceous, cineolic aroma. Sweet spicy and slightly bitter. The flavor is piney, nutmeg, and clove like with delicate camphor-like notes. It has a slight bitter aftertaste. The aroma of crushed leaf is sweet with a lemon clove-like perception.

Table 12.1 Nutrient composition of bay leaf (*Laurus nobilis*)

Nutrient	Units	Value per 100 g
Water	g	5.44
Energy	kcal	313
Protein	g	7.61
Total lipid (fat)	g	8.36
Carbohydrate, by difference	g	74.97
Fiber, total dietary	g	26.3
Calcium, Ca	mg	834
Vitamin C, total ascorbic acid	mg	46.5
Vitamin B-6	mg	1.740
Vitamin B-12	mcg	0.00
Vitamin A, RAE	mcg_RAE	309
Vitamin A, IU	IU	6,185
Vitamin D	IU	0
Fatty acids, total saturated	g	2.280
Fatty acids, total monounsaturated	g	1.640
Fatty acids, total polyunsaturated	g	2.290

Source: USDA National Nutrient Database for Standard Reference, Release 24 (2011)

Active Constituents

Leaves contain water 4–10%, protein 7–11%, fat 4–9%, carbohydrates 65%, ash 4% (Ca, P, K, Na, Zn, Fe), thiamine, riboflavin, niacin, ascorbic acid, vitamin, catechin, and essential oil (0.5–3.5%). Major constituents in oil are 1,8-cineole, α-terpinylacetate, sabinene, and α-pinene (Yalcin et al. 2007; Verdian-rizi and Hadjiakhoondi 2008; Marzouki et al. 2011). The nutritional constituents of bay leaf are given in Table 12.1.

Preparation and Consumption

It is an active ingredient of the genuine *bouquet garni* and is added to dishes early in cooking, but removed before serving. It is indispensable to Mediterranean cooking, especially in Turkish, Greek, and Armenian dishes. Crushed or powdered leaves are an essential ingredient of pickling spices and spiced vinegar, extensively used for meats and meat products. The ground spice or its extractives is used in seasonings for delicatessen-style meats, like chicken loaf, corned beef, pressed sausage, as well in barbecue sauces, preserves, pastries, and some condiments. Today, bay leaf is a sought after spice for flavoring soups, stews, fish, fish sauces, poultry, meat, and puddings. The oil of bay leaf is used to scent soaps, candles, and nonalcoholic beverages.

Medicinal Uses and Functional Properties

In traditional medicine, bay has been used mainly for gastrointestinal complaints (indigestion, dyspepsia, flatulence). It has been used for kidney and bladder ailments. It has diuretic, spasmolytic, and antimicrobial properties. Bay leaf eases cramps and earaches and aids digestion by stimulating gastric functions.

It has been reported to have antibacterial, antimicrobial, antifungal (Rahari Velomanana 1989; Syed et al. 1991; Dadalioglu and Evrendilek 2004; Erkmen and Ozcan 2008; Fukuyama et al. 2011; Ramos et al. 2011), hypoglycemic (Ashaeva et al. 1984; Khan et al. 2009), antiulcerogenic (Afifi et al. 1997), antiproliferative activity (Al-Kalaldeh et al. 2010), and antioxidant properties. The bay leaves were found to potentiate the action of insulin in glucose metabolism and reduce glucose transport (Khan et al. 1990; Gurman et al. 1992). Consumption of turmeric and laurel extracts was shown to exhibit hypolipidemic and antioxidant activities in a hypercholesterolemic zebrafish model (Jin et al. 2011). Ham et al. (2010) reported that spirafolide from bay has neuroprotective effects against dopamine toxicity. These effects may contribute to the treatment of neurodegenerative diseases. Lauroside B (1), a megastigmane glycoside isolated from *Laurus nobilis* (bay laurel) leaves, was shown to suppress the proliferation of three human melanoma cell lines, namely, A375, WM115, and SK-Mel-28 (Panza et al. 2011). Laurus nobilis chloroform fraction protected against cerebral ischemia neuronal damage (Cho et al. 2010).

Antioxidant Properties

The antioxidant activity of bay has been studied and found to be very effective (Saab et al. 2012; Ozcan et al. 2010; Dall'Acqua et al. 2009; Ozcan et al. 2009; Papageorgiou et al. 2008; Conforti et al. 2006; Misharina and Polshkov 2005; Simic et al. 2003; Kang et al. 2002). The essential oil and different extracts of bay leaves had antioxidant and antibacterial activity (Ramos et al. 2011). Speroni et al. (2011) studied the antioxidant capacity of different extracts of bay leaves in vitro and also evaluated their gastroprotective activities in rats. The gastric damage was significantly reduced by all the extracts examined. Thus, they showed that the results obtained after oral administration of bay leaf extracts were in good agreement with their antioxidant capacity, confirming the relationship between pharmacological efficacy and antiradical activity (Speroni et al. 2011). The ethyl acetate extract of bay leaves exhibited the largest RSC capacity in neutralization of DPPH, NO, ($O2^{\cdot -}$), and OH radicals. Similar results were found for lipid peroxidation (Kaurinovic et al. 2010). Administration of a spice mixture which included bay leaf along with fructose diet reduced the levels of peroxidation markers in tissues of male Wistar rats and improved the antioxidant status (Suganthi et al. 2007). Bay leaf extracts and isolated compounds have been found to inhibit nitric oxide (NO) production in lipopolysaccharide (LPS)-activated murine macrophages (De Marino et al. 2004, 2005; Matsuda et al. 2000). Ethanol extracts of bay leaves were found to prevent

protein glycation (Dearlove et al. 2008). Cinnamtannin B-1 extracted from bay wood exerted an effective antioxidant action in platelets from patients with type 2 diabetes mellitus and reversed the enhanced Ca^{2+} mobilization and hyperaggregability (Bouaziz et al. 2007). Ben Amor et al. (2007) found cinnamtannin B-1 to exert antiaggregant and antiapoptotic effects in human platelets and suggested that it may prevent thrombotic complications associated with platelet hyperaggregability and hyperactivity. Conforti et al. (2006) found higher antioxidant activities for wild *L. nobilis* than cultivated *L. nobilis* and found this to be due to the higher concentration of monoterpenes in the wild *L. nobilis*. Ferreira et al. (2006) reported high acetylcholinesterase inhibitory capacity and antioxidant activity for *L. nobilis* from interior Portugal.

Regulatory Status

GRAS 182.10 and GRAS 182.20.

Standard

ISO 6576 (Specification), ISO 3045 (Oil).

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Chapter 13
Capsicum

Botanical Names:	*Capsicum annuum* L. var. *annuum*; *Capsicum annum* L. var. *glabriusculum* (Dunal) Heiser & Pickersgill; *Capsicum baccatum* L.; *Capsicum chinense* Jacq.; *Capsicum frutescens* L.; *Capsicum frutescens* L. = *Capsicum annuum*; *Capsicum pubescens.*
Synonyms:	Cayenne pepper, Tabasco pepper, red pepper, hot pepper, chili pepper, paprika, cayenne, Hungarian pepper, Pimento pepper.
Family:	Solanaceae.
	Note: Each of the above listed species of *Capsicum* has numerous subspecies, varieties, and cultivars. Numerous common names such as "aji," "bird pepper," "cayenne," "chili," etc. are recorded and used interchangeably throughout the genus. The assignment of a Standardized Common Name reflects the most established usage.
Common Names:	**French**: piment; **German**: paprika; **Italian**: paprica; **Spanish**: pimenton, pimiento; **Hindi**: mircha; **Hungarian**: paprika.

Introduction

History

The genus name *Capsicum* is believed to be derived from the Greek *capsicon* via the Latin *kaptein*, meaning to bite, apparently in reference to the fruits' pungency, and the name bell pepper coming from the Latin *capsa*, meaning boxlike. In pre-Colombian Mexico and South America, spices, particularly pepper, occupied an important place in Aztec and Inca cookery and medicine. The oldest known reference to *C. annum* dates to preagricultural Ocampo culture in caves near Tamaulipas, dating back from 7000 BC and elsewhere in Mexico. Since 7000 BC, chili peppers have

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been part of the diets of Mayans and Aztecs in Central Mexico and the Yucatan. By 5200 BC and 3400 BC local people were cultivating peppers. The earliest dates for South America date from 6000 BC in Bolivia and are for *C. pubescens*, while the cultivated forms of *C. baccatum* var. *pendulum* were identified from Ancon and Huaca Prieta, Peru about 2500 BC. The Aztec ruler, The Great Speaker, maintained arboreta, pleasure, and kitchen gardens for herbs, spices, and vegetables. In the Aztec language Nahuatl, peppers are known as *axl* or *axi*, though there are other names for the various types, degree of hotness, and culinary use. The Spaniards pronounced *axi* as chili. In 1492, when Columbus landed on Hispaniola, capsicum was grown all over the Caribbean, Mexico, Central and northern South America. Columbus recorded in his journal, "Also there is much axi, which is their pepper, and it is stronger than pepper, and the people won't eat without it, for they find it very wholesome. One could load 50 caravels a year with it." Dom Nicholas Monardes, a Spanish physician, wrote about pepper, some 50 years later, "A certain kind of long pepper, which has a sharper taste than the pepper of the Oriente and it does bite more, and it is of more sweet taste and better smell than that of Asia." "I have caused it to be put in to dreste meats in place of the Oriental papper, and it giveth a gentle taste." Columbus took back capsicums to Europe, and shortly afterwards to India and Southeast Asia on Portuguese voyages. Charles de Lecluse (Carolus Clusius), the French botanist, in his *Rariorum planetarium historia* of 1601 mentions *Capsicum brazilianum* as being bought to India from the Spanish West Indies by the Portuguese. By the end of the seventeenth century, *C. annum* var. *annum* and *C. frutescens* were being grown in most of the warmer regions of the world. It was Columbus's finding of chili or capsicums that became the New World's most important contribution to the family of spices, for capsicums spread throughout the tropics and warm temperate regions of the Old World. It is now almost impossible to imagine the dishes of Asia and the Pacific region without chili peppers, while the traditional African sorghum or maize porridge (*ugali*) would be tasteless without chili pepper. It is the national spice of Ethiopia, an essential ingredient of the hot *wat*, and as one historian commented, "Without capsicum pepper one cannot imagine a food, almost not even an Ethiopian!" There is a pepper cult whose devotees collect, photograph, discuss, write about, use, and try to extend the culinary and medicinal uses. There is a similar cult for garlic. Many historians believe that the Turks and Bulgarians of the Ottoman Empire brought peppers in the sixteenth century to Hungary. They were taken to India by the Portuguese and to Southeast Asia by the Arabs, Indians, and Portuguese. Red pepper was referred to as Ginnie Pepper and according to Gerard's Herbal, "it hath a malicious quality whereby it is an enemy of the liver and the entrails."

Producing Regions

Pepper is native to tropical America and the West Indies, but is now cultivated worldwide including India, Mexico, China, Africa, Japan, Southeast Asia, and the USA. It is produced commercially in Portugal, Spain, Central Europe, Southern Africa, and the USA.

Botanical Description

Currently five species and their varieties are recognized.

Capsicum annum is an erect annual herb while the other species are usually perennial woody shrubs. The stems are erect up to 1 m high, with alternate light to dark green leaves and terminal inflorescence with one to five flowers. The fruit is a pendulous or erect, many-seeded berry of variable size. The Guinness Book of Records includes a monster 32.5 cm long!

C. baccatum is distinguished from other species by the yellow, brown, or dark green markings in the corolla throat, and yellow anthers. The cultivated *C. baccatum* var. *pendulum* occurs in Argentina, Bolivia, Brazil, Chile, Ecuador, and Peru and also Costa Rica and Hawaii. It has been introduced into the USA.

C. chinense is the most commonly cultivated and widely distributed species in northern South America and the West Indies. Plants are up to 75 cm high, with glabrous, rarely dense short pubescent stem and leaves. The leaves are light to dark green, and the fruits are spherical to elongate, smooth, or wrinkled. When mature the fruits may be red, pink, orange, yellow, or brown. *C. chinense* resembles *C. frutescens* to which it is closely related.

C. frutescens is a rather woody perennial subshrub up to 1.5 m, similar in structure to *C. annuum*, and is known as bird pepper. The fruits are small and usually red when ripe and very pungent.

C. pubescens is known as apple chili. It is a perennial herb up to 0.5 m high, differing from other cultivated peppers by its overall pubescence, but similar in structure to *C. annuum*. The flowers are fragrant and blue or purple rather than white or greenish. The fruits are variable in shape and are green and yellow when immature, red-orange or brown when ripe, and late maturing.

All five species yield pungent fruits commonly called red pepper or simply capsicum. Mild fruits commonly known as paprika, bell pepper, sweet pepper, or green pepper are usually produced by varieties of *C. annuum*.

Parts Used

Fruit: Traditionally in the West, the smaller fruit types are called *chilis* and valued for their high pungency. The somewhat larger, mildly to moderate pungent types are known as *capsicums* and also valued for their color. However, in general most fruits are ground and sold as powdered spice, and broadly differentiated by consumers as paprika (mildly hot and spicy), chili pepper (hot), and cayenne pepper (very hot) to be incorporated in cooked dishes.

Red or chili pepper: Spice prepared from moderately pungent varieties mainly for domestic culinary purposes, in curry powder, and by food manufacturers for seasoning processed foods. The taste is spicy and hot but not burning. Red pepper is milder than cayenne and is prepared from the larger fruits, dark-red, less pungent capsicums.

Cayenne pepper: It is an extremely pungent spice prepared by blending small pungent fruits of any origin and is orange to dark red, and the taste is very hot and biting. It is used in Mexican and similar foods, processed meats, soups, and pickles.

Paprika pepper: Paprika was initially obtained from varieties of *C. annuum* grown in Hungary since the sixteenth century, but now it is widely distributed in Europe, North and South America. These carry the brand name of a specific company or are identified by region, like Hungarian, Spanish, etc.

There is an astonishing range of chili varieties depending on the region. Mexican types are Ancho, a mild dark chili, usually dried; Jalapeno, dark green, very hot, usually fresh or canned; Mulato, brown, hot, usually dried; Pasilla, long, thin, brown, hot rich flavor; Serrano, small, green, very hot, usually fresh, or canned. The Uganda or Mombasa chilies are the hottest; others are Hontaka and Santaks from Japan, Pequin, Tabasco, and Louisiana Sport peppers. Paprika is a traditional ingredient of Hungarian goulash, to which cayenne is added to increase pungency.

Flavor and Aroma

Pungent, hot, and somewhat sweet (depending on variety and type). Sharp, hot, fiery, mildly hot, sweet (depending on type and variety). The aroma of the red pepper at first is pleasant, warm, and peppery. The flavor is intensely pungent, biting hot, lingering, and overwhelming.

Active Constituents

The main source of pungency in peppers is the group of alkaloid compounds known as capsaicinoids (Andrews 1995). Capsicum contains up to 1.5% pungent principles, commonly composed of capsaicin, dihydrocapsaicin, and others. Other constituents present are carotenoids, fats (9–17%), proteins (12–15%), vitamins A, C, and others, small amount of volatile oil with more than 125 components. Mild peppers contain similar constituents as *Capsicum* but with little or no pungent principles. Varieties of chili differ widely in the capsaicinoids content. The red color of mature pepper fruits is due to the carotenoid pigments, including capsanthin. The nutritional constituents and ORAC values of cayenne or red pepper are given in Table 13.1.

Table 13.1 Nutrient composition and ORAC values of pepper red or cayenne

Nutrient	Units	Value per 100 g
Water	g	8.05
Energy	kcal	318
Protein	g	12.01
Total lipid (fat)	g	17.27
Carbohydrate, by difference	g	56.63
Fiber, total dietary	g	27.2
Sugars, total	g	10.34
Calcium, Ca	mg	148
Vitamin C, total ascorbic acid	mg	76.4
Vitamin B-6	mg	2.450
Vitamin B-12	mcg	0.00
Vitamin A, RAE	mcg_RAE	2,081
Vitamin A, IU	IU	41,610
Vitamin D	IU	0
Vitamin E (alpha-tocopherol)	mg	29.83
Fatty acids, total saturated	g	3.260
Fatty acids, total monounsaturated	g	2.750
Fatty acids, total polyunsaturated	g	8.370
H-ORAC		8,400
L-ORAC		11,271
Total-ORAC		19,671
TP		1,130

Source: USDA National Nutrient Database for Standard Reference, Release 24 (2011)

Preparation and Consumption

Peppers are used as a food colorant, a source of pungency in food, flavoring, as a repellant, and a source of pain relief. The ancient Aztecs and Mayans used chilies as food and medicine and in religious rituals. Chilies are principally associated with Indian cooking where they are an essential ingredient in curry blends and with Mexican food, where they are used in a wide variety of dishes, the best known of which is chili con carne. In India, a mixture of chili pepper and oil is added to spice up many curries and dals. They are used in South-eastern Asia in Indonesian, Malay, and Thai cuisines and in the Chinese province of Sichuan. In Japan ground chili is an ingredient of the much used seven-spice mixture. The ethnic cuisines use peppers to add flavor to their cuisines. In European cuisine, chilies are found in the Mediterranean region where they are used to flavor fish soups and add pungency to meat dishes. Rouille, the chili-based sauce from France, which traditionally accompanies bouillabaisse, is similar to romesco sauce in Spain and harissa, the fiery sauce served with couscous in North Africa. Chilies are imported in large quantities in Northern Europe and North America and are now a common household spice. The red pepper is used in many Mexican, Italian, and Indian dishes that look for pungency.

Medicinal Uses and Functional Properties

Capsicum is used internally as stomachic, carminative, and stimulant and to treat diarrhea, cramps, colic, and toothache. Externally it is used as counterirritant in rheumatism and arthritis. It has anti-inflammatory activity. Peppers clear the lungs and sinuses, protect the stomach by increasing the flow of digestive juices, trigger the brain to release endorphins (natural painkillers), make mouth water, which helps to neutralize cavity-causing acids, and help protect the body against cancer through antioxidant activity. The role of capsaicinoids in triggering the brain to release endorphins is well known and thus causing one to feel a mild euphoria.

Capsaicin has been reported to have substantial antigenotoxic and anticarcinogenic effects, suggesting this compound as another dietary phytochemical with a potential chemopreventive activity (Surh et al. 1998). Capsanthin and related carotenoids from fruits of *C. annuum* were found to show potent in vitro antitumor-promoting activity. Capsanthin, capsanthin 3′-ester, and capsanthin 3,3′-diester exhibited potent antitumor-promoting activity in an in vivo mouse skin two-stage carcinogenesis assay using 7, 12-dimethylbenz[a]anthracene as an initiator and TPA as a promoter (Maoka et al. 2001). Capsanthin and capsorubin from red paprika (*C. annuum*) was shown to enhance the rhodamine 123 accumulation 30-fold relative to nontreated lymphoma cells suggesting the potential of carotenoids as possible resistance modifiers in cancer chemotherapy (Molnár et al. 2004). Capsaicin has antitumor activity, but some carcinogenic potential has also been reported (Oikawa et al. 2006). Pepper exhibited both antihyperglycemia and antihypertension potential (Ranilla et al. 2010).

Antioxidant Properties

Peppers have been reported to show strong antioxidant activity (Shobana and Naidu 2000; Narisawa et al. 2000; Howard et al. 2000; Iorizzi et al. 2001; Perez-Galvez and Mínguez-Mosquera 2001; Racchi et al. 2002; Chu et al. 2002; Rosa et al. 2002; Larkins and Wynn 2004; Choi and Suh 2004; Materska and Perucka 2005; Ogiso et al. 2008; Danesi and Bordoni 2008; Kang et al. 2009; Martí et al. 2009; Rodov et al. 2010; Rodríguez-Burruezo et al. 2010; Airaki et al. 2011; Tundis et al. 2011). Iorizzi et al. (2001) reported that icariside E from ripe fruits of *C. annuum* had antioxidant properties that strengthened the importance of peppers in the Mediterranean diet. Capsinoids, capsiate, dihydrocapsiate, and their analogues from hot peppers showed good antioxidant activity in all systems tested (Rosa et al. 2002). The compound 6′,7′-dihydro-5′,5′ "-dicapsaicin, a new capsaicin derivative" was found to show almost the same antioxidant activity as capsaicin, but did not have the pungent taste (Ochi et al. 2003). Mateos et al. (2003) studied several activities in the peroxisomes isolated from green and red peppers (*C. annuum*) and found different antioxidative enzymes and their corresponding metabolites in the peroxisomes

suggesting that these organelles might be an important pool of antioxidants in fruit cells, where these enzymes could also act as modulators of signal molecules ($O_2{}^{*-}$, H_2O_2) during fruit maturation. Materska and Perucka (2005) studied the phenolic content and antioxidant activity of four cultivars of pepper fruit (*C. annuum*). Two fractions of phenolics, flavonoids (with phenolic acids), and capsaicinoids were isolated from the pericarp of pepper fruit at two growth stages (green and red) and their antioxidant oxidant capacity studied. The fractions from the red fruits had higher activity than those from green fruits. The antioxidant activity of the capsaicinoid fraction and the flavonoid and phenolic acid fraction from red fruits were similar. Ionization of mature green peeper fruits (*C. annuum*), at doses of 5 and 7 kGy, caused significant damage in the fruits, since it increased oxidation and decreased the antioxidant enzyme defense systems causing ultrastructural changes at cell level (Martínez-Solano et al. 2005). Sun et al. (2007) investigated the antioxidant activity of different antioxidant compounds from four different colored (green, yellow, orange, and red) sweet bell peppers (*C. annuum*). The red pepper had significantly higher total phenolic content and also higher levels of beta-carotene, capsanthin, quercetin, and luteolin. The green pepper had the lowest DPPH activity. All four colored peppers exhibited significant abilities in preventing the oxidation of cholesterol or docosahexaenoic acid (DHA) during heating. The extracts from different parts of the fruit of *C. baccatum* showed antioxidant activity but weak antimicrobial activity (Kappel et al. 2008). The methanolic extract of C. annuum seeds showed high antioxidant activity and had high contents of phenolics and flavonoid. The extract also had high inhibitory effect on linoleic acid peroxidation (Atrooz 2009). Kim et al. (2010) studied the composition and antioxidant activities of hot pepper fruits cultivated by organic and conventional agricultural practices. They found the ascorbic acid content to be higher in the organically grown hot pepper (OGP) in both green and red fruits and suggest that the consumption of pepper fruits may increase antioxidant activity in the blood, and OGP fruits may be more effective in increasing this antioxidant activity than CGP fruits. Alvarez-Parrilla et al. (2011) reported that processed peppers contained lower amounts of phytochemicals and had lower antioxidant activity, compared to fresh peppers. The ethanolic extracts from red pepper (RP) (*C. annuum*) showed the strongest antioxidant activity, and the amounts of capsanthin and L-ascorbic acid in RP correlated well with antioxidant activity (Kim et al. 2011). Oboh et al. (2011) found strong inhibitory activities of peppers against key enzymes linked to type 2 diabetes and $Fe^{(2+)}$-induced lipid peroxidation in rat pancreas in vitro, and coupled with their antioxidant properties, they suggest that pepper could be used in the prevention and management of type 2 diabetes.

Regulatory Status

GRAS 182.10 and GRAS 182.20, also 73.340 and 73.345.

Standard

ISO 972 (Chillies and capsicums, whole or ground), ISO 7540 (Ground paprika), ISO 7542 (Ground-Microscopical).

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Chapter 14
Caraway

Botanical Name:	*Carum carvi* L.
Synonyms:	*C. velenovskyi* Rohlena., caraway fruit, caraway seed, carum, carvies, Wild cumin, Roman cumin, Persian cumin, *Krishna jiraka*.
Family:	Apiaceae (Umbelliferae).
Common Names:	**French**: carvi; **German**: Kummel; **Italian**: carvi; **Spanish**: alcoravea; **Russian**: tmin; **Arabic**: karawiya.

Introduction

History

The genus name *Carum* is believed to be derived from the Greek *kapov*. The name is derived from the Arabic word *karawya*. In ancient times, the seeds of caraway were used to mask the breath. Its use predates history, as its remains have been found in food debris at Mesolithic sites. The evidence of caraway was found in Middle Eastern Asia about 5,000 years ago. It was used at least some 5,000 years ago during Mesopotamian times. It has been used in Dynastic Egypt, the ancient Mesopotamia, and also by the Greeks and Romans. Caraway was well known to the ancient Egyptians and was introduced about 1,000 years ago from northern Africa into Europe. Isaiah speaks of it in the Bible. The Persian King Khosru offered his wife 10% of the taxes to buy jewelry. But when she opened the bag, it had caraway seeds and not gold. The King assured her that they were worth more than gold as they had medicinal benefits. The *chara* of Julius Caesar eaten by Valerian's legionaries was the molded cakes made from cooked roots of caraway mixed with milk. In his *Materia Medica* (first century), Dioscorides recommended an extract of the fruit as a tonic for "pale faced girls," while the *Codex Aniciae Julianae* of AD 512 calls it *karia*. Banckes's *Herbal* indicated that the seeds "were good for the frenzy

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and the biting of venomous beasts." Caraway was probably brought to England by the Romans. It spread from Egypt up the Nile Valley to Sudan and has been found cultivated only in East Africa. The Germans and Austrians probably are the world's greatest users of caraway today. In the twelfth-century *Macers Herbal* it is described: "The virtue of hym (seed) is that it destroyeth wicked wyndes and caughs, and heleth men that hath the frenzy, and biting with venomous beestes." In Elizabethan England it was "deemed to confer the gift of retention, preventing theft of anything containing the seed, and holding the thief in custody within the violated house." It was considered a husband keeper, a few seeds in the husband's pocket prevented him from cheating. In Shakespeare's Henry IV, Falstaff was invited by Master Shallow to partake of "a last years pippin (apple) of my own grafting with a dish of caraways." In ancient times, Romans seasoned sausages with caraway seeds. German parents placed the seeds under a child's crib to protect the child from witchcraft. The Hungarian herdsmen used them to flavor goulash. Egyptians buried their dead with it.

Producing Regions

Native to the Mediterranean and West Asian regions. The major producing areas of caraway are northern Europe and the USA, where the biennial types are cultivated. The two major producers are the Dutch (better quality) and Egyptians. The major countries where it is cultivated are Denmark, Holland, Hungary, Netherlands, Poland, Russia, North India, Germany, and Norway. The major commercial sources are the Netherlands and Germany.

Botanical Description

Caraway is an annual or biennial, glabrous, erect herb up to 0.75 m (2 ft) high. It has well-developed taproot. The stem is cylindrical, robust, divertically branched, straight, and leafy. The leaves are bright green, pinnately compound, and all sheathed. The inflorescence is a terminal compound umbel, with white, sometimes pink bisexual flowers. Flowers are minute and have bracts 1–3, small, linear, or none. The fruit is a schizocarp, ellipsoidal, two dark brown, sickle-shaped mericarps, with five prominent ribs and wide, solitary vittae. The hard seeds are crescent-shaped, grayish tan marked with five light-colored ridges.

Parts Used

Seeds (light to dark brown), herb, essential oil, powder, and oleoresin. Caraway seed is used whole or ground while the leaf is used as a garnish. The root has a crispy texture, somewhat like parsnips.

Table 14.1 Nutrient composition of caraway seed

Nutrient	Units	Value per 100 g
Water	g	9.87
Energy	kcal	333
Protein	g	19.77
Total lipid (fat)	g	14.59
Carbohydrate, by difference	g	49.90
Fiber, total dietary	g	38.0
Sugars, total	g	0.64
Calcium, Ca	mg	689
Vitamin C, total ascorbic acid	mg	21.0
Vitamin B-6	mg	0.360
Vitamin B-12	mcg	0.00
Vitamin A, RAE	mcg_RAE	18
Vitamin A, IU	IU	363
Vitamin D	IU	0
Vitamin E (alpha-tocopherol)	mg	2.50
Fatty acids, total saturated	g	0.620
Fatty acids, total monounsaturated	g	7.125
Fatty acids, total polyunsaturated	g	3.272

Source: USDA National Nutrient Database for Standard Reference, Release 24 (2011)

Flavor and Aroma

Fresh sweet, slightly minty, slightly anise, aromatic. Caraway seed has a characteristic warm, slightly sweet, very sharp, somewhat acrid but pleasant aroma. Warm sweet minty, anisic, spicy, mildly astringent, slightly bitter. The flavor of plant roots is similar to the seeds but the flavor of leaves is more like that of dill.

Active Constituents

The fruit (seeds) contain moisture 10%, protein 20%, fat 14%, carbohydrates 37%, fiber 13%, and ash 6%, containing Ca, Fe, Mg, P, K, Na, and Zn, also vitamins, essential oil (1.5–5%), flavonoids (quercetin-3-glucuronide, isoquercetin). The major constituents of the oil are D-carvone (40–60%) and D-limonene (30–50%) and the total fatty acid from seeds varied from 2.95 to 5.68% w/w (Laribi et al. 2010). The other flavonoid constituents of caraway are quercetin-3-glucuronides, isoquercitrin, quercetin 3-0 caffeylglucoside, and kaempferol 3-glucoside. The coumarins identified are umbelliferone and scopoletin. Caraway seed extracts contain diverse flavonoids, isoflavonoids, flavonoid glycosides, monoterpenoid glucosides, lignins and alkaloids, and other phenolic compounds (Kunzemann and Herrmann 1977; Ishikawa et al. 2002; Matsumara et al. 2002a, b). The nutritional constituents of caraway seed are given in Table 14.1.

Preparation and Consumption

It is used extensively in East European, German, and Austrian cooking. It is a great spice used in commercial food products including baked goods, meat, and meat products. It pairs well with garlic, vinegar, pork, vegetables, fruits, and bread. Caraway oil is used in alcoholic and nonalcoholic beverages, frozen dairy desserts, candy, baked goods, gelatins, puddings, meat and meat products, condiments, and relishes. The fresh leaves are minced for green or fruit salads or used whole as a garnish. It is good with eggs, cheese, creamy soups and sauces, and vegetables. It is best known for its use in pickled vegetables, sauerkraut, split pea soup, and apple sauce. Ground caraway is used for seasoning of food. In American Gin caraway seeds are also used besides juniper berries and cardamom (Cole and Nobel 1995). Germans use caraway seed in many of their baked breads, piecrusts, and sauces. Italians boil chestnuts with caraway seed before roasting them.

Medicinal Uses and Functional Properties

It has carminative, stomachic, and laxative properties. The oil has antibacterial and larvicidal properties. It is antispasmodic and antihistaminic. It is used in toothpastes, mouthwashes, soaps, creams, lotions, and perfumes.

The seeds are expectorant and tonic and are frequently used in bronchitis and cough remedies, especially those for children (Chevalier 2001). Extracts and oils of caraway have revealed antidiabetic, anticarcinogenic, antimicrobial, insecticidal, antifungal, and antibacterial activity (Kim et al. 1995; Iacobellis et al. 2005; Srinivasan 2005; Dorman and Deans 2000; Kamaleeshwari et al. 2006; Ene et al. 2007; De Martino et al. 2009; Deb Roy et al. 2010; Fang et al. 2010; Lixandru et al. 2010). Aqueous extract of caraway was shown to exhibit lipid lowering activity (hypotriglyceridemic and hypocholesterolemic) in both normal and STZ-diabetic rats after single and repeated oral administration (Lemhadri et al. 2006). Caraway aqueous seeds extract also showed reno-protection against STZ-induced diabetic nephropathy in rats (Sadiq et al. 2010). Caraway was found to prevent the occurrence of rat colon cancer induced by a colon-specific carcinogen, 1,2-dimethylhydrazine (DMH) (Deeptha et al. 2006). This attenuation of carcinogenicity by caraway was attributed to their potential antioxidative action in the target tissues (Gagandeep et al. 2003; Deeptha et al. 2006). Histopathological and biochemical data clearly showed that inhibition of colon premalignant lesions induced by DMH was mediated by interference of caraway oil components in the activities of the main hepatic xenobiotic metabolizing enzymes (Dadkhah et al. 2011). The monoterpenes anethofuran, carvone, and limonene in caraway oil have specifically been highlighted for the anticarcinogenic action (Zheng et al. 1992; Deeptha et al. 2006). Many studies have related the anticarcinogenic actions of caraway to their potential apoptotic, antimutagenic, and antiproliferative properties. The apoptotic activities of caraway ethanol extract have been reported against several human cancer leukemia cell lines

(Bogucka-Kocka et al. 2008). Methanolic extracts of caraway showed antiproliferative activity in tumor cell lines MK-1, HeLa, and B16F10. These chemopreventive and antiproliferative actions were suggested to be related to bioactive polyacetylenic compounds and other monoterpenes, anethofuran, carvone, and limonene (Zheng et al. 1992). Aqueous and solvent caraway extracts have shown protective effect against several mutagens such as *N*-methyl-*N*′-nitro-*N*-nitrosoguanidine (MNNG), dimethylnitrosamine, nitrosodimethylamine, methylazoxymethanol acetate, methylated/ethylated nitrosourea, and methyl and ethylmethane sulfonates, in Salmonella typhimurium and other test strains (Higashimoto et al. 1993; Mazaki et al. 2006). This activity was attributed to carvone content which was found to inhibit the development of diethylsitosamine-induced stomach cancers in mice (Zheng et al. 1992; Wattenberg et al. 1990). Caraway seed extract has been shown to have remarkable antiepileptic and central depressant effects (Rezvani et al. 2011). Caraway has been shown to have both antihyperglycemic and hypolipidemic activity in diabetic rats (Haidari et al. 2011).

Antioxidant Properties

Aqueous extract of caraway had strong antioxidant activity and this correlated with the phenolic and flavonoid contents (Kim et al. 2011). Both the caraway (*C. bulbocastanum*) volatile oil and its oleoresins showed strong antioxidant activity in comparison with butylated hydroxyanisole (BHA) and butylated hydroxytoluene (BHT) (Kapoor et al. 2010). The essential oil was also found to strongly inhibit lipid peroxidation in both systems of induction (Samojlik et al. 2010). The hydrophilic antioxidant capacity and total content of phenolic compounds in caraway were closely correlated (Rodov et al. 2010). Caraway constituents, especially flavonoids and carvone, have strong antioxidant activity, which provides reno-protection against diabetes and its complications (Sadiq et al. 2010). The essential oil of caraway showed strong antioxidant, antibacterial, and antiviral activities (De Martino et al. 2009). Limonene from caraway was found to be an active molluscicidal component that inhibited the activity of alkaline phosphatase and acetylcholinesterase both in in vivo and in vitro exposure of *Lymnaea acuminata* (Kumar et al. 2009). Kamaleeswari and Nalini (2006) reported that caraway supplementation at a dose of 60 mg kg^{-1} had a modulatory role on tissue lipid peroxidation (LPO), antioxidant profile, and prevented dimethylhydrazine (DMH)-induced histopathological lesions in colon cancer rats. Their results showed diminished levels of intestinal, colonic, and cecal LPO products, such as conjugated dienes, lipid hydroperoxides, and thiobarbituric acid reactive substances and also the antioxidants superoxide dismutase, catalase, reduced glutathione, and glutathione reductase in DMH-treated rats, which were significantly reversed by caraway supplementation. Deeptha et al. (2006) found similar results in DMH-induced colon carcinogenesis and showed marked suppression of aberrant crypt foci development, bacterial enzyme activities, and modulation of oxidative stress by caraway supplemented diet as compared to the

unsupplemented DMH-treated group. Seed powder of caraway was found to be a potent molluscicide and was both time and concentration dependent (Kumar and Singh 2006). The antioxidant activity of aqueous extract of caraway was found to be superior to the known antioxidant ascorbic acid (Satyanarayana et al. 2004). The essential oils extracted from gamma-irradiated fruits of caraway were found to be more effective as an antioxidant in sunflower oil than those produced from microwaved fruits (Farag and el-Khawas 1998). The adaptogenic and antistress activity of an aqueous extract of caraway has been shown in normal and stress-induced rats (forced swim stress test) and this was related to its antioxidant property (Koppula et al. 2009). Caraway oil was reported to probably have a protective role in kidney tissue against oxidative injury in advanced stages of sepsis (Dadkhah and Fatemi 2011).

Regulatory Status

GRAS 182.10 and GRAS 182.20.

Standard

ISO 5561 (Specification), ISO 8896 (Oil).

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Chapter 15
Cardamom

Botanical Name:	*Elettaria cardamomum* (L.) Maton var. *cardamomum.*
Synonyms:	*Amomum cardamomum* L.; *Elettaria cardamomum* L. var. *miniscula* Burkill; *Elettaria cardamomum* L. var. *minus* Watt; cardamom; Mysore cardamom.
Family:	Zingiberaceae.
Common Names:	**French**: cardamomier; **German**: Kardamompflanze; **Italian**: cardamomo; **Spanish**: cardamomo; **Russian**: Kardamon; **Hindi**: Elaichi.

Introduction

History

The earliest reference to cardamom is from the ancient city of Nippur, Sumaria, dated 2000 BC, on a clay tablet. It indicates that ground cardamom was mixed with bread and added to soups. The Orientals used it over 2,000 years ago to sweeten their breath when appearing before the rulers. The Vikings purchased it from the traders in Constantinople over a thousand years ago. The genus name *Elettaria* is believed to derive from the Sanskrit *elat-eri*. In the Susruta Samhita (AD 600) it is named in Sanskrit *ela*, the seed *ela-tari*, and the plant or rhizome *ela-kai*, from whence is derived the modern Hindi *elaichi*. Cardamom is described in Ayurvedic literature of India from the third century BC. In India, fruits have been traded for at least 1,000 years, and known as Queen of Spices, with pepper the King. The Portuguese traveler Barbosa in 1514 described cardamom exports from the Malabar. Garcia da Orta in 1563 described the differences between the smaller cardamom (var. *cardamomum*) from India and the larger form (var. *major*) from Sri Lanka. Although the Arab geographer Idrisi describes cardamom as a product of Sri Lanka in Kitab Rujar, in 1154, Marco Polo does not mention it. The spice remains and is

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an important component of many South-East Asian dishes. Although Theophrastus, Dioscorides, and Pliny used the name *amomum* and *kardamomum* for several unrelated spices, it is unlikely that the Greeks or Romans had any access to the true cardamom. Cleopatra filled her chambers with the sweet smell of cardamom smoke before Mark Anthony's visit to Egypt. It is not mentioned in early European herbals. About 1,000 years, the Vikings found cardamom in the trading area in Constantinople, and thus introduced it into Scandinavia, where it is still very popular. The Greeks and Romans used cardamom over 2,000 years ago in food, perfumes, and medicines. Cardamom was grown in the gardens of Babylon around 700 BC.

Producing Regions

Cardamom is native to India, especially southern India, China, and Sri Lanka. It is cultivated in India, Sri Lanka, Guatemala, Malaysia, Indonesia, El Salvador, Costa Rica, and Laos.

Botanical Description

Cardamom is a robust, leafy, perennial herb of the ginger family that grows up to 5-m (16 ft) high, with hairless leaves along thick fleshy stalks. It has attractive small white flowers with purple tips on much branched flowering stems that develop into small green, brown, or white three-valved capsules or fruits, each containing several seeds. The fruits containing the oblong red-brown seeds are harvested prior to ripening and dried, which is completed by exposing them to sunlight. The seeds are unusually aromatic, pungent, and spicy with a flavor that is sweet and camphoraceous.

Parts Used

Fruit, seeds, essential oil, and oleoresin. It is used as pods, whole or crushed. The seeds are used whole or ground.

Flavor and Aroma

Pungent, warm and aromatic, sweet. Warm with camphoraceous and lemony undertones. The seed has a pleasant aromatic odor and a very characteristic warm, slightly pungent taste. The green pods have a delicate clean, sweet, and spicy floral flavor with a lemony scent.

Table 15.1 Nutrient composition and ORAC values of cardamom

Nutrient	Units	Value per 100 g
Water	g	8.28
Energy	kcal	311
Protein	g	10.76
Total lipid (fat)	g	6.70
Carbohydrate, by difference	g	68.47
Fiber, total dietary	g	28.0
Calcium, Ca	mg	383
Vitamin C, total ascorbic acid	mg	21.0
Vitamin B-6	mg	0.230
Vitamin B-12	mcg	0.00
Vitamin A, RAE	mcg_RAE	0
Vitamin A, IU	IU	0
Vitamin D	IU	0
Fatty acids, total saturated	g	0.680
Fatty acids, total monounsaturated	g	0.870
Fatty acids, total polyunsaturated	g	0.430
H-ORAC	μmol TE/100 g	2,764
Total-ORAC	μmol TE/100 g	2,764
TP	mg GAE/100 g	167

Source: USDA National Nutrient Database for Standard Reference, Release 24 (2011)

Active Constituents

The fruit from India has carbohydrates 42%, fiber 20%, moisture 20%, protein 10%, fat 2%, and ash 6%. It also contains pigments, silica, pentosans, minerals, and volatile oil. The seeds contain moisture 8%, volatile oil 8%, total ash 5%, nonvolatile ether extract 3%, crude fiber 9%, protein 10%, starch 46%, Ca 0.3%, P 0.2%, K 1.2%, and Fe 0.012%, also vitamins: thiamine, riboflavin, niacin, ascorbic acid, vit. A (Weiss 2002). The major constituent in volatile oil is 1,8-cineole (up to 50%) and α-terpinyl acetate (up to 50%). The major constituents in seed oils were α-terpinyl acetate, 1,8-cineole, limonene, linalyl acetate, and linalool (Marongiu et al. 2004). The nutritional constituents and ORAC values of cardamom are given in Table 15.1.

Preparation and Consumption

Cardamom enhances sweet and savory dishes. It is extensively used in curry, coffee, cakes, and bread in India, Middle East, Europe, and Latin America. The fruits, seeds, and oil are used to flavor alcoholic and nonalcoholic beverages, frozen desserts, baked goods, candies, puddings, meat and meat products, fish, condiments, and other relishes. The pods are used whole or split in Indian meals—such as pulses and pilaus

(rice dishes). It is also included in Indian sweet dishes and drinks. It is used in pickles, especially pickled herring. It flavors custards, and some Russian liqueurs. It is a flavoring for Arab and Turkish coffee and Indian tea. It is a very important flavoring in Saudi Arabian foods and beverages. Cardamom is good in beef and veal stews, hamburgers and meatloaf, chicken and turkey pie, fruit salads and soups, split pea soup, sweet potatoes, squash, carrots, and pies. Scandinavians use cardamom seed in Danish pastries. Green cardamom is an essential ingredient in Indian sweets, puddings, yogurt, and ice creams.

Medicinal Uses and Functional Properties

It is used in carminative, stomachic, and laxative preparations. It is an important Ayurvedic aphrodisiac and remedy in case of digestive problems, asthma, bronchitis, and urinary complaints. It is used against bad breath, cough, and nausea.

Aqueous extracts of cardamom were found to exert immunomodulatory roles and antitumor activities (Majdalawieh and Carr 2010). Regular consumption of tea fortified with herbs including cardamom was shown to enhance NK cell activity, which is an important aspect of the (early) innate immune response to infections (Bhat et al. 2010). The essential oil of cardamom was reported to have strong sporicidal activity (Lawrence and Palombo 2009). Jamal et al. (2006) showed significant gastroprotective effect of various extracts from cardamom fruits. Aqueous suspensions of cardamom provided protective effects on experimentally induced colon carcinogenesis (Sengupta et al. 2005).

Antioxidant Properties

Cardamom fruit powder was found to effectively reduce blood pressure, enhance fibrinolysis, and improve antioxidant status in stage 1 hypertensive individuals. They did not significantly alter blood lipids and fibrinogen levels (Verma et al. 2009). The essential oil of cardamom had significant antioxidant activity (Misharina et al. 2009). Sultana et al. (2010) studied the antioxidant activities of some commonly used spices in Bangladesh and found cardamom to have significant activity. Methanol extracts of several spices including cardamom were found to exert some level of protective ability against peroxynitrite-mediated biomolecular damage (Ho et al. 2008). Administration of a spice mixture, containing cardamom along with fructose diet, reduced the levels of peroxidation markers in tissues and improved the antioxidant status in male Wistar rats (Suganthi et al. 2007). Cardamom along with other spices showed strong DPPH radical scavenging activity and metal chelating activity (Yadav and Bhatnagar 2007). Aqueous suspensions of cardamom were shown to enhance the level of detoxifying enzyme (GST activity) with simultaneous decrease in lipid peroxidation levels in the treatment groups when compared to that

of the carcinogen control group (Bhattacharjee et al. 2007). Aqueous extract of cardamom protected platelets from aggregation and lipid peroxidation (Suneetha and Krishnakantha 2005). Phenolics have been reported in cardamom and other spices and these spices have shown medicinal properties because of these phenolics (Singh et al. 2004). Nair et al. (1998) reported significant levels of flavonoids in cardamom seeds. Cardamom showed moderate inhibitory effect on the histamine production and histidine decarboxylase activity of *Morganella morganii* (a potent histamine-producing bacteria in fish) at 30°C (Shakila et al. 1996).

Regulatory Status

GRAS 182.10 and GRAS 182.20.

Standard

ISO 882-1 (whole), ISO 882-2 (seeds), ISO 4733 (Oil).

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Chapter 16
Celery Seed

Botanical Name: *Apium graveolens* L. var. *dulce* (Mill.) Pers.
Synonyms: Celery fruit, chin.
Family: Apiaceae (Umbelliferae).
Common Names: **French**: Celeri; **German**: Sellerie; **Italian**: Sedano; **Spanish**: Apio; **Russian**: Syel'derey; **Hindi:** Karnauli, Ajmod.

Introduction

History

Celery actually dates back to "smallage," a wild, bitter marsh plant. The ancient Greeks and Romans used celery for its medicinal purposes and it was very widely believed that it was an aphrodisiac. In the Middle Ages, Italian farmers began to cultivate "smallage." Once begun, this cultivation steadily improved the quality of the Celery and it has become a popular item. Celery seed is a Western spice and a newcomer to the kitchen. The leaf of the vegetable was widely used in the nineteenth century in Europe and America, and this was mainly due to the breeding of the white-stalked variety in Italy during the eighteenth century. The first mention of its cultivation and use in France was reported in 1623. It was introduced in India around AD 1930 by France. Celery leaves and stalks have been used in Europe and Middle East for thousand of years as salad vegetables. The seeds are also used in the Middle East in medicine since ancient times.

Producing Regions

Celery is native to southern Europe. It is now extensively cultivated. The principal sources of celery seed are India and China. The Indian seeds are considered

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premium quality because of its color and taste. The Chinese seed is smaller and milder in flavor. The French also produce some celery seeds but they are slightly darker. The major countries in Europe producing celery are France, Germany, Hungary, Italy, UK, and Holland. California, Florida, Michigan, and New York are the major producers in the USA.

Botanical Description

Celery is an annual or biennial herbaceous plant of the carrot, caraway, and parsley family up to 1 m (3 ft) high with conspicuous branches bearing well-developed leaves on long expanded petioles. It has succulent roots and branching, angular stems. The stems are branched, angular or fistular, and conspicuously jointed. The leaves are oblong, pinnate, or trifoliate. The leaflets are ovate to suborbicular. The flower heads come up in the second year and produce masses of fruits. The flowers are borne on sessile compound umbels and are white or greenish white. The fruit is two united carpels with a single seed. The seeds are small, oval, and greenish brown. The seed results from the splitting of fruits and is also ribbed and much smaller than carrot seed.

Parts Used

Seeds and herbs. The essential oils and oleoresin are also used as flavoring agents. Commercially available are celery stalk dice, leaf and stalk flakes, celery powder, and stalk and leaf granules. These are used for flavoring soups, broth base, fish, and stuffings.

Flavor and Aroma

It has a characteristic celery-like aroma similar to fennel and anise. The flavor is grassy and hay like, rather bitter.

Active Constituents

Essential oil, fatty oils. Major component of the oil is D-limonene and β-selinene and phthalides. The phthalides give the characteristic aroma. Celery had flavonoids, tannins, volatile oils, alkaloids, sterols, and/or triterpenes (Al-Howiriny et al. 2010). Several triterpenoids and flavonoids have been reported in celery (Zhou et al. 2009). The phenolic acids in celery are caffeic acid, *p*-coumaric acid, and ferulic acid. The major flavonoids were apigenin, luteolin, and kaempferol (Yao et al. 2010; Han and Row 2011). The nutritional constituents of celery seed are given in Table 16.1. The nutritional constituents and ORAC values of dried celery flakes are given in Table 16.2.

Table 16.1 Nutrient composition of celery seed

Nutrient	Units	Value per 100 g
Water	g	6.04
Energy	kcal	392
Protein	g	18.07
Total lipid (fat)	g	25.27
Carbohydrate, by difference	g	41.35
Fiber, total dietary	g	11.8
Sugars, total	g	0.67
Calcium, Ca	mg	1,767
Vitamin C, total ascorbic acid	mg	17.1
Vitamin B-6	mg	0.890
Vitamin B-12	mcg	0.00
Vitamin A, RAE	mcg_RAE	3
Vitamin A, IU	IU	52
Vitamin D	IU	0
Vitamin E (alpha-tocopherol)	mg	1.07
Fatty acids, total saturated	g	2.190
Fatty acids, total monounsaturated	g	15.930
Fatty acids, total polyunsaturated	g	3.720

Source: USDA National Nutrient Database for Standard Reference, Release 24 (2011)

Table 16.2 Nutrient composition and ORAC values of celery flakes dried

Nutrient	Units	Value per 100 g
Water	g	9.00
Energy	kcal	319
Energy	kJ	1,334
Protein	g	11.30
Total lipid (fat)	g	2.10
Ash	g	13.90
Carbohydrate, by difference	g	63.70
Fiber, total dietary	g	27.8
Sugars, total	g	35.90
Calcium, Ca	mg	587
Vitamin C, total ascorbic acid	mg	86.5
Vitamin B-6	mg	0.460
Vitamin B-12	mcg	0.00
Vitamin A, RAE	mcg_RAE	98
Vitamin A, IU	IU	1,962
Vitamin D	IU	0
Vitamin E (alpha-tocopherol)	mg	5.55
Celery raw		
H-ORAC	μmol TE/100 g	512
L-ORAC	μmol TE/100 g	40
Total-ORAC	μmol TE/100 g	552
TP	mg GAE/100 g	42

Source: USDA National Nutrient Database for Standard Reference, Release 23 (2010)

Preparation and Consumption

Used in pickling, vegetables, salad dressings, breads, soups, and tomato items. Whole seeds can be added to bread dough or cheese biscuits. Celery seed is used in celery salt, bouquet garni, pickling, and curry spice blends. It is used in the ethnic cuisines of Germany, Italy, Russia, and the Orient. Ground celery is used in a variety of meat dishes, snack foods, gravies, and sauces. It is a notable ingredient in the Bloody Mary cocktail. Celery oleoresin is one of the most important flavoring agents as it imparts a warm, aromatic, and pleasing flavor to the food products. The oil is used as flavoring and in perfumery and pharmaceutical industry.

Medicinal Uses and Functional Properties

Celery seeds are known to have carminative, stimulant, stomachic, emmenagogue, diuretic, antirheumatic, anti-inflammatory, and laxative properties. It is prescribed for epilepsy or psychiatric problems due to its tranquilizing effect. The oil is used to treat asthma, flatulence, and bronchitis. Leaves and petioles are used for skin problems in addition to the above-mentioned uses.

Hexane extract of celery with 5 % vanillin had good protective effect against a wide range of mosquito species including *Aedes gardnerii*, *A. lineatopennis*, *Anopheles barbirostris*, *Armigeres subalbatus*, *Culex tritaeniorhynchus*, *Culex gelidus*, *C. vishnui* group, and *Mansonia uniformis* (Tuetun et al. 2005). Celery seeds were found to have marked liver protective activity, and the seed extracts also lowered blood fat levels (Chevallier 2001). Prajapati et al. (2003) reported the use of celery for curing rheumatic pain in muscles of neck and sacrum and curing dysmenorrhoea with short pains in both ovarian regions. Celery seed and herb are helpful in curing obstinate retention of urine, because of their diuretic properties (Prajapati et al. 2003). Celery seed extract and fractions from it have been found to show anti-inflammatory activity, gastro-protective activity, and anti-Helicobacter pylori activity (Powanda and Rainsford 2011).

Antioxidant Properties

Celery has been found to have strong antioxidant activity (Cao et al. 2012; Stankevicius et al. 2011; Boğa et al. 2011; Yao et al. 2010; Jimenez-Monreal et al. 2009; Lopez-Lazaro 2009; Ninfali and Bacchiocca 2003; Chu et al. 2002; Momin and Nair 2002). Essential oils from the leaves of celery were found to have significant toxic effects against the larvae of *A. aegypti* and also showed potential antioxidant activity (Nagella et al. 2012). The ethanol extract of celery significantly protected the gastric mucosa and suppressed the basal gastric secretion in rats, possibly

through its antioxidant potential (Al-Howiriny et al. 2010). Yao et al. (2010) in their study found a positive correlation between the antioxidant activity and the contents of total flavonoids, total phenolic acids, or total phenolics. The compound dl-3-*n*-butylphthalide (NBP) extracted from the seeds of celery was found to reduce the cytotoxicity of MPP(+) by suppressing the mitochondrial permeability transition, reducing oxidative stress, and increasing the cellular GSH content (Huang et al. 2010). Jimenez-Monreal et al. (2009) found the antioxidant activity of celery to increase in all cooking methods (microwaving, pressure-cooking, griddling, frying, baking) except boiling where it lost 14 %. Celery roots and leaves juices influenced the examined biochemical parameters (content of reduced glutathione, activities of catalase, xanthine oxidase, glutathione peroxidase, peroxidase, lipid peroxidation) in liver homogenate and blood hemolysate and showed protective effects when applied with doxorubicin (Kolarovic et al. 2009). Luteolin found in celery has been shown to possess pharmacological activities, including antioxidant, anti-inflammatory, and anticancer activities (Lopez-Lazaro 2009). Luteolin inhibits angiogenesis, induces apoptosis, prevents carcinogenesis in animal models, reduces tumor growth in vivo, and sensitizes tumor cells to the cytotoxic effects of some anticancer drugs, suggesting it has cancer chemopreventive and chemotherapeutic potential. The essential oils of mountain celery seed had strong hypolipidemic and antioxidant activity (Cheng et al. 2008). Apigenin found in celery and other vegetables has been found to contribute to the prevention of cancer (Meeran and Katiyar 2008; Takagaki et al. 2005; Shukla and Gupta 2006, 2007; Ujiki et al. 2006; Chiang et al. 2006). Extract of celery leaves and apiin showed strong inhibitory activity on iNOS expression and nitrite production when added before *E. coli* lipopolysaccharide (LPS) stimulation in the medium of J774.A1 cells (Mencherini et al. 2007). The essential oil of celery had great inhibitory activity toward malonaldehyde (MA) formation from squalene upon UV irradiation (Wei and Shibamoto 2007). The extracts of celery seed and root were good scavengers of OH* and DPPH* radicals and reduced liposomal peroxidation intensity in liposomes (Popovic et al. 2006). The phenylsulfotransferase-P activity was significantly induced by celery and was ascribed to the phenolic acids present (Yeh and Yen 2005). The essential oil of celery seed was shown to have good antiradical activity and thus could be used as natural antioxidants in food applications (Kiralan et al. 2012).

Regulatory Status

GRAS 182.10 and GRAS 182.20.

Standard

ISO 6574 (Specification), ISO 3760 (Oil).

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Chapter 17
Chervil

Botanical Name:	*Anthriscus cerefolium* L. Hoffm.
Synonyms:	Korvel, myrrhis, Cerefolio, garden chervil, English parsley, salad chervil.
Family:	Apiaceae (Umbelliferae).
Common Names:	**French**: Cerfenil; **German**: Kerbel, Gartenkerbel; **Italian**: Cerfoglio; **Spanish**: Perifollo, Certafolia; **Russian**: kervel; **Hebrew**: tamcha.

Introduction

History

Chervil is a much neglected relative of parsley and was once called *myrrhis* for its volatile oil, which has an aroma similar to myrrh. It is traditional to serve chervil on Holy Thursday, because it resembles myrrh given to Jesus and because it symbolized new life. It reached the Mediterranean long before the Christian era. To Europeans, chervil is a symbol of new life. Romans used chervil leaves more than 2,000 years ago because of their pleasant aroma. The Romans called it *cerefolium*. The Greek nobles carried a sprig to wave blessings to friends, with the Greek "*khairephyllon*" meaning "leaf of joy." The Englishman John Wesley said: "cerfille is cheering to the spirits." The great English botanist John Gerard in 1597 wrote that chervil, "eaten in salad when they are green, with oil and vinegar, by the agreeableness of their taste, are better than other salads through the sweetness of their aroma, and nothing is healthier for weak stomachs." It has been cultivated in England since 1597 and in America since 1806. The first-century Roman scholar Pliny and the seventeenth-century herbalist Nicholas Culpeper believed that chervil, "does much

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please and warm old and cold stomachs." Legend has it that chervil makes one merry, sharpens a dull wit, prods the memory, and gives the aged the dash of youth. It is supposed to symbolize sincerity.

Producing Regions

Chervil probably originated in southern Europe or Caucasus region. It is also believed to be native to Russia, Europe, and northwestern Asia. It is found in Asia and Europe. It is grown in California and New Mexico. It is now cultivated around the Mediterranean regions of Greece, France, Italy, Spain, in Britain, and the USA.

Botanical Description

Chervil is a hardy annual, small, rounded herb of the carrot family up to 70 cm (2 ft) high, with pale, light green, compound, bipinnate, opposite leaves. The lower leaves are pointed and the upper leaves are sessile with stem sheaths. The stems are round, much branched, light green, and hairy. The small flowers are white and arranged in umbels. The seeds are long and pointed with a conspicuous furrow from end to end. It has a white, thin, and single tapering root.

Parts Used

Leaves. It is used fresh or dried, whole, chopped, crushed, or as a paste in oil.

Flavor and Aroma

It has a sweet, aromatic, and anise-like flavor with slight hints of pepper and parsley. Peppery and anisic. The taste resembles parsley with licorice overtone.

Active Constituents

Essential oil (0.3% in leaves and 0.9% in seeds). Major compound in oil is methyl chavicol (Chizzola 2011). The herb has apiin, bitter principles, potassium, calcium, magnesium, phosphorus, and others. Fruits (seeds) contain luteolin-7-glucoside and around 13% fixed oils. The nutritional constituents of dried chervil are given in Table 17.1.

Table 17.1 Nutrient composition of chervil dried

Nutrient	Units	Value per 100 g
Water	g	7.20
Energy	kcal	237
Protein	g	23.20
Total lipid (fat)	g	3.90
Carbohydrate, by difference	g	49.10
Fiber, total dietary	g	11.3
Calcium, Ca	mg	1,346
Vitamin C, total ascorbic acid	mg	50.0
Vitamin B-6	mg	0.930
Vitamin B-12	mcg	0.00
Vitamin A, RAE	mcg_RAE	293
Vitamin A, IU	IU	5,850
Vitamin D	IU	0
Fatty acids, total saturated	g	0.169
Fatty acids, total monounsaturated	g	1.399
Fatty acids, total polyunsaturated	g	1.800

Source: USDA National Nutrient Database for Standard Reference, Release 24 (2011)

Preparation and Consumption

Chervil is a major ingredient in French cooking and has become part of the popular spice blend, "bouquet garni." Chervil is one of the ingredients in "*fines herbes*" along with chives, tarragon, and parsley. It can be used to flavor eggs, fish, poultry, and light sauces and dressings. With tarragon, it seasons ravigote, vinaigrette sauces, and the famous Bearnaise, a mainstay of French cuisine since 1835. Chervil is the fresh "*Pluches de cerfeuille*" used in many French stew and soup recipes, such as the famous "Melange de Potage au Cerfeuil" from Roubaix. Chervil can also be found in Spanish cooking. The Arabs for centuries made a chervil- (rig-el-ghurab) and cherry-flavored liqueur, which the fourteenth-century Europeans copied by soaking the ingredients in brandy for a few weeks and straining it. In Norway and France, bowls of minced fresh chervil leaves are served with meals. People sprinkle the chopped leaves on salads, soups, and stews. It can be used with salmon trout, asparagus, potatoes, baby green beans, carrots, and salads of spring greens. It should be added at the last minute. It makes an attractive garnish.

Medicinal Uses and Functional Properties

Poultices of chervil leaves have been used on boils, bruises, and other skin ailments by ancient Greeks, Romans, Arabs, and the Europeans. Chervil tonic has been used as an expectorant, stimulant, and diuretic. It has also been used to treat eczema, cure

high blood pressure, gout, kidney stones, pleurisy, dropsy, and menstrual problems. The whole plant probably relieves hiccups. The extracts of chervil were reported to have membrane protective effects and free radical scavenging activity (Fejes et al. 2000a).

Antioxidant Properties

Chervil extracts have been found to possess antioxidant and antilipoperoxidation activity (Fejes et al. 2000a, b; Dall'Acqua et al. 2006). Standardized aqueous extracts of chervil root and herb were investigated for antioxidant effect by numerous in vitro test methods for H-donor, metal binding, reductive, free radical scavenging, and membrane protective activity. The herb extract was found to have better activity than the root extracts, suggesting it to have antioxidant and antilipoperoxidant activity (Fejes et al. 2000a).

Regulatory Status

GRAS 182.10 and GRAS 182.20.

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Chapter 18
Chives

Botanical Name: *Allium schoenoprasum* L.
Synonyms: Chaibu, asatuki, bieslook.
Family: Liliaceae.
Common Names: **French**: Civette, ciboulette; **German**: Schnittlauch; **Italian**: Erba cipollina; **Spanish**: Cebollino.

Introduction

History

English *chive* derives from Middle English *cyve* or *cheve*, loaned from old French *cive*. The species name *schoenoprasum* literally means "rush-like leek." The Greek word "*schoinos*" means "rush" (kind of grass) and "*prason*" means "leek." It is a close relative of onion and is known since earliest times but was not cultivated until the Middle Ages. There were no written records of domesticated chives from the Mediterranean region until the sixteenth century in Europe, whereas in East Asia it was domesticated since ancient times. Siberians were the first ones to enjoy their native chives. Chives became so popular that the Dutch farmers fed them to their cows so they could produce a chive-flavored milk. A story has been told about the use of chives by the Siberians to appeal to Alexander the Great (356–323 BC). When Alexander was approaching Siberia and was still miles away they appealed to him with chives, the only treasure they had, in honor of his upcoming marriage to Princess Roxana. It was especially more appropriate as chives were considered an aphrodisiac. Chives are a very popular spice in French and Chinese cooking. Marcus Valerius Martialis (circa AD 100) wrote "He who bears chives on his breath/Is safe from being kissed to death."

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Producing Regions

Chives are believed to have originated in Siberia and spread from there into America. It is found growing in almost all temperate regions of the globe. It now thrives in temperate regions of Europe and North America. It is cultivated in Austria, Canada, France, Germany, Great Britain, Italy, the Netherlands, and USA.

Botanical Description

Chives belonging to the onion family are a perennial that is dense, grass-like clumps growing out of bulbs up to 20 cm (8 in.) high. They are aromatic, hardy, and grow in clumps of slender, onion-like green leaves with flowers in the spring. The leaves are green, straight, and hollow with sharp points. The flowers are pink to purple compact spheres consisting of many small flowers. The bulbs are oval shaped and often clumped together.

Parts Used

Fresh or dried leaves. The long cylindrical leaves are used for culinary purposes. The flowers can also be used for salad dressings. The entire length of the tubular leaf is used in foods.

Flavor and Aroma

Onion like, more subtle. Delicate, onion like. Unlike the pungent flavor of garlic and onions, the flavor of chives is very delicate and much milder.

Active Constituents

Essential oil, vitamins, minerals (iron, calcium, magnesium, phosphorus, potassium). Contains lutein, zeaxanthin, and β-carotene (Wang et al. 2011). Diallyl sulfides (diallyl monosulfide, diallyl disulfide, diallyl trisulfide, and diallyl tetrasulfide) are reported in chives (Rattanachaikunsopon and Phumkhachorn 2008). The flavonoid glycosides in chives are quercetin glucoside, isorhamnetin glucoside, and kaempferol glucoside (Justesen 2000). Chives have polyphenolic compounds (Parvu et al. 2010). The nutritional constituents (freeze dried chive) and ORAC (raw) values of chives are given in Table 18.1.

Table 18.1 Nutrient composition and ORAC values of chives freeze-dried

Nutrient	Units	Value per 100 g
Water	g	2.00
Energy	kcal	311
Energy	kJ	1,301
Protein	g	21.20
Total lipid (fat)	g	3.50
Ash	g	9.01
Carbohydrate, by difference	g	64.29
Fiber, total dietary	g	26.2
Calcium, Ca	mg	813
Vitamin C, total ascorbic acid	mg	660.0
Vitamin B-6	mg	1.996
Vitamin B-12	mcg	0.00
Vitamin A, RAE	mcg_RAE	3,415
Vitamin A, IU	IU	68,300
Vitamin D	IU	0
Chives raw		
H-ORAC	μmol TE/100 g	2,094
Total-ORAC	μmol TE/100 g	2,094
TP	mg GAE/100 g	85

Source: USDA National Nutrient Database for Standard Reference, Release 23 (2010)

Preparation and Consumption

Fresh is better than dried. They add flavor to cheese, eggs, potato dishes, cucumber, or any dish that needs the delicate onion-like flavor. They enhance the flavor of fish. Chives are a very popular ingredient in European cooking because of their delicate flavor. They are an ingredient of the French *fines herbes*. The flowers make flavorful vinegar. Their delicate taste enhances sour cream and cream cheese. They are good in sauces such as *remoulade* and *ravigote* and in herb butters. Sprinkle on soups such as Vichyssoise and use to garnish tomato and potato salads in particular. Chives can be used as seasonings for many dishes or as a garnish.

Medicinal Uses and Functional Properties

It is used in the Orient as a cold, flu, and lung congestion remedy. Chives have been used to help lower blood pressure and aid digestion. They also stimulate the appetite and possess some antiseptic properties. Chives have been found to have applications as antimicrobial, antithrombotic, antitumor, hypolipidemic, antiarthritic, and hypoglycemic agents.

Diallyl sulfides (diallyl monosulfide, diallyl disulfide, diallyl trisulfide, and diallyl tetrasulfide) are believed to be responsible for the health promoting effects and antimicrobial activity of chives (Block et al. 1992; Yin and Tsao 1999). Different extracts of chives were shown to have antinematodal activities, the intensity of which depended on the method of extraction (Klimpel et al. 2011). Chives have been found to reduce prostate cancer risks, including 5-alpha-reductase inhibitors (Colli and Amling 2009). Chive oil was shown to inhibit several strains of food-borne pathogens in the laboratory level and *E. coli* O157:H7 in food (Rattanachaikunsopon and Phumkhachorn 2008). Consumption of Allium vegetables including chives reduces the risk for gastric cancer (Zhou et al. 2011). Phenolic compounds from the flowers of chives were found to exhibit significant antiproliferative effects (Kucekova et al. 2011).

Antioxidant Properties

Methanolic extract of chives showed an antioxidant activity comparable with those of DL-alpha-tocopherol and quercetin (Souri et al. 2004). Stajner et al. (2004) investigated the antioxidant properties of the bulb, leaf, and stalk of chives by measuring the activities of antioxidant enzymes (superoxide dismutase, catalase, peroxidase, glutathione peroxidase), quantities of malonyldialdehyde, superoxide and hydroxyl radicals, and reduced glutathione and also the content of total flavonoids, chlorophylls a and b, carotenoids, vitamin C, and soluble proteins. They found antioxidant activity in extracts from all plant organs studied, and the highest antioxidant activity being observed in the leaves. Stajner et al. (2008) reported that the bulbs of *Allium* species could be used in the human diet as a source of natural antioxidants and also in the pharmaceutical and cosmetics industries. The high antioxidant activity was due to high antioxidant enzyme activities (SOD, CAT, GPx, and GSH-Px) and non-enzymatic antioxidants (GSH and flavonoids). The tissue culture plants of chives exhibited the highest antioxidant and scavenging activities in the roots in contrast to the cultivated plants where highest activities were observed in the leaves (Stajner et al. 2011).

Regulatory Status

GRAS 182.10.

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Chapter 19
Cinnamon

Botanical Name:	*Cinnamomum verum* J. Presl.
Synonyms:	*Cinnamomum zeylanicum* Nees; Ceylon cinnamon; true cinnamon.
Family:	Lauraceae.
Common Names:	**French**: cannellier, canella de Ceylan; **German**: Ceylon-Zimtbaum; **Italian**: canella; **Spanish**: canelo de Ceilan; **Sinhalese**: kurundu; **Hindi**: dalchini, ilayangam.

Introduction

History

Cinnamon is one of the finest sweet spices, with cassia as a coarser substitute. The botanical name *Cinnamomum* is derived from the Hebraic and Arabic term *amomon*, meaning fragrant spice plant. Both cinnamon and cassia were popular spices in Greece and Rome. Cinnamon's name is derived from the Greek word, *kinamon*. From the days long before Moses, cinnamon has been one of the spices burned in incense at religious ceremonies. Cinnamon is widely used by humans, both as a spice and as a traditional medicine. It is, perhaps, one of the oldest herbal medicines, having been mentioned in the Bible (Exodus, Proverbs, and Song of Songs) and in Chinese texts as long as 4,000 years ago (Dugoua et al. 2007). In Exodus 30: 22–26, the Lord spoke to Moses saying "Take thou also unto thee principal spices, of pure myrrh 500 shekels, and of sweet cinnamon half so much, even 250 shekels, and of sweet calamus 250 shekels. And of cassia 500 shekels, after the shekel of the sanctuary, and of olive oil an hin: And thou shalt make it an oil of holy ointment, an ointment compound after the art of the apothecary; it shall be an holy anointing oil." At some point, cinnamon was more valuable than gold. Roman Emperor Nero is believed to have burned 1 year's supply of Rome's cinnamon at his wife's funeral.

D.J. Charles, *Antioxidant Properties of Spices, Herbs and Other Sources*,
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It was sought after for embalming by the Egyptians over 3,600 years ago. The Arab writer Kasawini mentions cinnamon about 1275 AD, and John of Montecorvino, a Minorite friar, writes about cinnamon around 1293 AD. The noted Arab traveler Ibn Batutah also mentions cinnamon in his books around 1340 AD. In the eighteenth century, Dutchman Francois Valentijn described cinnamon bark harvesting in detail in his writings. Vasco da Gama the great Portuguese captain in the fifteenth century brought cinnamon and other spices to Portugal from Calicut, India. Systematic cinnamon cultivation began between 1767 and 1770 in Sri Lanka by a Dutch colonist named de Kok. Cinnamon was brought to Seychelles in 1771 by Pierre Poivre. The Dutch also introduced cinnamon into their East Indian colonies. It was one of the more profitable spices in the Dutch East India spice trade. Both Herodotus in the fifth century BC and Theophrastus in the fourth century BC believed that cinnamon and cassia came from Arabia. The Chinese used it as a medicine as early as 2500 BC. The Portuguese invaded Sri Lanka immediately after reaching India in 1536 mainly for cinnamon.

Producing Regions

Cinnamon is native to Sri Lanka and parts of India. It is cultivated commercially in India, Africa, South America, the West Indies, Indonesia, and the Seychelles.

Botanical Description

A tropical medium-sized, bushy evergreen tree up to 15-m (50 ft) high. Has long, very stiff, lanceolated, leathery, bright green leaves, with small yellow flowers in clusters and small ovoid bluish or blackish fruits. The bark and leaves are highly aromatic. The commercial cinnamon bark is a dull, pale brown. The cinnamon quills of commerce are known as cinnamon sticks. The broken quills of various grades are called quillings.

There are other varieties of cinnamon. *Cinnamomum cassia* or Chinese cassia, *C. burmanii* or Indonesian cinnamon, *C. loureirii* or Vietnamese cinnamon.

Parts Used

Bark (quills), bark powder, bark essential oil, leaf essential oil, and oleoresin.

Flavor and Aroma

The spice is reddish-brown and has a sweet, warm, spicy, woody aroma. The flavor is warm, spicy, and aromatic. The essential oil has a sweet, aromatic, spicy, slightly woody, and clove-like aroma.

Table 19.1 Nutrient composition and ORAC values of cinnamon ground

Nutrients	Units	Value per 100 g
Water	g	10.58
Energy	kcal	247
Protein	g	3.99
Total lipid (fat)	g	1.24
Carbohydrate, by difference	g	80.59
Fiber, total dietary	g	53.1
Sugars, total	g	2.17
Calcium, Ca	mg	1,002
Vitamin C, total ascorbic acid	mg	3.8
Vitamin B-6	mg	0.158
Vitamin B-12	mcg	0.00
Vitamin A, RAE	mcg_RAE	15
Vitamin A, IU	IU	295
Vitamin D	IU	0
Vitamin E (alpha-tocopherol)	mg	2.32
Fatty acids, total saturated	g	0.345
Fatty acids, total monounsaturated	g	0.246
Fatty acids, total polyunsaturated	g	0.068
H-ORAC	μmol TE/100 g	143,264
L-ORAC	μmol TE/100 g	3,326
Total-ORAC	μmol TE/100 g	131,420
TP	mg GAE/100 g	4,533

Source: USDA National Nutrient Database for Standard Reference, Release 24 (2011)

Active Constituents

Cinnamon bark contains essential oil (up to 2%), with cinnamaldehyde (60–80%) as the major constituent. Other minor constituents are trans-cinnamic acid, *o*-methoxycinnamaldehyde, eugenol, and monoterpenoids. The bark also contains procyanidins, diterpenes, phenylpropanoids, mucilage, and polysaccharides. The leaf oil has eugenol (70–90%) as the major constituent. The methanol extract had tannins, flavonoids, glycosides, terpenoids, coumarins, and anthraquinones (Shihabudeen et al. 2011). The nutritional constituents and ORAC values of ground cinnamon are given in Table 19.1.

Preparation and Consumption

Used extensively as a flavor ingredient in alcoholic and nonalcoholic beverages, frozen dairy desserts, baked goods, candies, milk and rice puddings, meat and meat products, poultry, fish, soups, gravy, condiments, and relishes. It is used in curries and pilaus and in garam masala. In Mexico it is drunk with coffee and chocolate and the Indians use it in their curries. The Greeks use a stick of cinnamon in their beef stews.

European and Mediterranean regions use the ground form of cinnamon. The Latin Americans and Asians use both whole and ground forms. The Chinese use the ground form in a five-spice blend for soups and sauces. In India and Sri Lanka, it is the essential spice in the curries, pickles, garam masala, teas, and biryanis.

Medicinal Uses and Functional Properties

It is a traditional remedy for dyspeptic conditions like flatulence, gastrointestinal spasms, loss of appetite, and diarrhea. It is also used to improve the flavor of other nonmedicinal products. In folk medicine it is used to treat colds, nausea, inflammation, rheumatism, vomiting, and menstrual disorders. It has carminative and astringent properties.

The available in vitro and animal in vivo evidence suggests that cinnamon has anti-inflammatory, antimicrobial, antibacterial, antioxidant, antitumor, cardiovascular, cholesterol-lowering, and immunomodulatory effects (Meades et al. 2010; Du et al. 2009; Nuryastuti et al. 2009; Guerra et al. 2011; Jayaprakasha and Rao 2011; Lee et al. 2011; Mandal et al. 2011; Wang et al. 2011). In vitro studies have demonstrated that cinnamon may act as an insulin mimetic to potentiate insulin activity or to stimulate cellular glucose metabolism. Furthermore, animal studies have demonstrated strong hypoglycemic properties (Gruenwald et al. 2010; Unlu et al. 2010; Zu et al. 2010). Cinnamaldehyde (CA), one of the active components of cinnamon, has been known to exert several pharmacological effects such as anti-inflammatory, antioxidant, antitumor, and antidiabetic activities (Anand et al. 2010). Cinnamaldehyde was shown to inhibit COX-2 (Huss et al. 2002). Polyphenolic polymers from cinnamon function as antioxidants and control glucose intolerance and diabetes (Anderson et al. 2004). The methanol extract of cinnamon displayed excellent NO-scavenging ability, and the inhibition of iNOS expression was the primary mechanism of action as regards its NO-suppressing activity (Tsai et al. 2007). The leaf and bark volatile oils of cinnamon were found to be highly effective against all tested fungi except *Aspergillus ochraceus* (Singh et al. 2007). Cinnamaldehyde from cinnamon displayed significant antiproliferative effects on human colon cancer cells in concentration and kinetic-dependent manners (Duessel et al. 2008). A cinnamon polyphenol extract (CPE) was found to reduce OGD-induced cell swelling as well as cause a decline in DeltaPsi(m) in cultures, and this protective effect could be attributed to the inhibition of mPT (Panickar et al. 2009). Peterson et al. (2009) reported that compounds endogenous to cinnamon may be beneficial to Alzheimer's disease themselves. Cinnamon bark is effective in the alleviation of diabetes because of its antioxidant and insulin-potentiating activities, and other activities, and this is attributed to the water-soluble polyphenolic oligomers (Jia et al. 2009; Shen et al. 2010). In their study on cinnamon cassia they found that antitumor effect of cinnamon extracts is directly linked with enhanced pro-apoptotic activity and inhibition of NF-kappaB and AP1 activities and their target genes in vitro and in vivo mouse melanoma model (Kwon et al. 2010). Cinnamon

extract could be a good source of natural antimicrobial substances for the treatment of cases of *M. cattarhalis* (Rasheed and Thajuddin 2011). The essential oil of cinnamon showed promising larvicidal and repellant agent against *C. tritaeniorhynchus* and *A. subpictus* (Govindarajan 2011). In another study the essential oil showed anticandidal activity against *C. orthopsilosis* and *C. parapsilosis* in both suspension and biofilm cultures (Pires et al. 2011) and antibacterial activity against *P. aeruginosa* (Bouhdid et al. 2010). The essential oil was also shown to have good antifungal activity (Cvek et al. 2010; Kouassi et al. 2010). The essential oil containing almost 98% cinnamaldehyde was found to protect against alloxan-induced renal damage in a dose-dependent manner (Mishra et al. 2010). Cinnamon extract was shown to induce apoptosis in the cervical cancer cells through increase in intracellular calcium signaling as well as loss of mitochondrial membrane potential and thus cinnamon could be used as a potent chemopreventive drug in cervical cancer (Koppikar et al. 2010). Cinnamon was identified a natural VEGF inhibitor and could thus be useful in cancer prevention and/or treatment (Lu et al. 2010). Metabolic syndrome is associated with insulin resistance, elevated glucose and lipids, inflammation, decreased antioxidant activity, increased weight gain, and increased glycation of proteins. Cinnamon was shown to improve all of these variables in in vitro, animal, and/or human studies. In addition, cinnamon has been shown to alleviate factors associated with Alzheimer's disease by blocking and reversing tau formation in vitro and in ischemic stroke by blocking cell swelling. In vitro studies also show that components of cinnamon control angiogenesis associated with the proliferation of cancer cells. Daily cinnamon and usual care were found to lower HbA1C in patients with type 2 diabetes (Crawford 2009). Human studies involving control subjects and subjects with metabolic syndrome, type 2 diabetes mellitus, and polycystic ovary syndrome all showed beneficial effects of whole cinnamon and/or aqueous extracts of cinnamon on glucose, insulin, insulin sensitivity, lipids, antioxidant status, blood pressure, lean body mass, and gastric emptying (Qin et al. 2010a). CE was shown also to effectively ameliorate circulating levels of adipokines partially mediated via regulation of the expression of multiple genes involved in insulin sensitivity and lipogenesis in the epididymal adipose tissue (Qin et al. 2010b). Cinnamon oil had a regulative role in blood glucose level and lipids, and improved the function of pancreatic islets and thus may be useful in the treatment of type 2 diabetes mellitus (Ping et al. 2010). Cinnamon exhibits effects against obesity and insulin resistance (Aggarwal 2010). The methanol cinnamon bark extract effectively inhibited the α-glucosidase leading to suppression of postprandial hyperglycemia in STZ-induced diabetic rats loaded with maltose and sucrose (Shihabudeen et al. 2011). Adisakwattana et al. (2011) also showed that cinnamon bark extracts were useful for the control of postprandial glucose in diabetic patients by inhibiting intestinal α-glucosidase and pancreatic α-amylase. Cinnamon extract and/or cinnamon was shown to improve fasting blood glucose in people with type 2 diabetes or prediabetes (Davis and Yokoyama 2011). The A- and B-type procyanidin oligomers in different Cinnamon species had hypoglycemic activities and may improve insulin sensitivity in type 2 DM (Lu et al. 2011). Cinnamon extract was found to significantly increase insulin sensitivity, reduce

serum, and hepatic lipids, and improve hyperglycemia and hyperlipidemia possibly by regulating the PPAR-medicated glucose and lipid metabolism (Kim and Choung 2010). Trans-cinnamaldehyde (TC) exerted antimicrobial effects by several mechanisms, including disruption of carbohydrate, amino acid, and lipid metabolism. Additionally, TC compromised the motility, attachment, and invasion ability and cellular defenses of *C. sakazakii* against oxidative stress, thereby reducing its virulence (Amalaradjou and Venkitanarayanan 2011a–c; Amalaradjou et al. 2010). Treatment with cinnamon extract inhibited maturation of MHCII(+) APCs or CD11c(+) dendritic cells (DCs) by suppressing expression of co-stimulatory molecules (B7.1, B7.2, ICOS-L), MHCII and cyclooxygenase (COX)-2. Cinnamon extract induced regulatory DCs (rDCs) that produce low levels of proinflammatory cytokines [interleukin (IL)-1β, IL-6, IL-12, interferon (IFN)-γ, and tumor necrosis factor (TNF)-α] while expressing high levels of immunoregulatory cytokines (IL-10 and transforming growth factor-β). In addition, rDCs generated by cinnamon extract inhibited APC-dependent T-cell proliferation and converted CD4(+) T cells into IL-10(high) CD4(+) T cells. Furthermore, oral administration of cinnamon extract inhibited development and progression of intestinal colitis by inhibiting expression of COX-2 and proinflammatory cytokines (IL-1β, IFN-γ, and TNF-α), while enhancing IL-10 levels. These results suggest the potential of cinnamon extract as an anti-inflammatory agent by targeting the generation of regulatory APCs and IL-10(+) regulatory T cells (Kwon et al. 2011). Studies by Huang et al. (2011a) suggest that CA exerts antiadipogenic effects through modulation of the PPAR-γ and AMPK signaling pathways. The polyphenol extract was shown to rapidly induce TTP mRNA and reduce VEGF mRNA and also affect a number of other genes in the cultured adipocytes (Cao and Anderson 2011; Cao et al. 2010). Cinnamon extract was shown to inhibit the toxic oligomeric Aβ species formation in Alzheimer's disease (Frydman-Marom et al. 2011). Cinnamon extract and essential oil have been shown to be good natural food preservatives (Irkin et al. 2011; Shan et al. 2011). The cinnamon-coated gold nanoparticles could serve as excellent CT/photoacoustic contrast-enhancement agents and could provide a novel approach towards tumor detection through nanopharmaceuticals (Chanda et al. 2011). The extract of *Capsicum annuum* (red pepper) (fruit) *Zingiber officinale* (ginger) (root), *Cuminum cyminum* (cumin), *Alpinia ficinarum* (galingale), *Coriandrum sativum* (coriander), *Cinnamomum zeylanicum* Nees (cinnamomum), *Origanum onites* L. (thyme), *Folium sennae* (senna), *Eugenia caryophyllata* (cloves), *Flos tiliae* (lime), *Folium menthae crispae* (peppermint), and *Piper nigrum* (blackpepper) were shown to have antibacterial activity (Keskin and Toroglu 2011). Myristicin, an active aromatic compound found in nutmeg (the seed of *Myristica fragrans*), carrot, basil, cinnamon, and parsley, was found to have anti-inflammatory properties related with its inhibition of NO, cytokines, chemokines, and growth factors in dsRNA-stimulated macrophages via the calcium pathway (Lee and Park 2011). *C. zeylanicum* bark powder methanol extract equivalent to 0.75 g kg^{-1} bark powder and simvastatin (0.6 mg kg^{-1} b. wt.) were found to be equieffective in treating hyperlipidemia (Javed et al. 2012).

Antioxidant Properties

Cinnamon has been shown to have strong antioxidant activity (Mancini-Filho et al. 1998; Dhuley 1999; Shobana and Naidu 2000; Okawa et al. 2001; Lee and Shibamoto 2002; Dragland et al. 2003; Blomhoff 2004; Singh et al. 2004, 2007; Shan et al. 2005; Prakash et al. 2007; Suganthi et al. 2007; Ho et al. 2008; Buyukbalci and El 2008; Chohan et al. 2008; Peng et al. 2008; Wang et al. 2008; Hasani-Ranjbar et al. 2009; Dudonné et al. 2009; Moselhy and Ali 2009; Wei and Shibamoto 2010; Kannappan et al. 2011; Boga et al. 2011; Huang et al. 2011b; Jayaprakasha and Rao 2011; Junli Lv et al. 2012). Cinnamon increased the antioxidant enzyme activities and restored the GSH content in rats fed a fat diet with cinnamon (Dhuley 1999). The essential oils were reported to show strong antioxidant activity using in vitro models (Jayaprakasha et al. 2003). Lee et al. (2003) found cinnamate, a phenolic compound in cinnamon bark, to significantly lower hepatic cholesterol and triglyceride levels in rats fed high cholesterol diet. The dietary cinnamate inhibited hepatic HMG-CoA reductase activity, which resulted in lowered hepatic cholesterol content, and suppressed lipid peroxidation via enhancement of hepatic antioxidant enzyme activities. A concentrated water extract of defatted cinnamon fruit powder contained the maximum amount of phenolics and showed highest antioxidant activities (Jayaprakasha et al. 2006). The purified compounds from this extract showed strong antioxidant and radical scavenging activities. Kim et al. (2007) reported cinnamaldehyde to possess anti-inflammatory properties and to play a significant role in the regulation of age-related alterations in signal transduction pathways. They found that age-related NF-kappaB activation upregulated NF-kappaB targeting genes, inflammatory iNOS, and COX-2, and all of these were effectively inhibited by cinnamaldehyde. They also showed that cinnamaldehyde inhibited the activation of NF-kappaB via three signal transduction pathways, NIK/IKK, ERK, and p38 MAPK. These results indicate that its anti-inflammatory action is because of antioxidative effect and the restoration of redox balance. Several phenolic compounds from an aqueous extract of cinnamon bark showed significant inhibitory effects on the formation of advanced glycation end-products (AGE) by effectively scavenging reactive carbonyl species (Peng et al. 2008; Peng et al. 2010). The inhibition of fructose-mediated protein glycation was correlated with total phenolic content, and the total phenolic was highly correlated with ferric reducing antioxidant potential (FRAP) (Dearlove et al. 2008). Acute alcohol ingestion in a mouse model caused a >20-fold increase in hepatic lipid accumulation. However, pretreatment with cinnamon extract significantly reduced this hepatic lipid accumulation, and this was associated with an inhibition of the induction of the myeloid differentiation primary response gene (MyD)88, iNOS, and plasminogen activator inhibitor 1 mRNA expression found in livers of alcohol-treated animals (Kanuri et al. 2009). Inclusion of cinnamon extract in the diet increased FRAP and plasma thiol (SH) groups while decreasing the plasma MDA levels, and this supports the theory that cinnamon in diet could reduce the risk factors associated with diabetes and cardiovascular disease (Roussel et al. 2009). The elevated serum AST and ALT enzymatic activities in rats induced by CCL4 were

significantly restored to near normal by oral administration of either aqueous or ethanolic extract of cinnamon as compared to untreated rats. However, the ethanolic extract was found to have more potent hepatoprotective action against CCL4 by lowering MDA level and elevating antioxidant enzyme activities (SOD and CAT). The possible mechanism may be the radical scavenging activity of the polyphenol compounds (Moselhy and Ali 2009). Amin and Abd El-Twab (2009) in their study on high cholesterol group (HCD) found that cinnamon provided protection against the lipemic-oxidative disorder and acts as hypocholesterolemic, hepatoprotective agent and improves cardiovascular function through modulation of oxidative stress, NO, and Hcy. The essential oil of cinnamon was found to confer significant dose-dependent protection against alloxan-induced renal damage (Mishra et al. 2009). Cinnamaldehyde was found to be a potent activator of the Nrf2-orchestrated antioxidant response in cultured human epithelial colon cells and therefore represent an underappreciated chemopreventive dietary factor targeting colorectal carcinogenesis (Wondrak et al. 2010). Azab et al. (2011) investigated the protective role of cinnamon extract against inflammatory and oxidative injuries in gamma-irradiated rats. The rats were subjected to fractionated doses of gamma radiation and cinnamon extract was daily administrated before starting irradiation and continued after radiation exposure. The administration of cinnamon extract to irradiated rats significantly ameliorated the changes induced in liver antioxidant system; catalase, superoxide dismutase, and glutathione peroxidase activities as well as reduced glutathione concentration. The liver's lipid peroxidation and protein oxidation indices were significantly decreased when compared with their equivalent values in irradiated rats. Furthermore, the changes induced in xanthine oxidoreductase system were significantly diminished. In addition, the changes in liver nitric oxide contents, serum TNF-α, and C-reactive protein levels were markedly improved. They concluded that the administration of cinnamon extract might provide substantial protection against radiation-induced oxidative and inflammatory damages. Hydrophilic ingredients of cinnamon showed potent activities to suppress the incidence of atherosclerosis and diabetes via strong antioxidant potential, prevention of apoA-I glycation and LDL-phagocytosis, inhibition of CETP, and hypolipidemic activity (Jin and Cho 2011). The phenolic compounds in the essential oils of cinnamon bark yielded a positive correlation with the DFRS, TPC, TEAC, and FTC assays (Huang et al. 2011b).

Regulatory Status

GRAS 182.10 and GRAS 182.20.

Standard

ISO 6539, ISO 6538.

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Chapter 20
Clove

Botanical Name:	*Syzygium aromaticum* (L.) Merr. and L. M. Perry.
Synonyms:	*Caryophyllus aromaticus* L.; *Eugenia aromatica* (L.) Baill.; *Eugenia caryophyllata* Thunb.
Family:	Myrtaceae.
Common Names:	**French**: giroflier; **German**: Gewurznelkenbaum; **Italian**: chiodi di garofano; **Spanish**: clavero; **Hindi**: laong, lavang.

Introduction

History

In the Moluccas, where cloves were first found, parents planted a clove tree when a child was born. It is first recorded in the Chinese Han period (220–206 BC). The name clove is derived from the French word *clou* and Spanish *clavo*, both meaning "nail," because of its resemblance to the shape of a nail. Burkill (1966) suggests that the habit of chewing cloves was general and that the Chinese imported both. This custom began early in the days of Han dynasty in China and was carried on for centuries. It is recorded in the Ramayana and Susruta of the second century AD. The Sanskrit *kalikaphala* is probably the origin of the Arabic *karanful*, the postulated origin of the Greek *caryophyllon*. Clove trees were probably introduced to India as seedlings from Mauritius, toward the end of the nineteenth century. Clove is discussed in the Ain-i-Akbari, written at the end of the sixteenth century in Agra. Cloves reached Alexandria, Egypt, in the first century. Emperor Constantine presented 70 kg of cloves to St. Silvestor, Bishop of Rome (314–335 AD). The Alexandrian, Cosmas Indicopleustes, describes clove in his Topographia Christiana (548 AD). Chilperic II, King of the Franks, sent cloves to the monastery of Corbie in Normandy, in 716 AD. Venice was the leading European source of cloves in the thirteenth century. Around sixteenth century, the Portuguese broke the Arab

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monopoly of seaborne spice trade. Cloves became known in Europe after the publication of Marco Polo's journeys in 1298 AD and brought Vasco da Gama to India in 1498. The Dutch broke the Portuguese monopoly around 1600 AD. Clove was introduced to Mauritius and Malaysia in 1776 and 1786. In the eighteenth century, clove was introduced into Zanzibar. In the early seventeenth century, the Dutch directed removal of clove trees from all islands except Amboina and Ternate, in order to raise the price. Portuguese women used to distill a liquor from green cloves for its effectiveness in consoling the heart and its sweet fragrant aroma.

Producing Regions

Clove is indigenous to southeast Asia (Moluccas—now part of Indonesia). It is now cultivated worldwide, especially Indonesia, Zanzibar, Madagascar, Philippines, India, Sri Lanka, Tanzania, and Brazil.

Botanical Description

An evergreen tropical tree that grows up to 15-m (50 ft) high. The tree can live up to 100 years. It has large glossy green leaves which are opposite, oblong ovate in shape. The inflorescent is a terminal, with flowers borne in clusters. They have small white fragrant flowers. The buds appear as rosy-pink corolla; as corolla fades the calyx turns red. Clove clusters are picked when buds are full-sized, and the calyx base has developed the characteristic pink flush, but no buds have opened or petals fallen to expose the stamens.

Parts Used

Cloves (whole or ground), clove bud essential oil, clove leaf essential oil, clove stem essential oil, and oleoresin.

Flavor and Aroma

Cloves have a warm, spicy, peppery, sweet, pungent, aromatic, and musty aroma. The flavor is very sweetly pungent, fruity, strongly aromatic, and astringent and leaves a numbing sensation in the mouth.

Table 20.1 Nutrient composition and ORAC values of cloves ground

Nutrient	Units	Value per 100 g
Water	g	9.87
Energy	kcal	274
Protein	g	5.97
Total lipid (fat)	g	13.00
Carbohydrate, by difference	g	65.53
Fiber, total dietary	g	33.9
Sugars, total	g	2.38
Calcium, Ca	mg	632
Vitamin C, total ascorbic acid	mg	0.2
Vitamin B-6	mg	0.391
Vitamin B-12	mcg	0.00
Vitamin A, RAE	mcg_RAE	8
Vitamin A, IU	IU	160
Vitamin D	IU	0
Vitamin E (alpha-tocopherol)	mg	8.82
Fatty acids, total saturated	g	3.952
Fatty acids, total monounsaturated	g	1.393
Fatty acids, total polyunsaturated	g	7.207
H-ORAC	μmol TE/100 g	111,490
L-ORAC	μmol TE/100 g	178,793
Total-ORAC	μmol TE/100 g	290,283
TP	mg GAE/100 g	16,550

Source: USDA National Nutrient Database for Standard Reference, Release 24 (2011)

Active Constituents

Clove buds contain essential oil (15–20%), protein 6%, lipids 20%, carbohydrates 61%, vitamins. The major constituents of the oil are eugenol (up to 85%), eugenyl acetate (up to 15%), and β-caryophyllene (up to 8%). Cloves also contain flavonoids, galloyltannins, phenolic acids, and triterpenes. The leaf and stem oil have more eugenol and very little or no eugenyl acetate. The nutritional constituents and ORAC values of cloves are given in Table 20.1.

Preparation and Consumption

Clove goes well with sweet, fruity, caramelized, and meaty notes. Clove bud and oil are used extensively in flavoring many food products like alcoholic and nonalcoholic beverages, frozen dairy desserts, baked goods, candies, puddings, meat products, gravies, and condiments. The use of clove (whole or ground) is mainly for domestic culinary purposes and as a flavoring agent in the food industry.

Whole cloves are used to stud hams, pork, and lamb. It is used in a number of spice mixtures including curry powders, mulling spices, pickling spices, and ras el hanout. They also are included in the flavor of Worcestershire sauce. Rice is flavored or aromatized with a few clove buds (biryani). Indians and Sri Lankans use cloves in garam masala, biryanis, meat dishes, and pickles. In England, it is added to apple tarts, pickles, and mincemeat.

Medicinal Uses and Functional Properties

Cloves and clove oil are used as a first aid remedy for toothache and mucosal inflammations of the mouth and throat. It is used internally as carminative and antiemetic, and externally against rheumatism and myalgia. In Indonesia, it is used in cigarettes. Jambolan bark is used against diarrhea and topically against inflammation of the mouth, throat, and skin.

Clove has known antifungal, antiseptic, anesthetic, antispasmodic, and carminative activity. It has been reported to aid digestion, stomach disorders, and pain relief (Rosengarten 1969). The hydro-alcoholic extract of clove was shown to have antistress activity (Singh et al. 2009). Solvent extracts of clove were shown to have strong antimicrobial activity (Keskin and Toroglu 2011). Eugenol, the major constituent of clove oil, possesses significant antioxidant, anti-inflammatory, antigiardial, and cardiovascular properties, in addition to analgesic and local anesthetic activity (Pramod et al. 2010; Machado et al. 2011). The essential oil is a potent bactericide, fungicide, and nematicide. In addition to its antimicrobial, acaricidal, antifungal, antiviral, antiulcer, and antioxidant activity, clove essential oil has been shown to possess anti-inflammatory, cytotoxic, insect repellant, and anesthetic properties (Chaieb et al. 2007a, b; Wang et al. 2008, 2011; Antonio et al. 2009; Barbosa et al. 2009; Du et al. 2009; Rodrigues et al. 2009; Warnke et al. 2009; Pasay et al. 2010; Choi et al. 2010; Devi et al. 2010; George et al. 2010; Kouassi et al. 2010; Ponce et al. 2011; Kim et al. 2011a–c; Moon et al. 2011; Kannappan et al. 2011; Pohlit et al. 2011; Sanchez-Vazquez et al. 2011; Park et al. 2011; Kim and Sharma 2011; Irkin et al. 2011; Santin et al. 2011; Uju and Obioma 2011). Clove along with allspice and cinnamon was found to strongly inhibit fructose-mediated protein glycation (Dearlove et al. 2008). Clove oil and eugenol (major constituent of clove oil) have considerable antifungal activity against clinically relevant fungi, including fluconazole-resistant strains (Pinto et al. 2009). Clove oil was shown to modulate immune response by augmenting humoral immunity and decreasing cell-mediated immunity (Halder et al. 2011b). Extracts of clove rich in eugenol and eugenol derivatives were found to have bone-preserving efficacy against hypogonadal osteoporosis (Karmakar et al. 2012). Aqueous extract of clove at 4% was shown to cause large reduction of acrylamide in cookies (Zhu et al. 2011). Clove extract had strong antimicrobial activity against *S. typhimurium*, *E. coli*, and *L. monocytogenes* (Kim et al. 2011b).

Clove oil showed melanin inhibition in B16 melanoma cells (Arung et al. 2011). Eugenol was shown to exert its anticancer activities via apoptosis induction and anti-inflammatory properties and also that synergism between eugenol and gemcitabine could enhance the therapeutic index of prevention and/or treatment of cervical cancer (Hussain et al. 2011).

Antioxidant Properties

Clove has been reported to have strong antioxidant properties (Ivanov and Davcheva 1992; Shahidi et al. 1995; Oya et al. 1997; Beddows et al. 2000; Feng et al. 2000; Lee and Shibamoto 2001; Dragland et al. 2003; Kim and Kim 2003; Blomhoff 2004; Cai et al. 2004; Abdel-Wahhab and Aly 2005; Shan et al. 2005, 2011; Jirovetz et al. 2006; Tapsell et al. 2006; Suganthi et al. 2007; Wei and Shibamoto 2007, 2010; Pezo et al. 2008; Büyükbalci and El 2008; Kong et al. 2010; Kim et al. 2011a; Petrovic et al. 2011). The scavenging activity against DPPH radical of the essential oil of clove was better than eugenol, BHT, and BHA. The inhibition of lipid peroxidation by clove leaf oil as determined using a linoleic acid emulsion system indicated a higher antioxidant activity than the standard BHT (Jirovetz et al. 2006). Cloves were found to have the highest antioxidant activity among the spices tested, and this was probably due to the higher polyphenol content as compared to other spices. The spices had significant ability to inhibit LPO due to their polyphenol content, strong reducing power, and superoxide radical scavenging activity (Yadav and Bhatnagar 2007b). Clove bud essential oil had the strongest antioxidant activity among the oils tested which included lemon, grapefruit, and coriander (Misharina and Samusenko 2008). Cloves showed the highest DPPH radical scavenging activity and highest FRAP values, better than licorice, mace, and cardamom (Yadav and Bhatnagar 2007a). The free radical scavenging ability and total phenolic content of clove bud and cinnamon leaf oils were found to be the best among the 45 essential oils tested (Wang et al. 2008). Clove aqueous extract showed strong antioxidant properties and high phenolic content with a significant relationship between total phenolic content and antioxidant capacity (Dudonné et al. 2009). Clove had the highest total phenolic content and the DPPH scavenging activity among the spices tested (Kim et al. 2011a). Eugenol, a major phenolic component from clove oil, had very strong antioxidant activity and radical scavenging activity (Gulcin 2011). Hydrophilic ingredients of clove showed potent activities to suppress the incidence of atherosclerosis and diabetes via strong antioxidant potential, prevention of apoA-I glycation and LDL-phagocytosis, inhibition of CETP, and hypolipidemic activity (Jin and Cho 2011). Clove oil was shown to reverse the short-term and long-term memory deficits induced by scopolamine (0.3 mg kg^{-1}, i. p.) and this effect can, to some extent, be attributed to decreased oxidative stress (Halder et al. 2011a). Eugenol, the major constituent of clove oil and allspice berry oil, showed the most potent antioxidative activity (Yoshimura et al. 2011).

Regulatory Status

GRAS 184.1257.

Standard

ISO 2254.

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Chapter 21
Coriander

Botanical Name:	*Coriandrum sativum* L.
Synonyms:	*Coriandrum majus* Gouan; Chinese parsley, Culantro, coriander (fruit), cilantro (leaf).
Family:	Apiaceae (Umbelliferae).
Common Names:	**French**: schwindelkraut, coriandre; **German**: koriander; **Italian**: coriandolo; **Spanish**: cilantro; **Russian**: koriandr; **Hindi**: dhania.

Introduction

History

A Babylonian recipe on a clay tablet lists coriander, cumin, and five other spices as ingredients in stew. The name is derived from the Greek *koris*, meaning bedbug, due to the perception of a "buggy" odor from unripe seeds. It is mentioned for culinary and medicinal uses in the Medical Papyrus of Thebes (Ebers Papyrus) in 1500 BC. Seeds have been found in Pharaohic tombs. It was placed in Egyptian tombs during the 21st Dynasty, between 1091 and 961 BC. It was grown in Persia 3,000 years ago and used to fragrance the hanging gardens of Babylon. It is one of the bitter herbs used in the Jewish Passover ritual, and referred to in the Bible, where manna is described as being "like a Coriander Seed, white" (Exodus 16: 31). The 11th chapter of Numbers, verse 7, in the *Old Testament of the Bible*, when the Israelites moved through the wilderness from Sinai to Paran, the manna is referred as: "and the manna was as coriander seed, and the color thereof as the color of '*bdellium*'." Hippocrates (400 BC) records its use as a drug, Pliny (77 AD) in his *Historia Naturalis*, and Marcus Cato (234–149 BC) in *De Re Rustica*. In Europe it was used not only in kitchens, but also as herbal remedy. Charlemagne (812 AD) ordered coriander and other herbs to be grown on Imperial farms. In 1611, Carmelite monks in Paris used

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it in *Eau de Carmes*, as toilet water or cordial. William Turner states, "Coriandre layd to with breade or barley mele is good for Saynt Antonyes fyre" (A New Herball, 1551). The Herbalist states: "the seeds are good to do away with the fevers that come from the third day and when drunken with honey will slay worms." Coriander is a popular flavoring and crop in India, and is mentioned in Sanskrit literature as *kustumburu*. According to Sanskrit writings, coriander was known as early as 5000 BC. The first Chinese records of coriander are from the Han Dynasty (207 BC). The Chinese have cultivated coriander since the fourth century and believed that anyone who ate seeds of coriander during a spiritual trance would achieve immortality. In the Middle Ages, the seeds were used to flavor meat, soups, wine, and preserves. Coriander was probably introduced into Britain by the Romans, but there is no mention in Gerard's or other herbal books. In Victorian England, it was widely used as an aphrodisiac. It was introduced to North America by the first colonists, apparently into Massachusetts in the mid-seventeenth century. Coriander later spread to South America. The leaves and stems are called cilantro, while the seeds are called coriander.

Producing Regions

Coriander is native to western Asia, eastern Mediterranean region, and Europe. It is now cultivated worldwide. It has been cultivated as a spice in other parts of the world for centuries. In addition to India, it is also cultivated in Romania, France, Spain, Italy, Pakistan, Morocco, Turkey, Mexico, Argentina, and also in the UK and USA. Morocco, Romania, Egypt, Holland, and Mexico are the principal commercial sources for American imports of coriander.

Botanical Description

A strongly aromatic, erect, herbaceous annual herb about 1.5-m (5 ft.) high with hollow stem. It has shiny, bright green leaves, umbels of small white or pale-pink flowers. The globular coriander fruits (seeds) are uniform light-brown, round consisting of two pericarps with a warm pleasant odor.

Parts Used

Ripe, dry fruits (seeds) (ground or whole), essential oil, herb, oleoresin. The leaves are used fresh (whole or chopped) and dried (whole and crushed). The stem and roots are used fresh or dried.

Table 21.1 Nutrient composition of coriander leaf dried

Nutrient	Units	Value per 100 g
Water	g	7.30
Energy	kcal	279
Protein	g	21.93
Total lipid (fat)	g	4.78
Carbohydrate, by difference	g	52.10
Fiber, total dietary	g	10.4
Sugars, total	g	7.27
Calcium, Ca	mg	1,246
Vitamin C, total ascorbic acid	mg	566.7
Vitamin B-6	mg	0.610
Vitamin B-12	mcg	0.00
Vitamin A, RAE	mcg_RAE	293
Vitamin A, IU	IU	5,850
Vitamin D	IU	0
Vitamin E (alpha-tocopherol)	mg	1.03
Fatty acids, total saturated	g	0.115
Fatty acids, total monounsaturated	g	2.232
Fatty acids, total polyunsaturated	g	0.328

Source: USDA National Nutrient Database for Standard Reference, Release 24 (2011)

Flavor and Aroma

Seeds are aromatic and sweet, spicy (coriander). The leaves have a very characteristic and distinctive aroma (cilantro). The seeds are mild, warm and sweet, spicy, fruity, with a slightly citrusy and minty undertone. The oil flavor is warm, spicy-aromatic, sweet, and fruity.

Active Constituents

Ripe, dried fruit contains moisture 11%, fiber 23–36%, carbohydrates 13–20%, fatty oil 16–28%, proteins 11–17%, minerals 5%, and essential oil 1–3%. The major constituent of the oil is D-linalool (55–90%), neryl acetate, γ-terpinene, camphor, α-pinene, and geranyl acetate (Nejad et al. 2010). The major compounds in the seeds and plants are tocopherols, carotenoids and chlorophylls and sugars, ascorbic acid, phenolics, flavonols, and anthocyanins (Dias et al. 2011). The nutritional constituents of dried coriander leaf are given in Table 21.1. The nutritional constituents of coriander seed are given in Table 21.2. The nutritional constituents and ORAC values of raw coriander leaves (cilantro) are given in Table 21.3.

Table 21.2 Nutrient composition of coriander seed

Nutrient	Units	Value per 100 g
Water	g	8.86
Energy	kcal	298
Protein	g	12.37
Total lipid (fat)	g	17.77
Carbohydrate, by difference	g	54.99
Fiber, total dietary	g	41.9
Calcium, Ca	mg	709
Vitamin C, total ascorbic acid	mg	21.0
Vitamin B-6	mg	0
Vitamin B-12	mcg	0.00
Vitamin A, RAE	mcg_RAE	0
Vitamin A, IU	IU	0
Vitamin D	IU	0
Fatty acids, total saturated	g	0.990
Fatty acids, total monounsaturated	g	13.580
Fatty acids, total polyunsaturated	g	1.750

Source: USDA National Nutrient Database for Standard Reference, Release 24 (2011)

Table 21.3 Nutrient composition and ORAC values of coriander (cilantro) leaves raw

Nutrient	Units	Value per 100 g
Water	g	92.21
Energy	kcal	23
Energy	kJ	95
Protein	g	2.13
Total lipid (fat)	g	0.52
Ash	g	1.47
Carbohydrate, by difference	g	3.67
Fiber, total dietary	g	2.8
Sugars, total	g	0.87
Calcium, Ca	mg	67
Vitamin C, total ascorbic acid	mg	27.0
Vitamin B-6	mg	0.149
Vitamin B-12	mcg	0.00
Vitamin A, RAE	mcg_RAE	337
Vitamin A, IU	IU	6,748
Vitamin D	IU	0
Vitamin E (alpha-tocopherol)	mg	2.50
H-ORAC	μmol TE/100 g	5,141
Total-ORAC	μmol TE/100 g	5,141
TP	mg GAE/100 g	151

Source: USDA National Nutrient Database for Standard Reference, Release 23 (2010)

Preparation and Consumption

The dried seeds or fruits are extensively used in the preparation of curry powder, pickling spices, sausage, and seasonings. The Romans were the first Europeans to introduce coriander as a cooking spice. The entire plant is used in making chutneys, and the leaves for flavoring curries, sauces, stews, and soups. Seeds blend well with smoked meats and game and feature in the English black pudding recipes and Italian mortadella sausage. Ground coriander can be used to flavor confections, pastries, chili dishes, cream, apple desserts, stews, and beans. Coriander with cumin is common in falafel and Egyptian appetizer dukka. Seeds and oil are used primarily in baked goods, desserts, candy, beverages, meat, poultry and fish products, condiments, and relishes. The fresh leaves feature in Middle Eastern, Indian, Oriental, Spanish, and South American dishes. In the United States, the ground seeds and oil are used in hot dogs, chilis, sausages, frankfurters, stews, cookies, and desserts. Cilantro is commonly used by Mexicans, Puerto Ricans, and Central and South Americans as a garnish in salsa, fillings, ceviches, taco toppings, and soups. Coriander oil and oleoresin are primarily used in seasonings for sausage and other meat products.

Medicinal Uses and Functional Properties

Fruits have carminative, stomachic, spasmolytic, and antimicrobial properties. It is used to treat loss of appetite and dyspeptic complaints and as a laxative to ease griping. In Chinese medicine, it is also used in dysentery, measles, hemorrhoids, toothache, and vomiting.

Coriander oil was found to have good antibacterial activity against *S. pyogenes* and *S. aureus* (MRSA) and excellent skin tolerance, and hence could be useful as an antiseptic for the prevention and treatment of skin infections with Gram-positive bacteria (Casetti et al. 2011). Coriander essential oil was shown to have strong antifungal activity on *Candida* spp. and could be useful for candidiasis treatment (Silva et al. 2011a). The coriander essential oil was also shown to have excellent antibacterial activity, nematicidal activity, and antimicrobial activity (Michalczyk et al. 2012; Toroglu 2011; Silva et al. 2011b; Duman et al. 2010; Lixandru et al. 2010; Rattanachaikunsopon and Phumkhachorn 2010; Kim et al. 2008). It has also been reported to be promising for the treatment of intestinal dysbiosis (Hawrelak et al. 2009). The administration of coriander extract in OHH *Meriones shawi* rats normalized glycemia and decreased the elevated levels of insulin, insulin resistance, total cholesterol, LDL-cholesterol, and triglycerides and thus could have cardiovascular protective effect (Aissaoui et al. 2011). The essential oil and extract of coriander were found to have strong antifungal activity (Furletti et al. 2011). Fresh coriander leaves in the diet could be used as a remedy in the management of

Alzheimer's disease because of its different activities like anticholinesterase activity, memory-improving property, and cholesterol-lowering property (Mani et al. 2011). Coriander seeds were also found to have cholesterol-lowering property (Dhanapakiam et al. 2008).

Antioxidant Properties

Coriander has been shown to have strong antioxidant activity and medicinal properties because of its constituents (Dias et al. 2011; Gallo et al. 2010; Samojlik et al. 2010; Sultana et al. 2010; Usta et al. 2009; Sreelatha et al. 2009; Adam et al. 2009; Misharina and Samusenko 2008; Apak et al. 2006; Bajpai et al. 2005; Misharina and Polshkov 2005; Singh et al. 2004; Ramadan et al. 2003; Tarwadi and Agte 2003; Stashenko et al. 2002; Nair et al. 1998; Chithra and Leelamma 1999; Krishnakantha and Lokesh 1993). Coriander is reported to have a very effective antioxidant activity profile showing 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging activity, lipoxygenase inhibition, phospholipid peroxidation inhibition, iron chelating activity, hydroxyl radical scavenging activity, superoxide dismutation, glutathione reduction, and antilipid peroxidation. The ethanolic, methanolic, chloroform, ethyl acetate, and water extracts of coriander were found to have high total phenolic content with constituents like pyrogallol, caffeic acid, glycitin, etc. (Wangensteen et al. 2004; Hashim et al. 2005; Melo et al. 2005; Wong and Kitts 2006). Linalool obtained from coriander was found to decrease cell viability of HepG2 cells, inhibit complexes I and II, and decrease adenosine triphosphate (ATP). It also increased reactive oxygen species generation and decreased glutathione (Usta et al. 2009). An ethanolic extract of coriander showed good antioxidant activity and flavonoid content (Nickavar and Abolhasani 2009). Sreelatha et al. (2009) reported that the extract of coriander protected liver from oxidative stress induced by CCl_4. The aqueous extract of coriander had strong antioxidant activity and was superior to known antioxidant ascorbic acid (Satyanarayana et al. 2004). Wu et al. (2010) demonstrated that the aerial parts of coriander had strong anti-inflammatory property which inhibits proinflammatory mediator expression by suppressing NF-kappaB activation and MAPK signal transduction pathway in LPS-induced macrophages. The administration of coriander significantly protected against lead-induced oxidative stress in mice testis (Sharma et al. 2010). Hot water extract of coriander had high antioxidant activity and this was due to the phenolic and flavonoid compounds (Kim et al. 2011). Dietary intake of coriander seeds was shown to decrease the oxidative burden in diabetes mellitus and it not only showed antihyperglycemic properties but also antioxidative properties. The seeds showed both scavenging activity against superoxides and hydroxyl radicals and inhibited the process of peroxidative damage in diabetic rats. It also reactivated the antioxidant enzymes and antioxidant levels in diabetic rats (Deepa and Anuradha 2011). The ethanolic extract of *C. sativum* was shown to possess hepatoprotective activity which may be due to the antioxidant potential of phenolic compounds (Pandey et al. 2011).

Regulatory Status

GRAS 182.10 and GRAS 182.20.

Standard

ISO 2255 (Specification), ISO 3516 (Oil).

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Chapter 22
Cumin

Scientific Name:	*Cuminum cyminum* L.
Synonyms:	*Cuminum odorum* Salisb., *Ligusticum cuminum* (L.) Crantz., *Selinum cuminum* L. Krause.
Family:	Apiaceae (Umbelliferae).
Common Names:	**French**: cumin; **German**: stachelkummel; **Italian**: cumino; **Spanish**: comino; **Russian**: kmin; **Hindi**: jerra, zira; **Arabic**: kimum akhdar; **Dutch**: Komijn; **Swedish**: Spiskummin; **Turkish**: Kimyon; **Thai**: met yeera; **Hebrew**: Kamun.

Introduction

History

Cumin has been used since ancient times and is another spice of great antiquity. The genus *Cuminum* is derived from the Greek *kuminon*, itself probably derived from the Babylonian *ka-mu-na*. The ancient Mesopotamian civilizations of the Euphrates and Tigris valleys used its fruits for flavoring, and in Pharaohic Egypt cumin was used as a medicine around 1550 BC as the Ebers Papyrus states. The Myceanes used cumin to season food around 2000 BC, while the Egyptians used it to embalm bodies of royalties including King Tut's around 1323 BC. As early as 5000 BC, the Egyptians preserved the bodies of kings by mummifying them with cumin, anise, and marjoram. Later, cinnamon and cassia were used for the kings. The Greeks, in ancient times, associated it with cupidity. The Roman emperor Marcus Aurelius (AD 121–180) was nicknamed "Cumin" because of his avarice. Pliny in AD 77 in his Historia Naturalis mentioned a very interesting use for cumin paste—it can apparently whiten the skin, and scholars used it to make their faces appear pale to convince their tutors they were spending long hours in study. But Theophrastus in the fourth century wrote, "They who grow cumin say it must be cursed and abused

D.J. Charles, *Antioxidant Properties of Spices, Herbs and Other Sources*,
DOI 10.1007/978-1-4614-4310-0_22,

while sowing if the crop is to be fair and abundant." Cumin is mentioned in both the Bible (Isaiah 28: 25–27 and Matthew 23: 23) and the Torah. In Matthew chapter 23 and verse 23, cumin is referred along with other three tithes: "Woe unto you, scribe and Pharisees, hypocrites! for ye pay tithes of mint and anise and cumin and have omitted the weightier matters of the law, judgement, mercy and faith." Cumin spread along the Nile Valley and to Ethiopia. It has also been a popular spice in India since ancient times and also mentioned in the Ayurvedic manuscripts for medicinal purposes as well as for flavoring food. It was introduced to the western world including Britain by the Romans and later to North America by the Spanish. In Europe, cumin was very valuable, and the English and the Romans used cumin to pay taxes. Superstition during the Middle Ages cited that cumin kept chickens and lovers from wandering. It was also believed that a happy life awaited the bride and groom who carried cumin seed throughout the wedding ceremony.

Producing Regions

Cumin is now cultivated all over the world. A well-known native to northern Africa, it traveled through West Asia to Central Asia. The majority of cultivation is done in countries like Morocco, Turkey, Greece, Egypt, Iran, the southern part of the Mashad province. It is also widely cultivated in India—the Himalayas, Punjab, Baluchistan, and Kashmir. Southern Europe and Russia also contribute as producers of cumin. The major suppliers are India, Syria, Pakistan, and Turkey. Major oil producers are India and the USA.

Botanical Description

Cumin is a small, slender, or erect glabrous annual herb up to 0.6 m (2 ft) high, with light brown taproot. The leaves seem to be finely dissected and are alternate, compound of bluish-green hue. The flowers are bisexual with colors like pink and red growing on the inflorescence compound umbel up to 3.5 mm in diameter. The fruit is sometimes brownish or yellow, ovoid-oblong shaped with slightly curved schizocarp. The seeds are approximately 2–3 mm long and 2 mm thick with a light brown and a yellow hue. They have slight ridge-like lines overlapping as many oil channels.

Parts Used

The ripe and dry fruits (seeds) are used ground or whole, essential oil, oleoresin.

Table 22.1 Nutrient composition and ORAC values of cumin seed

Nutrient	Units	Value per 100 g
Water	g	8.06
Energy	kcal	375
Protein	g	17.81
Total lipid (fat)	g	22.27
Carbohydrate, by difference	g	44.24
Fiber, total dietary	g	10.5
Sugars, total	g	2.25
Calcium, Ca	mg	931
Vitamin C, total ascorbic acid	mg	7.7
Vitamin B-6	mg	0.435
Vitamin B-12	mcg	0.00
Vitamin A, RAE	mcg_RAE	64
Vitamin A, IU	IU	1,270
Vitamin E (alpha-tocopherol)	mg	3.33
Vitamin D	IU	0
Fatty acids, total saturated	g	1.535
Fatty acids, total monounsaturated	g	14.040
Fatty acids, total polyunsaturated	g	3.279
H-ORAC	μmol TE/100 g	47,600
L-ORAC	μmol TE/100 g	3,933
Total-ORAC	μmol TE/100 g	50,372
TP	mg GAE/100 g	849

Source: USDA National Nutrient Database for Standard Reference, Release 24 (2011)

Flavor and Aroma

With a strong and distinctive aroma which appears to be warm, spicy, fatty, and medicinal. With a pungent aftertaste, the flavor is often nutty, hay like, spicy if roasted earthy, warm, and lemony to taste.

Active Constituents

The ripe, dried fruit contains moisture 7%, fiber 17%, carbohydrates 29%, fatty oil 4%, proteins 18%, ash 6%, and essential oil 2–5% (oil has cuminic aldehyde 33%, β-pinene 13%. Terpinene 25%, *p*-cymene 8.5%, *p*-mentha-1,3-dien-7-al 5.6%, β-farnesene 1.1%), flavonoid glycosides, tannin, resin, and gum. Cumin leaves, flowers, and roots have phenolics, flavonoids, and tannins (Bettaieb et al. 2010). Cumin contains many minerals like calcium, potassium, vitamin A, sodium, iron, phosphorous, and magnesium. The nutritional constituents and ORAC values of cumin seed are given in Table 22.1.

Preparation and Consumption

It is a major ingredient and flavoring agent in curry and chili powders, spice mixes like the Indian "Panch Phoran," "Garam Masala," Sambar Podi." It is used widely in baked goods, meat like lamb, meat products, condiments and relishes, processed vegetables, soups, gravies, and snack foods. It is a common flavor in confectionery, meat, sausage, and bread manufacturing, and as a preservative in food processing. Ground cumin can be added to lime or lemon-based marinades for chicken, turkey, lamb, and pork. In Mexican cooking, the seeds or oil is combined with chili and added to commercial chili powders and pepper sauces. It is widely used in Iran and India both as a condiment and flavoring in many eastern dishes. Whole cumin is used to make various pickles in Iran, Pakistan, and India.

Medicinal Uses and Functional Properties

Cumin seed and cumin essential oil are used as a stimulant, antispasmodic, carminative, and antimicrobial agent. It is widely used in traditional medicine to treat flatulence, digestive disorders, diarrhea, and also for the treatment of wounds. With its antibacterial and larvicidal activities, cumin seed can be used in the relief for diarrhea and indigestion. In India it is often used to relieve stress and lower blood pressure. Cumin relieves menstrual cramps, stimulates circulation, and even promotes breast milk production. It can be used as a diuretic because of its high content of linoleic acid. It also has immunostimulant action against viruses harming the spleen and liver.

The extracts and essential oil of cumin were shown to have strong larvicidal, acaricidal, antibacterial, and antifungal activities (Singh et al. 2002, 2005; Iacobellis et al. 2005; Jirovetz et al. 2005; Gachkar et al. 2007; De Martino et al. 2009; Youssef and Hammad 2010; Singha and Chandra 2011; Martinez-Velazquez et al. 2011; Mandal et al. 2011; Khosravi et al. 2011; Pajohi et al. 2011; Romagnoli et al. 2010; Wanner et al. 2010). Cumin is considered abortive, galactagogue, antiseptic, and antihypertensive herb, while in Italy, it is used as bitter tonic, carminative, and purgative (Leporatti and Ghedira 2009). Cumin has been shown to have strong antidiabetic and anticarcinogenic activity (Roman-Ramos et al. 1995; Nalini et al. 1998, 2006; Dhandapani et al. 2002; Jagtap and Patil 2010; Johri 2011).

Antioxidant Properties

The cumin extracts and essential oil have shown excellent antioxidative activity in several test methods (Thippeswamy and Naidu 2005; Gachkar et al. 2007; Milan et al. 2008; De Martino et al. 2009; Allaghadri et al. 2010; Bettaieb et al. 2010;

El-Ghorab et al. 2010; Makchuchit et al. 2010; Koppula and Choi 2011; Kim et al. 2011). The antiradical profile of cumin has been proposed as the underlying mechanism for their multifaceted pharmacological properties such as antimicrobial, antidiabetic, anticarcinogenic/antimutagenic, antistress, and antiulcerogenic. Farag and el-Khawas (1998) evaluated the antioxidant property of cumin essential oils extracted from untreated, gamma-irradiated, and microwaved seeds against sunflower oil oxidative rancidity. They showed that the irradiated and microwaved essential oil exhibited a stronger antioxidant activity than the mixture of BHT and BHA (200 ppm). They also reported that the gamma-irradiated seed essential oils were more effective than the microwaved seed oils. Total flavonoid content in cumin was found to range between 50 and 100 mg/100 g (Nair et al. 1998). Beddows et al. (2000) found that cumin extracts (2,000 mg kg^{-1}) delayed rancidity in sunflower oil and preserved alpha-tocopherol. They suggest that the mode of action appeared to be due to free radical activity rather than through singlet oxygen generation. Martinez-Tome et al. (2001) reported that deoxyribose damage was partially inhibited in the presence of cumin extract that exhibits the strongest protective action. They also found that the extracts had significant stabilizing effects on the oxidative stability of refined olive oil tested by the Rancimat method. Aqueous extract of cumin had great antioxidant activity than ascorbic acid in in vitro studies (Satyanarayana et al. 2004). Singh et al. (2004) found high levels of caffeic, chlorogenic, and ferulic acids in cumin. Ho et al. (2008) found that the methanol extract of cumin exerted some level of protective ability against peroxynitrite-mediated biomolecular damage and also the phenolic content correlated well with the cumin protective effect against peroxynitrite-mediated tyrosine nitration and lipid peroxidation. The supercritical carbon dioxide extracted essential oil from cumin had higher antioxidant activity than the steam distilled oils (Topal et al. 2008). Nickavar and Abolhasani (2009) found that the ethanol extracts of cumin had good scavenging activity and flavonoid content. Cumin essential oil showed good antioxidant activity by DPPH method and was found to be best in reducing $Fe^{(3+)}$ ions (El-Ghorab et al. 2010). Methanolic extract of cumin had strongest overall antioxidant activity of the spices tested (Sultana et al. 2010).

Regulatory Status

GRAS 182.10 and GRAS 182.20.

Standard

ISO 6465 (Specification), ISO 9301 (Oil).

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Chapter 23
Curry Leaf

Botanical Name: *Murraya koenigii* Spreng.
Synonyms: *Chaleos koenigii*, *Bergera koenigii*, Indian bay, Indian curry tree.
Family: Rutaceae.
Common Names: **French**: feuille de cari; **German**: Curryblatt; **Italian**: foglia di cari; **Spanish**:zhoja; **Hindi**: karipatta, mitha neem.

Introduction

History

Curry leaf is mentioned in Tamil literature dating back as far as the first to fourth centuries AD, as a flavoring for vegetables. Curry leaves (or leaflets) come from the tropical tree belonging to the rue-citrus family. Its use is also mentioned in the Kannada (neighboring state to Tamil Nadu) language a few centuries later. The word curry originates from the Tamil "*kari,*" meaning "soup" or "sauce." It is also well known as "*karipatta*" in India. It is named "Murraya" after John Adam Murray, Professor of Botany at Gottingen, editor of many of Linnaeus's works. It is widely cultivated as an ornamental for its aromatic leaves and is found in almost every home in South India.

Producing Regions

It is native to India and Sri Lanka. Curry leaves are extensively used in Southern India and Sri Lanka (absolutely essential for the authentic flavor), but are also of some importance in Northern India. Together with South Indian immigrants, curry leaves reached Malaysia, South Africa, and Reunion Island. Curry leaf is grown in India, Bangladesh, and Sri Lanka.

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Botanical Description

It is a small, fast growing, deciduous, aromatic shrub, or tree up to 6 m (20 ft) high, with bright, glossy dark leaves. They are highly aromatic and look like bay leaves. The flowers are white and arranged in small clusters. The ripe fruits are purplish-black and berry-like.

Parts Used

Leaves (usually fresh, but also dried). The fresh leaves are used whole, crushed, or chopped.

Flavor and Aroma

Curry leaves have a strong, warm, spicy, curry aroma. It has a very aromatic, spicy, curry flavor.

Active Constituents

Essential oil (up to 2.5%) (Chowdhury et al. 2008). The major constituents of the essential oil are β-caryophyllene, β-gurjunene, β-elemene, β-phellandrene sabinene, α-pinene, and β-pinene. The other important phytoconstituents are the alkaloids (Nayak et al. 2010). Also present in the leaves are terpenoids, phenolics, minerals, proteins, fat, carbohydrate, fiber, carotene, nicotinic acid, free amino acids, and vitamin C.

Preparation and Consumption

Curry leaves are popular and extensively used in South Indian and Sri Lankan dishes. They are particularly used in South Indian cooking to provide a characteristic flavoring for curries, vegetable, fish and meat dishes, chicken and poultry, soups (rasams), lentils, samosas, pickles, butter milk preparations, chutneys, scrambled eggs, and curry powder blends. A famous way of using curry leaves is as dhal-bhagar. In this mustard seeds are fried in hot ghee; then a little asafoetida with several curry leaves is added for a few seconds before stirring them into the plain dhal dish or dhal-based Indian soups. They are also used in Madras-style curry powders and pastes, and in shellfish dishes.

Medicinal Uses and Functional Properties

Traditionally, curry leaf has been used in ayurvedic and unani medicine (Drury 1978; Dastur 1970; Kirthikar and Basu 1935). It is reported to have tonic, stomachic, and carminative properties and has been used to treat constipation, nausea, stomach problems, indigestion, snakebites, and spots and rashes. The whole plant is considered to be a tonic and stomachic. The roots and bark are stimulant and are applied externally for skin eruptions and poisonous bites.

It is used as a carminative agent for treating piles, influenza, fever, itching, dropsy, bronchial asthma, eruptions, diarrhea, body aches, fresh cuts, kidney pains, and vomiting (Kumar et al. 1999; Rana et al. 2004). It has been reported to possess antifungal, antibacterial, anthelmintic, antineoplastic, antitumor, antihypercholesterolemic, antidiabetic, and antispasmodic activities (Adebajo et al. 2006; Lawal et al. 2008; Shah et al. 2008; Pande et al. 2009; Shivkanya et al. 2009; Bhattacharya et al. 2010; Birari et al. 2010; Chatterji et al. 2010; Gupta et al. 2010; Mandal et al. 2010; Mishra et al. 2010; Ningappaa et al. 2010; Parmar et al. 2010; Shah and Juvekar 2010; Sharma et al. 2010; Darvekar et al. 2011; Khuntia and Panda 2011; Mathur et al. 2011a, b; Patidar 2011; Yankuzo et al. 2011).

Curry leaf essential oil has been shown to have strong antibacterial and antifungal activity against microorganisms (Goutam and Purohit 1974). Crude curry leaf extracts possess antibacterial activity (Thakare 1980). It has been found to have antiamnesic potential. Curry leaves fed to mice showed nootropic effect and this could be attributed to pro-cholinergic activity and a cholesterol lowering property and thus could have potential in the management of Alzheimer patient (Vasudevan and Parle 2009).

Curry leaf has been traditionally used in the treatment of diabetes (Yadav et al. 2002). Curry leaves were found to have a hypoglycemic action on carbohydrate metabolism in rats fed curry leaves (Khan et al. 1995). Glutathione levels in liver, heart, and kidney were lowered in rats administered with curry leaves (Khan et al. 1996a). A single oral dose of aqueous extract of curry leaf led to lowering of blood glucose level in both normal and diabetic rats (Kesari et al. 2005). Kesari et al. (2007) found the aqueous extract of curry leaf to have a favorable effect in bringing down the severity of diabetes in rats. Curry leaf extract was found to decrease both the blood cholesterol level and blood glucose level in diabetic ob/ob mice. Thus, curry leaf could improve the management of high cholesterol level and type 2 diabetes (Xie et al. 2006). Ethanolic extract of curry leaf possesses significant hypoglycemic potential in STZ-induced diabetic rats and appeared to be more effective than glibenclamide, a known antidiabetic drug (Arulselvan et al. 2006). Curry leaves were found to be useful in diabetes associated with ischemic heart disease (Dwivedi and Aggarwal 2009).

Morphological and histological studies in rats administered 1,2-dimethyl hydrazine revealed that the mean number of neoplasms in the colon and intestine was significantly reduced in the group fed with curry leaf (Khan et al. 1996c). Curry leaf in diet with 20% coconut oil fed to male albino rats resulted in a reduction in total

serum cholesterol and low-density lipoproteins and very low-density lipoproteins, an increase in the high-density lipoproteins, lower release of lipoproteins into the circulation, and an increase in the lecithin cholesterol acyl transferase activity (Khan et al. 1996b). A 50% reduction was seen in the micronuclei induced by dimethylhydrazine hydrochloride and a 30% reduction in the activity of γ-glutamyl transpeptidase when rats were fed a curry leaf supplemented diet (Khanum et al. 2000).

Antioxidant Properties

Curry leaf has been reported to have strong antioxidant activity (Tachibana et al. 2003; Singh et al. 2004; Rao et al. 2007; Ningappaa et al. 2008; Gupta and Prakash 2009; Gupta et al. 2010; Gupta and Sharma 2010; Tembhurne and Sakarkar 2010). Curry leaf was reported to exert antioxidant effects in rats fed with high fat diet (Khan et al. 1997). They found lower levels of hydroperoxides, conjugated dienes, and free fatty acids in the liver and hearts of rats supplemented with curry leaves compared to rats fed only on the high fat diet. The activities of the enzymes superoxide dismutase, catalase, and glutathione transferase were increased in both heart and liver of rats supplemented with curry leaves, while the activities of glutathione reductase, glutathione peroxidase, and glucose-6-phosphate dehydrogenase increased in the liver and the concentration of glutathione decreased. Thus, curry leaf can prevent the formation of free radicals and maintain the tissues at normal levels (Khan et al. 1997). Patel and Rajorhia (1979) found 1% curry leaf concentration to be better than butylated hydroxyl toluene (BHT) and butylated hydroxyl anisole (BHA) for extending the shelf life of ghee, due to the presence of naturally occurring antioxidants. Tachibana et al. (2003) studied the antioxidative properties of 12 carbazole alkaloids isolated from curry leaves and suggest that an aryl hydroxyl substituent on the carbazole ring plays a role in stabilizing the thermal oxidation and rate of reaction against DPPH radical. Arulselvan and Subramanian (2007) evaluated the protective effect of curry leaf extract against beta-cell damage and antioxidant defense systems of plasma and pancreas in streptozotocin-induced diabetes in rats. They found the levels of glucose, glycosylated hemoglobin, insulin, TBARS, enzymatic and nonenzymatic antioxidants to be altered in diabetic rats. However, these alterations were reverted back to near control levels after treatment of the curry leaf extract. This suggests a therapeutic protective nature of curry leaf treatment in diabetes by decreasing oxidative stress and pancreatic beta-cell damage (Arulselvan and Subramanian 2007). The antioxidant protein from curry leaves (APC) inhibited lipoxygenase activity by 71% at 0.8 μM; effectively prevented diene, triene, and tetraene lipids formation at 3 μM; and scavenged about 85% hydroxyl and DPPH radicals at 150-fold lesser concentration compared to α-tocopherol (400 μM) and BHA (Ningappa and Srinivas (2008). They also found that APC reduced cytochrome c and ferric ion, chelated ferrous ion, and inhibited ferrous sulfate:ascorbate-induced fragmentation and sugar oxidation to 80–90%. Aqueous extract of curry leaves produced marked increase in the levels of plasma antioxidant capacity in diabetic treated rats (Yankuzo et al. 2011).

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Chapter 24
Dill

Botanical Name:	*Anethum graveolens* L.; *Anethum sowa* Roxb., Indian Dill.
Synonyms:	*Anethum arvense* Salis.; *P. graveolens* (L) Hiern; *Peucedanum sowa* (Roxb. Ex. Flem.) Kurz; *Selinum anethum* Roth., garden dill.
Family:	Apiaceae (Umbelliferae).
Common Names:	**French**: aneth batard; **German**: dill; **Italian**: aneto; **Spanish**: eneldo; **Arabic**: shibith; **Hindi**: surva, sowa.

Introduction

History

The name is probably derived from the Greek *anethon* as used by Aristophanes (448–388 BC), and maybe from *aemi*, meaning "I breathe." *A. graveolens* comes from the Greek *anethum* and the Latin *gravedens* for strong smelling. The common name dill is believed to have originated from the Norse *dylle* meaning "to lull" or *tylle* meaning "to sleep." Dill was probably carried by the Roman armies northward into Europe and was commonly known as dill as early as AD 1000. It is one of the herbs used as a flavoring in dynastic Egypt and the Mesopotamian civilization and by the Greeks and Romans as a flavoring agent and medicine. Dill was well attributed by Archbishop of Canterbury Alfric (tenth century) for its medicinal values. He highly recommended it for flatulence and asked it be "grown by every household for hindering witches and countering their enchantments." In Dratons *Nymphidia* (AD 1627), it says "Herewith her Vervain and her Dill/That hindereth Witches of their Will." According to Joseph Cooper in his Receipt Book (1640), King Charles

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I loved dill cucumbers. Both the Greek physician Dioscorides (AD 60) and Rembert Dodoens (A Niewe Herball, 1578) recommended "A decoction of the toppes and croppes of dill with the seed boiled in water and drunken, causeth women to have plenty of milke." Parkinson in his *Paradisus* of 1629 says, "It is also put among pickled cow-cumbers where it doth very well agree, giving unto the cold fruit a pretty spice taste or rellish." And pickled dill cucumbers remain popular. Dill seeds were referred to as *Meeting House Seeds*, because they were brought to church generations ago, and the congregation would nibble on it during prolonged sermons. In The English Physician of 1652, Culpeper notes, "Dill added to oils or plasters dissolved impostumes of the fundemunt." European dill was introduced into Jammu and Kashmir regions of India in the early 1950s, and later went to Indonesia through Indian traders, and is now commonly grown in Java, and is known as *adas sowa*. Dill was introduced to the USA at the beginning of the seventeenth century and was listed by John Winthrop (1605–1676) as grown by early European settlers. It is now cultivated commercially in the North Central and Pacific Northwest States, and California. It is now naturalized in the Caribbean region and South America.

Producing Regions

Dill is probably native to the Mediterranean and West Asia. It is now grown worldwide. Dill weed is mostly from the USA, which is of better quality than the Egyptian dill weed. Dill seed is mostly from India.

Botanical Description

Dill is an erect, annual herb up to 1 m (3 ft) high, with deeply divided, green leaves that are long and fine, compound umbels of small yellow flowers, and small pungent fruit (the seeds). Dill weed is medium to dark green and the seed is light brown. The seed is winged, oval, brown in color with one side flat, and with two ridges. The stem is erect, dull-green, cylindrical, fistular with longitudinal light-green streaks. It has long fusiform tap root with few secondary rootlets.

Parts Used

Dill seed (whole or ground) and dill weed, oleoresin. Sold as dried whole seeds or ground. The leaves called dill weed are sold whole, finely chopped, or ground.

Table 24.1 Nutrient composition of dill seed

Nutrient	Units	Value per 100 g
Water	g	7.70
Energy	kcal	305
Protein	g	15.98
Total lipid (fat)	g	14.54
Carbohydrate, by difference	g	55.17
Fiber, total dietary	g	21.1
Calcium, Ca	mg	1,516
Vitamin C, total ascorbic acid	mg	21.0
Vitamin B-6	mg	0.250
Vitamin B-12	mcg	0.00
Vitamin A, RAE	mcg_RAE	3
Vitamin A, IU	IU	53
Vitamin D	IU	0
Fatty acids, total saturated	g	0.730
Fatty acids, total monounsaturated	g	9.410
Fatty acids, total polyunsaturated	g	1.010

Source: USDA National Nutrient Database for Standard Reference, Release 24 (2011)

Flavor and Aroma

The seed is aromatic and somewhat sweet. Aromatic, warm, slightly bitter, and similar to caraway, with grassy, tea-like notes. The back notes are slightly sharp and pungent.

Active Constituents

Dill seed contains moisture 7–9%, protein 16–18%, fat 15–20%, carbohydrates 25–35%, pectin 5–7%, fiber 20–30%, essential oil (1–8%), flavonoids, petroselenic, and phenolic acids. Dill herb has been reported to be a rich source of carotenoids (Daly et al. 2010). The major constituent in the essential oil is carvone (35–60%). The nutritional constituents of dill seed are given in Table 24.1. The nutritional constituents (dried weed) and ORAC values (fresh weed) of dill weed are given in Table 24.2.

Table 24.2 Nutrient composition and ORAC values of dill weed dried

Nutrient	Units	Value per 100 g
Water	g	7.30
Energy	kcal	253
Protein	g	19.96
Total lipid (fat)	g	4.36
Carbohydrate, by difference	g	55.82
Fiber, total dietary	g	13.6
Calcium, Ca	mg	1,784
Vitamin C, total ascorbic acid	mg	50.0
Vitamin B-6	mg	1.710
Vitamin B-12	mcg	0.00
Vitamin A, RAE	mcg_RAE	293
Vitamin A, IU	IU	5,850
Vitamin D	IU	0
Fatty acids, total saturated	g	0.234
Dill weed fresh		
H-ORAC	μmol TE/100 g	4,392
Total-ORAC	μmol TE/100 g	4,392
TP	mg GAE/100 g	243

Source: USDA National Nutrient Database for Standard Reference, Release 24 (2011)

Preparation and Consumption

Dill weed is mainly used in pickling. Dill pickles are a North American classic and in Europe Sauerkraut and dill vinegars have been popular for centuries. The chopped fresh leaves are used with trout and salmon, shrimp, eggs, green beans, cauliflowers, beets, soups, cottage, and cream cheese. In Russia and Scandinavia, it is very popular and is used in courts-bouillons and sauces for fish, pickled salmon, casseroles, and soups. It is used in cakes and breads. It is also used in the seasoning to flavor rice pilaf. Good for meats and vegetables, like lamb and spinach, German potato soup. The seeds, leaves, and oils are used by Europeans and North Americans, in pickled cucumbers, sauerkraut, dill pickles, potato salad, breads, processed meats, seafood, soups, and stews. In north India, the dill seed is used in beans, lentils, and other vegetable dishes.

Medicinal Uses and Functional Properties

Dill is considered carminative, stomachic, slightly stimulant, spasmodic, sedative, lactagogue, and diuretic. It is also used for sleep disorders, gastrointestinal, kidney and urinary tract infections.

Myristicin and apiol from dill were found to be toxic to the newly emerged adults of *Parasarcophaga dux* (Khalaf 2004). Dill essential oil was found to significantly

reduce TC, TG, and LDL-C, and increase HDL-C, and thus could be a promising cardioprotective agent (Hajhashemi and Abbasi 2008). Hot water and acetone extracts of dill seed showed good antibacterial activity against several bacteria (Kaur and Arora 2009). The furanocoumarin, 5-[4″-hydroxy-3″-methyl-2″-butenyloxy]-6,7-furocoumarin and oxypeucedanin, oxypeucedanin hydrate, and falcarindiol isolated from the whole herb of *Anethum graveolens* exhibited antibacterial activity against a panel of rapidly growing mycobacteria (Stavri and Gibbons 2005). The essential oil of dill had significant fumigant antitermitic activity, antibacterial activity, and mosquito repellent activity (Singh et al. 2002; Choochote et al. 2007; Seo et al. 2009). Ethanol extract of dill was found to have significant antimicrobial activity (Wahba et al. 2010). The essential oil of dill seed was shown to be effective against vulvovaginal candidiasis in immunosuppressed mice (Zeng et al. 2011). Dill extract could be useful in improving elasticity of dermis equivalents in vitro and as well as skin biochemical properties and appearance in vivo (Sohm et al. 2011).

Antioxidant Properties

Dill has been reported to have phenolics which are important for some of its medicinal properties (Singh et al. 2004). Souri et al. (2004) found the methanolic extract of dill to have an antioxidant activity comparable with those of DL-alpha-tocopherol and quercetin. Panda (2008) evaluated the role of dill leaf extract in the regulation of corticosteroid-induced type 2 diabetes mellitus in female rats. Treatment with dill leaf extract caused a decrease in the concentration of both serum glucose and insulin. Dexamethasone-induced alterations in the levels of thyroid hormones as well in hepatic lipid peroxidation, superoxide dismutase, catalase, and reduced glutathione were also reversed by dill extract. The antioxidant activity of dill was found to be superior to that of the known antioxidant ascorbic acid (Satyanarayana et al. 2004). Treatment of rats with different fractions of dill caused a significant decrease in TC, TG, and LDL-C levels. They also found that treatment with different fractions of dill significantly increased hepatic antioxidant system activities such as SOD, CAT, and GSH, along with decreased lipid peroxidation in high-fat diet-treated rats (Bahramikia and Yazdanparast 2009). Ethanol extract of dill inhibited NO and TNF-alpha production without exerting cytotoxicity (Tuntipopipat et al. 2009). Dill leaf extract had high phenolic compounds and high radical scavenging activity (Stankevicius et al. 2011). Dill fresh and dry and in paste form had significant antioxidant capacity (Henning et al. 2011).

Regulatory Status

GRAS 184.1282.

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Chapter 25
Fennel

Botanical Name:	*Foeniculum vulgare* Mill.
Synonyms:	*F. officinale*; *F. capillaceum*; *Anethum foeniculum*; fenkel; common fennel, sweet fennel.
Family:	Apiaceae (Umbelliferae).
Common Names:	**French**: fenouil; **German**: fenchel; **Italian**: finocchio; **Spanish**: hinojo; **Russian**: fyenkhel; **Hindi**: saunf; **Arabic**: shamar.

Introduction

History

Genus name *Foeniculum* is derived from Latin *foenum*, meaning hay; thus the dried leaves were thought to resemble fine dried hay. Ancients believed that fennel improved eyesight and increased strength. The Greeks believed that Prometheus brought fire from Olympus to earth in a stalk of giant fennel. In ancient Greece, it was considered a symbol of success, and hence was called "marathon" in reference to the battle where Greeks defeated the Persians in 490 BC. Fennel was popular in Rome and they distributed it throughout Europe including Britain. In the thirteenth century, King Edward I was a great fan of fennel, which was used to flavor the English sack. Parkinson in his *Theatricum Botanicum* (1640) describes fennel to be derived mainly from Italy, where it was used to flavor fish. Fennel together with St. John's Wort was hung over doors and stables on Midsummer's Eve to ward off evil spirits. Emperor Charlemagne required fennel cultivated on imperial farms. William Cole in his Nature's Paradise (1650) states "Seeds, leaves and root of garden fennel are much used in drinks and broths for those that are grown fat, to abate their unweildiness and cause them to grow more gaunt and lank." Greek physician

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Dioscorides (first century) ascribes medicinal properties to fennel in his *De Materia Medica*. Pliny also wrote about fennel's medicinal value (23–79 AD). In India fennel is chewed as a breath freshener and to aid digestion. Longfellow, the American poet (1807–1882), wrote a poem in virtue of fennel: Above the lower plant it towers/The fennel with its yellow flowers/And in an earlier age than ours/Was gifted with the wondrous powers/Lost vision to restore. Fennel was transported to Asia, Southeast Asia, China, and Japan by early traders and is now cultivated all over the world. Spanish priests brought fennel to North America. Around the eighteenth century, The Shakers grew fennel commercially.

Producing Regions

Fennel is native to the Mediterranean region, grows wild, or is cultivated all over the world—India, China, Egypt, Turkey, Argentina, Central Europe, and USA. Sweet fennel is cultivated in Italy, France, Morocco, USA, and India. Bitter fennel is mostly in central Europe, Russia, Argentina, and USA.

Botanical Description

It is an erect, robust, perennial plant growing up to 2 m (6 ft) high. It has fine feathery green leaves with golden flowers borne in distinctive umbels. The leaf stalks form sheaths around the thick stems. Among the medicinally used subsp. *vulgare*, bitter fennel (var. *vulgare*) and sweet variety (var. *dulce*) are recognized. The seeds are yellowish to greenish brown, slightly curved, and oval in shape.

Parts Used

Seed (whole or ground), essential oil, herb. The green leaf, stalk, and bulbs of Florence fennel are used as vegetable or garnish in the Mediterranean region.

Flavor and Aroma

Fennel has anise-like, slightly licorice, camphoraceous aroma. The flavor is warm, anisic with a bittersweet aftertaste. Fennel is generally described as having a sweet aromatic flavor and aroma that is similar to Anise (licorice-like) but less intense. It has a slight menthol undertone with musty/green flavor notes.

Table 25.1 Nutrient composition of fennel seed

Nutrient	Units	Value per 100 g
Water	g	8.81
Energy	kcal	345
Protein	g	15.80
Total lipid (fat)	g	14.87
Carbohydrate, by difference	g	52.29
Fiber, total dietary	g	39.8
Calcium, Ca	mg	1,196
Vitamin C, total ascorbic acid	mg	21.0
Vitamin B-6	mg	0.470
Vitamin B-12	mcg	0.00
Vitamin A, RAE	mcg_RAE	7
Vitamin A, IU	IU	135
Vitamin D	IU	0
Fatty acids, total saturated	g	0.480
Fatty acids, total monounsaturated	g	9.910
Fatty acids, total polyunsaturated	g	1.690

Source: USDA National Nutrient Database for Standard Reference, Release 24 (2011)

Active Constituents

Fruit contains moisture 9%, protein 16–20%, fat 14.9%, carbohydrates 36.6%, fiber 15.7%, ash 8% (Ca, Na, Mg, Fe, K, P, Zn), vitamins (niacin, thiamine, riboflavin), fixed oil (15–20%), flavonoids, iodine, kaempferol, umbelliferone, stigmasterol, ascorbic acid, and essential oil (6%). Two types of essential oil are produced-bitter fennel oil (var. *vulgare*) and sweet fennel oil (var. *dulce*). The major constituent in the essential oil is *trans*-anethole. Methanolic extract had flavonoids, terpenoids, alkaloids, phenols, and sterols (Mohamad et al. 2011). The nutritional constituents of fennel seed are given in Table 25.1. The nutritional constituents and ORAC values of raw fennel bulb are given in Table 25.2.

Preparation and Consumption

Fennel seed is a major culinary and processing spice. It is used as a flavoring in baked goods, meat and meat products, snack foods, fats and oils, gravies, stews, soups, salad dressing, vegetable dishes, alcoholic beverages, and also used in herbal teas. Fennel leaves are used in French and Italian cuisines in sauces for fish and in mayonnaise. In Italy, fennel is used to season pork roasts and spicy sausages, especially the Florentine salami *finocchiona*. The English use fennel in all fish dishes and seafood. It is an ingredient of Chinese five-spice, Herbes de Provence, curry powders. It is an important ingredient of the Mediterranean, Scandinavian, Italian, and Chinese seasonings. The chopped fresh leaves are used to garnish or flavor fish diseases, salads, sauces, soups, and curries. The bulb and stalk are used in soups and sauces.

Table 25.2 Nutrient composition and ORAC values of fennel bulb raw

Nutrient	Units	Value per 100 g
Water	g	90.21
Energy	kcal	31
Energy	kJ	130
Protein	g	1.24
Total lipid (fat)	g	0.20
Ash	g	1.05
Carbohydrate, by difference	g	7.29
Fiber, total dietary	g	3.1
Calcium, Ca	mg	49
Vitamin C, total ascorbic acid	mg	12.0
Vitamin C, total ascorbic acid	mg	12.0
Vitamin B-12	mcg	0.00
Vitamin A, RAE	mcg_RAE	7
Vitamin A, IU	IU	134
Vitamin D	IU	0
H-ORAC	µmol TE/100 g	307
Total-ORAC	µmol TE/100 g	307
TP	mg GAE/100 g	26

Source: USDA National Nutrient Database for Standard Reference, Release 23 (2010)

Medicinal Uses and Functional Properties

Used to treat menstrual disorders, dyspepsia, flatulence, and cough, and to reduce the griping effect of laxatives. Fruits are traditional ingredients of domestic gripe water to treat flatulence in infants. External uses include skin disorders, conjunctivitis, and blepharitis of the eye. Fennel is recommended for diabetes, bronchitis, and chronic coughs.

Fennel extracts and oils have spasmolytic, carminative, anti-inflammatory, estrogenic, nematicidal, antifungal, and antimicrobial properties and promotes gastrointestinal motility (Shahat et al. 2011; Bertoli et al. 2011; Ntalli et al. 2011; Alizadeh et al. 2010; Conti et al. 2010; Cwikla et al. 2010; Lixandru et al. 2010; Pai et al. 2010; De Martino et al. 2009; Kaur and Arora 2009; Lo Cantore et al. 2004).

Antioxidant Properties

The extracts from fennel and essential oil have been shown to have antioxidant activity (Shahat et al. 2011; Guimarães et al. 2011; Mohamad et al. 2011; Kiralan et al. 2012; Kim et al. 2011; Miguel et al. 2010; Ozcan et al. 2009; Nickavar and Abolhasani 2009; Singh and Kale 2008; Papageorgiou et al. 2008; Faudale et al. 2008; Chohan et al. 2008; Celik and Isik 2008; De Marino et al. 2007; Conforti et al.

2006; Misharina and Polshkov 2005; Singh et al. 2004; Satyanarayana et al. 2004; Choi and Hwang 2004; Parejo et al. 2002, 2004; El and Karakaya 2004; Baliga et al. 2003; Stashenko et al. 2002; Ruberto et al. 2000; Farag and el-Khawas 1998). The methanolic extract of fennel was shown to exhibit an antitumor effect in Ehrlich ascites carcinoma-bearing mice with or without exposure to radiation, by modulating lipid peroxidation and augmenting the antioxidant defense system (Mohamad et al. 2011). Nickavar and Abolhasani (2009) reported a positive correlation between the antioxidant potency and flavonoid content of ethanol extracts of fennel fruits. The shoots of fennel were shown to have the highest radical scavenging activity and lipid peroxidation inhibition capacity. It also had the highest phenolics and ascorbic acid content (Barros et al. 2009). Fennel seeds exhibited a significant reduction in the skin and the forestomach papillomagenesis in Swiss albino mice as compared to the control group (Singh and Kale 2008). Cooking and storage processes had significant effects on the antioxidant activity of fennel extracts. Simmering, soup making, and stewing were found to significantly increase the antioxidant capacity, while grilling and stir frying decreased it (Chohan et al. 2008). Aqueous extracts of fennel had gastroprotective effect and antioxidant properties (Birdane et al. 2007). Conforti et al. (2006) found the wild plants of fennel to possess higher radical scavenging activity than the cultivated plants. The aqueous extract of fennel was found to have superior antioxidant activity than the known antioxidant ascorbic acid (Satyanarayana et al. 2004). Methanolic extracts of fennel exhibited inhibitory effects against acute and subacute inflammatory diseases and type IV allergic reactions and showed a central analgesic effect (Choi and Hwang 2004). It was found to significantly increase the plasma superoxide dismutase and catalase activities and the high-density lipoprotein-cholesterol level, while malondialdehyde level was significantly decreased compared to the control group. Baliga et al. (2003) reported that an aqueous extract of fennel showed greatest nitric oxide (NO) scavenging effect of 79.75% at 62.5 μg mL^{-1} as compared to the positive control, *Ginkgo biloba*, where 36.22% scavenging was observed at similar concentration. Hepatotoxicity produced by carbon tetrachloride in rat livers was inhibited by the fennel essential oil with decreased levels of serum aspartate aninotransferase, alanine aminotransferase, alkaline phosphatase, and bilirubin (Ozbek et al. 2003).

Regulatory Status

GRAS 182.10 (common and sweet fennel) and GRAS 182.20 (sweet fennel).

Standard

ISO 7927 (Specification), ISO 17412 (Oil).

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Chapter 26
Fenugreek

Botanical Name:	*Trigonella foenum-graecum* L.
Synonyms:	Foenugreek, Greek hay, methi.
Family:	Fabaceae (Leguminosae).
Common Names:	**French**: fenugrec senegree; **German**: bockshornklee; **Italian**: fieno greco; **Spanish**: alholva; **Russian**: pazhitnik; **Hindi**: methe; **Arabic**: halba

Introduction

History

The name *Trigonella foenum-graecum* L. comes from the generic name *Trigonella*, stated to be derived from the Latin for little triangle, referring to the flower shape, and *foenum-graecum*, which is Latin for Greek hay or grass. The first written record of fenugreek is dated back to 4000 BC. In ancient Egypt and Greece, fenugreek was first used as a fodder crop, before its medicinal properties were known. In Dynastic Egypt, the seeds were first roasted and then boiled to make a tonic, while the fresh leaves or sprouted seeds were used as a vegetable, and it was also an important ingredient in embalming herbs and the incense, *kuphi*. It was discovered in King Tut's tomb (1323 BC). It has been cultivated since 1000 BC in Egypt. A Middle Eastern greeting speaks of fenugreek, or *helbah*: "May you tread in peace on the soil where it gave new strength, and fearless mood, and gladiators, fierce and rude, helbah grows." The Greek Dioscorides, who also served as an army doctor under Emperor Nero, wrote in his *De Materia Medica* that fenugreek powder dissolved in wine should be used to alleviate the pain of gout, and taken as snuff to cure headaches. Pliny prescribed the powder/wine mixture as a treatment for deafness (*Historia Naturalis*, AD 77). Emperor Charles promoted the cultivation of fenugreek and was grown by the Benedictine monks in the ninth century. In the Middle

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Ages in Europe, the paste of fenugreek seeds used as a cure for baldness became known as "Greek excrement," because of its offensive odor. It was introduced into Britain in the sixteenth century. Its cultivation was spread throughout the Arab world, to Europe, Ethiopia, Soviet Union, India, and China. The Arabs highly prized fenugreek. It was grown in the Mediterranean region, West Asia, and India for culinary and medicinal purposes. In Europe and North America it is a minor crop. In Australia it is grown as a specialty crop. It was introduced into China during the Sung Dynasty in the eleventh century. The great English food writer Elizabeth David said about fenugreek: "Fenugreek is to curry much as malt vinegar is to English salads."

Producing Regions

Fenugreek is native to the Mediterranean West Asian regions and south-eastern Europe. It is now cultivated worldwide, including Mediterranean region, northern Africa, South America, China, and India.

Botanical Description

Fenugreek is an annual herb, with a well-developed taproot and a spreading, fibrous root system. The stem is green to purple, smooth, and erect up to 140 cm (1.5 ft) high. The light-green leaves are alternate and pinnate, consisting of three ovate leaflets. The inflorescence is a terminal, compound umbel. The flowers are white to whitish-yellow. The fruit is light green to yellow brown, ovoid-cylindrical, and slightly curved, with 20–30 small, smooth brownish seeds. The pod shape also gives the name "goat's horn" to the plant.

Parts Used

Dried ripe seed (hard, smooth, oblong, somewhat flattened, and resembling a triangle), essential oil, oleoresin. The seeds are sold whole or ground. The leaves are called methi sag in North India and come fresh or dried both whole or crushed.

Flavor and Aroma

Warm and penetrating, more pronounced when roasted, faint smell of burnt sugar. When ground they give off a spicy aroma, pungent, spicy but bitter. Powerful, aromatic, and bittersweet like burnt sugar with a bitter aftertaste.

Table 26.1 Nutrient composition of fenugreek seed

Nutrient	Units	Value per 100 g
Water	g	8.84
Energy	kcal	323
Protein	g	23.00
Total lipid (fat)	g	6.41
Carbohydrate, by difference	g	58.35
Fiber, total dietary	g	24.6
Calcium, Ca	mg	176
Vitamin C, total ascorbic acid	mg	3.0
Vitamin B-6	mg	0.600
Vitamin B-12	mcg	0.00
Vitamin A, RAE	mcg_RAE	3
Vitamin A, IU	IU	60
Vitamin D	IU	0
Fatty acids, total saturated	g	1.460

Source: USDA National Nutrient Database for Standard Reference, Release 24 (2011)

Active Constituents

Fruit contains moisture 8–10%, protein 15–28%, fat 6–12%, carbohydrates 35–45%, fiber 8–16%, ash 4–8% (Ca, P, K, Na, Fe, Zn), and 0.3% essential oil. Seeds also contain vitamin A, niacin, thiamine, riboflavin, tryptophan, flavonoids (vitex and vitexin glucoside), alkaloids present as trigonelline, choline, gentianine, and carpaine. Seeds contain saponins, which on hydrolysis yield 2.5% steroid sapogenins, mainly diosgenin. The major constituents of the fenugreek seed essential oil are β-pinene, camphor, β-caryophyllene, and neryl acetate. The nutritional constituents of dried fenugreek are given in Table 26.1.

Preparation and Consumption

Fenugreek seed (ground or whole) is a well-known spice of southern Europe and west Asia, and a common ingredient of Asian cuisine, especially curries. It is an ingredient of curry powders, especially vindaloo and hot curries of Sri Lanka. It is an ingredient of the Indian five-spice mixture, known as "Panch phoron." It is an essential ingredient in fish, such as tuna and mackerel. It is also used in pickles and chutneys. The seeds are an important ingredient in halva, a famous Middle Eastern and Indian confection. Flour mixed with ground fenugreek makes a spicy bread. The leaves both fresh and dried are used in meat curries, dhal and vegetable dishes, and chutneys. In USA, its major use is in imitation maple syrups. It is used in beverages, frozen dairy desserts, candy, baked goods, meat and meat products, and gelatins.

Medicinal Uses and Functional Properties

It is used for reducing fever, treating mouth ulcers, bronchitis, chronic coughs, chapped lips, milk promotion, digestive aid, cancers, in hair tonics, and to cure baldness. Seeds are emollient, laxative, and a vermifuge. In Chinese medicine it is used to treat abdominal pain, kidney ailments, hernia, arthritis, beriberi, and male impotence. In India, it is a traditional anthelmintic, commonly used as a diuretic and in the treatment of dropsy, heart diseases, spleen, and liver enlargement.

It is also used in diabetes and lowers blood pressure (Preet et al. 2005; Jung et al. 2006; Hannan et al. 2007; Modak et al. 2007; Dixit et al. 2008; Krishnaswamy 2008; Kannappan and Anuradha 2009; Kassaian et al. 2009; Tripathi and Chandra 2010; Singh et al. 2010; Hamden et al. 2010; Yadav et al. 2010; Baquer et al. 2011; Ramadan et al. 2011; Uemura et al. 2011). Fenugreek was also found to have antimicrobial activity (Panghal et al. 2011). Dietary fenugreek had beneficial antilithogenic effect which primarily was due to the reduction in the cholesterol content in bile (Reddy and Srinivasan 2009, 2011a). The antihyperglycemic compound (GII) purified from fenugreek seeds was found to decrease the lipid content of liver and stimulate the enzymes of glycolysis (except glucokinase), and inhibit enzymes of gluconeogenesis in the liver of the diabetic especially moderately diabetic rabbits (Moorthy et al. 2010a, b). Diosgenin from fenugreek was shown to be a novel blocker of STAT3 activation pathway and thus could be useful in the treatment of hepatocellular carcinoma and other cancers (Li et al. 2010). Fenugreek and its active constituents could be useful in protecting skin damage (Kawabata et al. 2011).

Antioxidant Properties

Fenugreek has been reported to possess strong antioxidant properties (Yadav and Sehgal 1997; Nair et al. 1998; Ravikumar and Anuradha 1999; Panda et al. 1999; Choudhary et al. 2001; Langmead et al. 2002; Madar and Stark 2002; Mohamad et al. 2004; Rababah et al. 2004; Randhir et al. 2004; Kaviarasan et al. 2004; Singh et al. 2004; Siddiqui et al. 2005; Bajpai et al. 2005; Dixit et al. 2005; Bhatia et al. 2006; Gupta and Bains 2006; Jung et al. 2006; Sinha et al. 2007; Suganthi et al. 2007; Nautiyal et al. 2008; Gupta and Prakash 2009; Lakshminarayana et al. 2009; Tripathi and Chandra 2010; Xue et al. 2011; Reddy and Srinivasan 2011b; Middha et al. 2011; Marathe et al. 2011). Phenolic antioxidants in fenugreek are involved in preventing lipid peroxidation (Chatterjee et al. 2009). Fenugreek supplementation in diet resulted in lowered lipid peroxidation and increased level of antioxidants in alloxan diabetic rats (Ravikumar and Anuradha 1999). Aqueous extracts of fenugreek seed normalized the alterations in lipid peroxidation, oxidative stress in the liver, kidney, and pancreas of diabetic rats (Anuradha and Ravikumar 2001). Fenugreek seeds prevented the rise in lipid peroxidation induced by ethanol, and this was probably because of the enhanced oxidative potential of the gastric mucosa and thus lowering mucosal injury (Pandian et al. 2002). Thirunavukkarasu et al. (2003) studied the

effect of aqueous fenugreek seed extracts on lipid peroxidation and antioxidant status in rats with ethanol induced toxicity. The simultaneous administration of fenugreek seed aqueous extract with ethanol prevented the rise in lipid peroxidation and the enzymatic leakage and enhanced the antioxidant potential. Kaviarasan et al. (2006) also found the polyphenolic compounds of fenugreek seeds to have cytoprotective effect during ethanol-induced liver damage in Chang liver cells. Kaviarasan et al. (2008) reported significantly reduced levels of lipid peroxidation products and protein carbonyl content, increased activities of antioxidant enzymes, and restoring levels of thiol groups by administration of polyphenol extract of fenugreek seed to ethanol-fed rats. Devasena and Menon (2002, 2007) reported a decrease in lipid peroxidation with enhancement of circulatory antioxidants by inclusion of fenugreek in the diet of male Wistar rats with 1,2-dimethylhydrazine-induced colon carcinogenesis. An aqueous extract of germinated fenugreek seeds was found to exhibit the highest antioxidant activity as measured by ferric reducing antioxidant power, radical scavenging by 1,1-diphenyl-2-picrylhydrazyl, ferrylmyoglobin/2,2′-azobis-3-ethylbenzthiazoline-6-sulfonic acid, pulse radiolysis, oxygen radical absorbance capacity, and inhibition of lipid peroxidation in mitochondrial preparations from rat liver (Dixit et al. 2005). Fenugreek leaf powder supplementation significantly reduced oxidative stress in streptozotocin-induced diabetic rats (Annida and Stanely 2005). They reported significantly lowered lipid peroxidation and significantly increased antioxidant system in the diabetic rats. Treatment with fenugreek in combination with vanadate was found to effectively counter diabetic alterations in alloxan diabetic rat brains without any toxic effects (Siddiqui et al. 2005). Preet et al. (2006) also found fenugreek seed powder alone or in combination with sodium orthovanadate to prevent diabetic retinopathy and other ocular disorders. Dilsiz et al. (2006) found fenugreek and other antioxidants like lutein, germander, and vitamin E to exert protection against in vivo retinal ischemia–reperfusion in rats. Meera et al. (2009) reported significant hepatoprotective effects by ethanolic extract of the leaves of fenugreek against liver damage by H_2O_2 and CCl_4 and this was evidenced by decreased levels of antioxidant enzymes. The extract was also found to exhibit significant activity in superoxide radical and NO radical scavenging and significant anti-lipid peroxidation effects in vitro, thus proving their antioxidant effects. The protective role of fenugreek against experimental cataract because of its antioxidant properties has been suggested by Gupta et al. (2010). The ethyl acetate extract of fenugreek seeds showed significant antioxidant activity and hypocholesterolemic effects in high-cholesterol fed rats (Belguith-Hadriche et al. 2010). Aqueous extract of fenugreek provided protection against functional and morphologic injuries in the kidneys of diabetic rats by increasing the activities of antioxidants and inhibiting accumulation of oxidized DNA in the kidney (Xue et al. 2011).

Regulatory Status

GRAS 182.10 and GRAS 182.20.

Standard

ISO 6575.

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Chapter 27
Garlic

Botanical Name: *Allium sativum* L.
Synonyms: Common garlic, allium, lashuna.
Family: Amaryllidaceae (Liliaceae) (Alliaceae).
Common Names: **French**: ail; **German**: knoblauch; **Italian**: aglio; **Spanish**: ajo; **Russian**: galgant; **Hindi**: lahsun.

Introduction

History

The common name garlic describes the leaves and use, taken from the Anglo-Saxon *gar* (lance) and *leac* (leek, or pot-herb). Garlic has been grown and used as a medicinal since ancient times. The Indians, Chinese, Sumerians, and ancient Egyptians consumed garlic over 4,000 years ago. Hippocrates (430 BC) and Theophras Tuso (322 BC) described the use of garlic in Greek and Roman periods. According to the famous Greek historian Herodotus, garlic was eaten by the slaves employed in the construction of the famous Cheops pyramid. It was found in King Tut's tomb, probably to keep away evil spirits. The Israelites yearned for it in the wilderness "We remember the fish we did eat in Egypt freely; the cucumbers and the melons and the leeks and the onions and the garlick" (Numbers 11: 5). In Homer's epic, Odysseus escapes death at the hands of the sorceress Circr by using garlic as a charm to make her fall in love with him. The Greeks used it to treat colds and coughs, the Egyptians used it to provide strength and prevent diseases, and the Romans for providing courage. The great herbalist Culpeper said that garlic cured all diseases. King Ashurbanipal of Assyria (668–633 DC) wrote about garlic on a cuneiform scroll. In the first century AD, the East Indian herbalist said about garlic "garlic would be worth its weight in gold, if it weren't for its smell." It was the main ingredient in the "Four Thieves Vinegar" used by the four Marseilles thieves, who confessed that

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"garlek" protected them while they robbed the bodies of plague victims. In the early eighteenth century, the French priests living in London's poor section used garlic to protect themselves from a highly contagious fever, while their Anglican counterparts who did not use garlic were not so lucky. During WW I and WW II, European doctors applied sterilized swabs of sphagnum moss and garlic to dress wounds and prevent gangrene. Garlic's legendary reputation against vampires is well known. In Mediterranean countries, it is used in rituals against the evil eye and traditionally it was hung on babies' cradles to ward off evil spirits and a protection against witchcraft. It is still ceremoniously used not only in an Egyptian festival as old as the Pharaohs, but also in an annual festival held at Gilroy, California, the center of garlic production in the USA.

Producing Regions

Garlic is native to Asia, but introduced into the warm climates worldwide. It is grown in the Mediterranean region and central Asia for centuries. China, India, Korea, Egypt, Argentina, Spain, and USA are the major garlic growing countries.

Botanical Description

Garlic is a frost-hardy, bulbous perennial herb up to 100 cm (1 ft) high, with long, narrow firm flat leaves. The flowers are small and white. It is an herbaceous annual for bulb production and a biennial for seed production. Garlic is smooth, round and solid, unlike onion which is hollow. The garlic bulb consists of 6–35 bulbets called cloves and is surrounded by a thin white or pinkish papery sheath.

Parts Used

Whole bulbs, cloves, dried as granules, flakes, or powder, dried powder with salt, garlic oil, and garlic juice. Fresh garlic is also available sliced, minced, crushed, chopped, or roasted. Dried comes as powdered, flaked, granulated, diced, ground, chopped, and minced.

Flavor and Aroma

Warm, sweet, strong when crushed with penetrating sulfur aroma. Aromatic, sweet, mildly spicy, pungent with faint bitter notes.

Table 27.1 Nutrient composition and ORAC values of garlic powder

Nutrient	Units	Value per 100 g
Water	g	6.45
Energy	kcal	331
Protein	g	16.55
Total lipid (fat)	g	0.73
Carbohydrate, by difference	g	72.73
Fiber, total dietary	g	9.0
Sugars, total	g	2.43
Calcium, Ca	mg	79
Vitamin C, total ascorbic acid	mg	1.2
Vitamin B-6	mg	1.654
Vitamin B-12	mcg	0.00
Vitamin A, RAE	mcg_RAE	0
Vitamin A, IU	IU	0
Vitamin D	IU	0
Vitamin E (alpha-tocopherol)	mg	0.67
Fatty acids, total saturated	g	0.249
Fatty acids, total monounsaturated	g	0.115
Fatty acids, total polyunsaturated	g	0.178
H-ORAC	μmol TE/100 g	6,523
L-ORAC	μmol TE/100 g	143
Total-ORAC	μmol TE/100 g	6,665
TP	mg GAE/100 g	42

Source: USDA National Nutrient Database for Standard Reference, Release 24 (2011)

Active Constituents

Fresh garlic cloves contain moisture 63%, protein 6%, fat 0.1%, mineral matter 1%, fiber 1%, and carbohydrates 29%, with vitamins, iron, sodium, and potassium. Garlic powder contains moisture 5%, protein 17.5%, fiber 2%, and carbohydrates 71%. Garlic contains 0.1–0.4% volatile oil, alliin, enzymes, ajoenes, minerals, and proteins. The major compounds in the oil are the sulfur compounds. Allicin is the major odor principle produced by the action of the enzyme alliinase on alliin. The nutritional constituents and ORAC values of garlic powder are given in Table 27.1. The nutritional constituents and ORAC values of garlic clove (one clove, 1 g) are given in Table 27.2.

Preparation and Consumption

Garlic is used in almost every cuisine, but traditionally it is very popular in Mediterranean cooking, Mexican, Central and South American dishes, essential in Indian, Chinese, and south-eastern Asian cooking. The famous use is in the

Table 27.2 Nutrient composition and ORAC values of garlic raw, 1 clove

Nutrient	Units	Value per 1 g (1 clove)
Water	g	58.58
Energy	kcal	149
Energy	kJ	623
Protein	g	6.36
Total lipid (fat)	g	0.50
Ash	g	1.50
Carbohydrate, by difference	g	33.06
Fiber, total dietary	g	2.1
Sugars, total	g	1.00
Calcium, Ca	mg	181
Vitamin C, total ascorbic acid	mg	31.2
Vitamin B-6	mg	1.235
Vitamin B-12	mcg	0.00
Vitamin A, RAE	mcg_RAE	0
Vitamin A, IU	IU	9
Vitamin D	IU	0
Vitamin E (alpha-tocopherol)	mg	0.08
H-ORAC	μmol TE/100 g	5,541
L-ORAC	μmol TE/100 g	400
Total-ORAC	μmol TE/100 g	5,708
TP	mg GAE/100 g	92

Source: USDA National Nutrient Database for Standard Reference, Release 23 (2010)

French cuisine garlic mayonnaise (*aioli*), the restorative garlic soup and garlic butter served with snails, roast lamb studded with garlic, and rosemary is a common popular western dish. In the USA, almost 50% of the fresh garlic is dehydrated and used in mayonnaise products, salad dressings, tomato products, and in meat preparations. Raw garlic is used in the preparation of garlic powder, garlic salt, garlic vinegar, garlic cheese crotons, potato chips, garlic bread, garlicked meat tit-bits, and garlicked bacon. In India and Asian and Middle Eastern countries, it is used in pickles, curry powders, curried vegetables, meat preparations, and tomato ketchup. Oil of garlic is used for meat preparations, soups, canned foods, and sauces.

Medicinal Uses and Functional Properties

The medicinal uses of garlic have a long history (Block 1985). Garlic has been used as a carminative, nerve tonic, antiseptic agent, for treating coughs, chronic bronchitis, toothache, earache, dandruff, high blood pressure, arteriosclerosis, hysteria, and cancers. Garlic cloves, teas, and syrups have been used as an aphrodisiac, to treat fever, flu symptoms, shortness of breath, sinus congestion, headache, stomachache,

hypertension, gout, rheumatism, pinworms, old ulcers, and snakebites. Garlic has been used for cold (Lissiman et al. 2009). In Chinese medicine it has also been used for diarrhea, dysentery, pulmonary tuberculosis, blood urine, diphtheria, whooping cough, typhoid, hepatitis, trachoma, and vaginal trichomoniasis.

Recent studies have shown that it reduces cholesterol level, lowers blood pressure, has an influence on platelet aggregation, an important factor in cardiovascular disease, reduces risk of stomach cancer, has antidiabetic activity, has antioxidant properties which are helpful in preventing cancer and cardiovascular disease, also has antibiotic properties and used to treat wounds when other antibiotics failed (Lawson et al. 1992; Silagy and Neil 1994; Han et al. 1995; Gebhardt and Beck 1996; Adler and Holub 1997; Pinto et al. 1997; Kook et al. 2009; Krishnaswamy 2008; Altonsy and Andrews 2011; Sfaxi et al. 2009; Singh et al. 2008; Song et al. 2009; Ashraf et al. 2011; Liu et al. 2007; Grman et al. 2011; Antony and Singh 2011; Cilek et al. 2011; Haque et al. 2011; Lee et al. 2011; Liu et al. 2012). Garlic contains unique organosulfur compounds (OSC) which provide the characteristic flavor and odor, and most of its potent biological activities (Block 1985; Powolny and Singh 2008; Alam et al. 2009; Chowdhury et al. 2008; Luo et al. 2009; Nigam and Shukla 2007; Tedeschi et al. 2007; Tsao et al. 2007; Tsuchiya and Nagayama 2008; Yu et al. 2009; Zeng et al. 2009). Aged garlic extract (AGE) has been analyzed and studied for its high antioxidant content and health-protective potential (Amagase 1997; Lee et al. 2009c). Aqueous extract of garlic as intraperitoneal injection in rat model was found to effectively prevent Se-induced cataract (Javadzadeh et al. 2009). Garlic oil (GO) and allyl alcohol (AA) from garlic inhibited *Candida utilis* ATCC42416 in different ways: GO had fungistatic activity while AA had fungicidal activity. Both had good antimicrobial potencies against the yeast (Chung et al. 2007). Garlic extract was shown to have more potent antistaphylococcal activity than allicin (Fujisawa et al. 2009). Garlic essential oil had strong acaricidal activity (Martinez-Velazquez et al. 2011). Diallyl sulfide from garlic protects the brain from ischemia/reperfusion injury and this is related to its antiapoptotic effects in part (Lin et al. 2012). Extracts of cardamom, chili, coriander, onion, garlic, ginger, and galangale were shown to have significant antifungal activity (Touba et al. 2012).

Antioxidant Properties

The mechanisms of garlic are recognized to its strong antioxidant properties (Yang et al. 1993; Imai et al. 1994; Ide et al. 1997; Wei and Lau 1998; O'Brien and Gillies 1998; Borek 2001; Gorinstein et al. 2007, 2010; Harisa et al. 2009; An et al. 2009; Butt et al. 2009; Brunetti et al. 2009; Galano and Francisco-Marquez 2009; Hadji et al. 2007; Hasani-Ranjbar et al. 2009; Horev-Azaria et al. 2009; Kaur and Singh 2007; Liu and Xu 2007; Medina-Campos et al. 2007; Murugavel and Pari 2007; Nencini et al. 2007; Park et al. 2008; Pedraza-Chaverri et al. 2008; Sener et al. 2007; Zalejska-Fiolka et al. 2007; Koseoglu et al. 2010; Park et al. 2009; Anoush et al.

2009; Castro et al. 2010; Asdaq and Inamdar 2009; Asdaq et al. 2010; Sharma et al. 2010; Hassan et al. 2010; Nahdi et al. 2010; Savas et al. 2010; Vazquez-Prieto et al. 2011; Colin-Gonzalez et al. 2011; Kilikdar et al. 2011; Deniz et al. 2011; Lu et al. 2011; Javed et al. 2011; Morihara et al. 2011; Luo et al. 2011; Henning et al. 2011; Cazzola et al. 2011; Nencini et al. 2011; Olalekan et al. 2011; Nepravishta et al. 2012), its ability to stimulate immunological responsiveness (Reeve et al. 1993), and its modulation of prostanoid synthesis (Dimitrov and Bennink 1997). Garlic in addition to its antiatherogenic effect has diverse biological activities like antitumorigenesis, antidiabetes, antioxidation, hepatic protection, and immune modulation effects (Agarwal et al. 2007; Rivlin 2001; Liang et al. 2011; Chandrashekar et al. 2011). *S*-allylmercaptocysteine (SAMC), one of the water-soluble organosulfur garlic derivatives suppressed the growth and metastasis of colorectal cancer cells both in vivo and in vitro (Liang et al. 2011). Diallyl sulfide inhibits the growth and induces apoptosis of human cervical cancer HeLa cells in vitro (Wu et al. 2011).

Oxidized LDL promotes vascular dysfunction and this contributes to atherosclerosis, in part by its cytotoxic effects on endothelial cells. Aged garlic extract (AGE) and *S*-allylcysteine (SAC) were reported to scavenge ROS, inhibit oxidation of LDL, and inhibit the injury to endothelial cells by oxidized LDL in an in vitro system of endothelial cells exposed to oxidant copper ions (Ide and Lau 1997). AGE has been found to inhibit lipid peroxide formation in a number of studies (Wei and Lau 1998). Yamasaki et al. (1994) found AGE and SAC to inhibit the increased TBARS induced by hydrogen peroxide, in a concentration-dependent manner, thus mitigating oxidation events which are implicated in the formation of atherogenic lesions (Efendy et al. 1997). A garlic preparation was found to significantly lower lipid level and level of lipid peroxidation products in blood and increase vitamin E concentration in the serum of patients with primary arterial hypertension (Duda et al. 2008). This study suggests that garlic preparation could be used in the treatment of arterial hypertension because of its hypolipemic and antioxidant properties. Lei et al. (2008) examined whether diallyl sulfide (DAS), diallyl disulfide (DADS), and diallyl trisulfide (DATS) reduce adhesion molecule expression induced by oxidized-LDL, and if so through what mechanism. Their results suggested suppression of oxidized-LDL-induced E-selectin and VCAM-1 expression, and thus monocyte adhesion to endothelial cells is most likely dependent on the P13K/PKB or PKA/CREB signaling pathway in an adhesion molecule-specific manner.

Garlic administration to streptozotocin (STZ)-induced hyperglycemic rats in a dose-dependent manner was found to attenuate the glycemia-mediated oxidative stress as all the parameters were almost normalized to that of control rats and delaying the progression of lens opacity (Raju et al. 2008). These results suggest that garlic extract possesses hypoglycemic and antioxidant properties that could delay the progression of cataract. In another study (Mariee et al. 2009), fresh garlic homogenate (FGH) was found to attenuate significantly the STZ-induced diabetic nephropathy as evaluated by the assessment of serum glucose, insulin, total triacylglycerol (TAG), total cholesterol (TC), and creatine clearance (Ccr) in control and STZ-induced rats. There were other marked improvements observed with FGH supplementation, suggesting FGH participation in STZ-induced diabetic nephropathy

through inhibition of oxidative damage to kidney and/or increased kidney NO bioavailability. Garlic administration in a dose-dependent manner was found to attenuate the STZ-induced oxidative stress in hepatic and intestinal tissues of Wistar rats (Rajani Kanth et al. 2008). Lee et al. (2009c) found aged black garlic extracts and garlic extracts to have strong antioxidant activity in vitro and in vivo, suggesting their use in preventing diabetic complications.

The presence of AGE suppressed the production of superoxide radical and H_2O_2 in a dose-dependent and time-related fashion in bovine arterial endothelial cells exposed to oxidants hypoxanthine and xanthine, by increasing the levels of SOD, CAT, and (GPx) glutathione peroxidase (Wei and Lau 1998). This suggests the potential use of AGE to prevent atherosclerosis and cardiovascular disease (Efendy et al. 1997; Wei and Lau 1998). AGE and SAC have also been reported to prevent oxidant-induced dense-body formation in sickle red blood cells, characteristic in sickle cell anemia (Onishi 1998). AGE has been shown to increase cellular glutathione in normal liver and mammary tissue (Liu et al. 1992) and its ability to increase GPx and other ROS scavenging enzymes (Wei and Lau 1998) is significant in radioprotection and UV suppression of immunity (Reeve et al. 1993), in reducing the risk of radiation and chemically induced cancer (Borek 1993) and in preventing range of ROS-induced DNA, lipid, and protein damage implicated in disease and aging processes (Gutteridge 1993). Oral administration of garlic was shown to protect against liver and kidney damage induced by $HgCl_2$ (El-Shenawy and Hassan 2008). Garlic powder has the ability to ameliorate cisplatin-induced renal injury and thus could be used as a renoprotective agent (Razo-Rodríguez et al. 2008). Administration of SAC in Wistar rats showed the inhibition of tumor incidence, modulated the lipid peroxidation, and increased the reduced glutathione, glutathione-dependent enzymes, SOD, and CAT in *N*-nitrosodiethylamine (NDEA)-induced hepatocarcinogenesis and this is due to the prevention by SAC from loss of oxidative capacity in NDEA-induced hepatocarcinogenesis (Sundaresan and Subramanian 2008). Garlic oil was found to prevent acute ethanol-induced fatty liver in mice. Garlic oil suppressed the elevation of MDA levels, restored the GSH levels, and enhanced the SOD, GR, and GST activities (Zeng et al. 2008). Aqueous extracts of garlic were evaluated for their protective effects on Cd-induced renal oxidative stress in male Wistar rats (Suru 2008). Treatment of Cd-intoxicated rats with different doses of garlic reduced the levels of LPO and GST, while the levels of GSH, SOD, CAT, and Na^+/K^+-ATPase was increased, suggesting a protective role of garlic via reduction in LPO and enhanced antioxidant defense. Similar results were reported by Obioha et al. (2009) in their study on Cd-induced oxidative damage in rats. Aqueous extracts of garlic provide protection against Cd-induced testicular oxidative damage and spermiotoxicity, possibly by reducing lipid peroxidation and increasing the antioxidant defense mechanism in rats (Ola-Mudathir et al. 2008). DAS was found to restore key steroidogenic enzymes, SDH, LDH, and G6PD and increased testicular weight significantly in male adult Wistar rats treated with cadmium. It also restored the testicular total antioxidant capacity level and increased testosterone level and relative testicular weight significantly (Sadik 2008). Garlic extract was found to reduce tissue accumulation of Cd and associated oxidative stress in freshwater catfish

(Kumar et al. 2009). AGE and SAC were shown to substantially reverse the status of parameters like liver marker enzymes aspartate transaminase (AST), alanine transaminase (ALT), and lactate dehydrogenase (LDH), enzymic antioxidants (SOD, CAT, GPx), nonenzymic antioxidants (vitamins C and E), reduced glutathione (GSH), LPO and ROS, in chromium-induced hepatocytes of Wistar rats (Kalayarasan et al. 2008). Their results further showed the promising role of Nrf2-mediated antioxidant defense of AGE and SAC against chromium. Similar results were reported for D-galactosamine- and lipopolysaccharide-induced hepatitis in rats (El-Beshbishy 2008). Das Gupta et al. (2009) reported garlic to prevent nickel II- or chromium VI-induced alterations in blood glucose homeostasis while exerting a hepatoprotective effect on glycogen levels and antioxidant status in male albino rats. The modulatory effect of SAC on CP-induced urotoxicity in mice was studied and the results showed that SAC not only improved the decreased activities of antioxidant enzymes but also showed protection in tissue histology, increased GSH levels, and reduced LPO (Bhatia et al. 2008). Treatment of cholesterol-induced hepatic steatosis in rabbits with garlic extract caused a significant increase in antioxidant potential and partly eliminated peroxide damage in the hepatic tissue and significantly reduced cholesterol levels of blood and hepatic tissues (Arhan et al. 2009). Hassan et al. (2009) studied the protective role of garlic oil against sodium nitrite ($NaNO_2$)-induced abnormalities in metabolic parameters and oxidative status in male albino rats. There was a significant increase in serum levels of glucose, AST, ALT, ALP, bilirubin, urea and creatine, as well as hepatic AST and ALT by $NaNO_2$ treatment for 3 months. There was also a significant decrease in liver ALP activity, glycogen content, and renal urea and creatinine levels. In the liver and kidney, a significant increase in lipid peroxidation and a decrease in glutathione content and CAT activity was observed. However, garlic oil supplementation showed a remarkable amelioration of these abnormalities (Hassan et al. 2009). Garlic extract was found to have a protective effect against skin cancer due in part to the induction of cellular defense systems (Das and Saha 2009). Garlic extracts inhibited the oxidative modification of lipids, thus protecting cells from injury by oxidized molecules produced by DMBA-induced skin carcinoma in Swiss albino mice. Shaarawy et al. (2009) investigated the chemopreventive effects of garlic extract and silymarin on *N*-nitrosodiethylamine (NDEA) and CCl_4-induced hepatotoxicity in male albino rats and found garlic and silymarin to have significant effect in preventing development of hepatotoxicity. Demirkaya et al. (2009) studied the effect of AGE on doxorubicin (DXR)-induced cardiotoxicity in Wistar male albino rats. Their results clearly showed the protective effects of AGE on all the parameters affected by DXR. Similar results were reported of aged garlic extract to have protective effect against DXR-induced cardiotoxicity (Alkreathy et al. 2010). Abdalla et al. (2010) found garlic extract to prevent the MeHg-induced cytotoxic effects on leukocytes and the effects on the adenosine deaminase activity. This protective effect of garlic extract is related to the removal of oxidant species generated in the presence of MeHg due to the strong antioxidant efficacy of garlic constituents.

AGE has been shown to inhibit lipid oxidation and oxidative modification of LDL (Ide and Lau 1997), platelet aggregation (Steiner 1996), suppress prostanoid

synthesis (Dimitrov and Bennink 1997), reduce serum cholesterol and other lipids (Lau et al. 1987; Steiner 1996), and inhibit lipid peroxidation-induced injury in endothelial cells (Geng and Lau 1997). These activities of AGE may help reduce accumulation of cholesterol in macrophages, smooth muscles, and blood vessel walls, thus inhibiting atherogenic fatty streaks, in anti-inflammatory, antiathrogenic, and antithrombotic effects (Efendy et al. 1997; Dimitrov and Bennink 1997), and help prevent heart disease and stroke.

Water soluble organosulfur compounds were found to protect against ROS-induced brain injury. AGE and SAC were also shown to attenuate ROS production and inhibition of brain damage caused by ischemia–reperfusion (IR), reducing post-ischemic edema, and thus having a role in protection against oxidant-induced brain damage and stroke (Numagami et al. 1996). They have also been found to inhibit TNF-α and H_2O_2-induced activation of NF-κB in human T cells, thus suggesting a role in modulating HIV replication (Geng et al. 1997). SAC treatment of rats subjected to IR was found to ameliorate the increase in blood urea nitrogen (BUN) and serum creatinine and to decrease the structural damage, thus suggesting the antioxidant properties of SAC being involved in its protective effects on renal ischemia and reperfusion injury (Segoviano-Murillo et al. 2008). Aguilera et al. (2010) found AGE to delay the effects of ischemia/reperfusion-induced neuronal injury and this neuroprotective effect of AGE could be due to the control of free-radical burst induced by reperfusion, preservation of antioxidant enzyme activity, and delay of other pathophysiological processes. Shaik et al. (2008) evaluated the effects of DAS on the warm hepatic IR injury in a rat model. The hepatoprotective effects of DAS were found to be associated with significant reductions in lipid peroxidation markers and in situ generation of superoxide in the liver and increases in glutathione levels of the liver and bile. There was a twofold increase in the protein expression of liver heme oxygenase-1 and a decrease in the protein levels and activity of CYP2E1 by DAS pretreatment. Rai et al. (2009) found DADS analogs to be effective in reducing the total lipid levels which were correlated with decrease in 3-hydroxy-3-methylglutaryl-CoA reductase (HMGR) activity in cholesterol administered Wistar rats. DADS analogs strongly inhibited HMGR activity in vivo but not in vitro. They also found DADS analogs to be effective in reducing the levels of oxidized low-density lipoprotein, lipid peroxidation as well as NF-kappaB activity, and showing good anti-inflammatory and antioxidant properties.

Allicin was found to inhibit aflatoxin-induced DNA damage and mutagenesis in *S. typhimurium*, in part by inhibiting the cytochrome P450 activity (Yamasaki et al. 1991), and preventing tumor promotion (Nishino et al. 1990). Allicin was found to induce growth inhibition and elicit apoptotic events such as blebbing, mitochondrial membrane depolarization, cytochrome c release into the cytosol, activation of caspase 9 and caspase 3, and DNA fragmentation in HL60 and U937 cell lines. This antiproliferative function of allicin involves the activation of mitochondrial apoptotic pathway by GSH depletion and changes in the intracellular redox status (Miron et al. 2008).

Garlic and its OSCs appear to have anticarcinogenic effects, and this is exerted through multiple mechanisms including modulation of carcinogen metabolism,

inhibition of DNA adduct formation, upregulation of antioxidant defenses and DNA repair systems, and suppression of cell proliferation by blocking cell cycle progression and/or inducing apoptosis (Nagini 2008; Powolny and Singh 2008; Antosiewicz et al. 2008). Thus garlic and OSCs offer promise as potential chemopreventive and chemotherapeutic agents. Garlic constituents have been shown to inhibit cancer cell growth in vivo in xenograft models (Sundaram and Milner 1996; Singh et al. 1996; Nakagawa et al. 2001; Chu et al. 2007; Zhang et al. 2008). Studies have shown that OSCs not only inhibit phase 1 enzymes but they also increase the expression of phase 2 enzymes (Shukla and Kalra 2007; Herman-Antosiewicz et al. 2007). The DADS-induced G2/M phase cell cycle arrest has been reported in human colon cancer cells (Knowles and Milner 2000), PC-3 prostate cancer cell line (Arunkumar et al. 2006), MGC803 human gastric cancer cell line (Yuan et al. 2004), and A549 lung cancer cell line (Wu et al. 2005). DATS-induced cell cycle arrest using prostate cancer cells (PC-3 and DU145) has been associated with ROS-dependent hyperphosphorylation and destruction of the cell division cycle 25C (Cdc25C) phosphatase, and also arrest in prometaphase (Antosiewicz et al. 2006; Herman-Antosiewicz and Singh 2005; Herman-Antosiewicz et al. 2007; Xiao et al. 2005). Treatment with *S*-allylmercaptocysteine (SAMC), a water soluble sulfur compound from garlic, has been shown to result in G2 and/or mitotic arrest in SW-480 and HT-29 human colon cancer cells and NIH3T3 fibroblasts (Shirin et al. 2001; Xiao et al. 2003). Allicin treatment was found to arrest human mammary cancer cells in both G0/G1 and G2/M phases of the cell cycle (Hirsch et al. 2000). Ajoene was shown to arrest G2/M phase cell cycle and disrupt cytoskeleton (Li et al. 2002). AGE has been shown to inhibit both early and late stages of carcinogenesis (Nishino et al. 1989; Reeve et al. 1993; Amagase et al. 1996). Selenium present in the AGE decreases DNA adduct formation (Amagase et al. 1996) and thus contributes to the anticarcinogenic/antioxidant effects (Borek et al. 1986). The lipid-soluble OSCs have been shown to inhibit carcinogenesis by modulating carcinogen metabolism and decreasing carcinogen binding to DNA. SAC also showed inhibition of DNA adduct formation in mammary cells (Amagase and Milner 1993; Milner 1996). Reeve et al. (1993) found AGE to protect bald mice from UV light-induced skin carcinogenesis. Allixin has been shown to inhibit tumor promotion in a multistep in vivo carcinogenesis skin tumor model and in vivo (Nishino et al. 1990). AGE and diallyl polysulfides have been shown to protect mice and cardiac cells in vitro against the cardiotoxic effects of doxorubicin by preventing doxorubicin-induced lipid peroxidation (Awazu and Horie 1997; Kojima et al. 1994). Wang et al. (1998) found AGE to inhibit lipid peroxidation in liver cells exposed to phenobarbital, a sedative and bromobenzene-3-4-oxide, an environmental toxic agent. Liver toxicity induced by benzo(a)pyrene and aflatoxin B_1, two strong free radical-producing environmental carcinogens was shown to be protected by AGE (Tadi et al. 1991). Uda et al. (2006) found AGE treated F344 rats to have significantly reduced glutathione S-transferase-P positive hepatocellular foci. Studies in mice have shown SAC and SAMC to be potent inhibitors of liver toxicity induced by industrial oxidant carbon tetrachloride and the common analgesic agent acetaminophen (Nakagawa et al. 1988). Prasad et al. (2008) studied the apoptosis-inhibiting effects of diallyl sulfide against a carcinogen,

7, 12-dimethyl benz(a)anthracene (DMBA), in Swiss albino mice. Their results showed diallyl sulfide to provide protection in mouse liver against oxidative damage induced by DMBA and thus could be an effective chemopreventive and therapeutic agent by modulating expression of cell-growth regulatory proteins. Seki et al. (2008) examined the anticancer activity of alk(en)yl sulfides from garlic using human colon cancer cells HCT-15 and DLD-1. They found the diallyl trisulfide (DATS) to significantly suppress the growth of the cells and found a specific oxidative modification of cysteine residues Cys 12 beta and Cys 354 beta, forming *S*-allylmercaptocysteines in the tubulin molecule. These results show that diallyl trisulfide is in part responsible for the epidemiologically proven anticancer effect for garlic eaters. Hosono-Fukao et al. (2009) reported that the hepatoprotective activity of trisulfides was due to their regulation of drug metabolizing enzymes. DAS and DADS-mediated apoptosis in SH-SY5Y neuroblastoma cell line and lung cancer cells (H460 and H1299) was well correlated with an increase in ratio of Bax/Bel-2 (Hong et al. 2000; Karmakar et al. 2007). The DATS treatment in LNCaP human prostate cancer cell line decreased Bcl-2 and Bcl-xl protein levels and increased Bak protein expression, and this correlated with loss of the mitochondrial membrane potential (Kim et al. 2007). The ability to disrupt microtubule network in human colon cancer cells via oxidative modification of the β tubulin at cysteine residues in positions 12 and 35 has been reported for DATS, but not DAS or DADS (Hosono et al. 2008). Das et al. (2007) reported OSC-mediated ROS generation and an increase in free intracellular calcium level. The ROS formation in DADS-induced SH-SY5Y neoblastoma cells was evident as early as 15 min after treatment and was accompanied by oxidation of cellular lipids and proteins (Filomeni et al. 2003). The ajoene-induced apoptosis in human promyeloleukemic cells was accompanied by activation of NF-κB and generation of ROS (Dirsch et al. 1998). Ajoene increased PKCdelta-dependent Nrf2 activation, GCL induction, and the cellular GSH concentration, and this may contribute to protecting cells from oxidative stress (Kay et al. 2010).

Sriram et al. (2008) studied the anticancerous effect and mode of action of DAS against Colo 320 DM colon cancer cells. DAS-induced apoptosis in Colo 320 DM cells, substantially arrested cell cycle, increased the ROS with time, and decreased the activities of ALP and LDH, suggesting antiproliferative and cytotoxic effects. Furthermore, expression of NF-κB was upregulated in DAS-treated cells, the expression of caspase-3 was promoted and extra regulatory kinase-2 (ERK-2) activity suppressed in Colo 320 DM cells. Lea et al. (2002) observed increased histone acetylation and correlated with it growth inhibition in cell culture models in response to a number of OSCs including allicin, SAMC and SAC on DS19 cells, and SAMC on Cacoo-2 human colon and T47D human breast cancer cells. Garlic DADS has been found to not only inhibit the HUVEC cell proliferation but also to attenuate activation of matrix metalloproteinase-2 (MMP-2) and MMP-9 (Meyer et al. 2004). Mousa and Mousa (2005) found allicin to inhibit fibroblast growth factor-2 and vascular endothelial growth factor (VEGF)-induced tube formation in human endothelial cells and inhibition of ex vivo neovascularization in chick chorioallantoic membrane assay. The capillary-like tube formation and migration of human umbilical vein endothelial cells were inhibited by DATS treatment (Xiao et al. 2006).

There was strong inhibition of lung metastasis in C57BL/6 mice injected with B16/BL6 melanoma cells by intraperitonial administration of ajoene (Taylor et al. 2006). Xiao et al. (2009a, b) found Bax and Bak proteins to be the critical targets of DATS-induced apoptosis in human lung cancer cells. Garlic has been found to inhibit *Heliobacter pylori* colonization, decrease gastric inflammation by inhibiting cytokine and chemokine release, and repress precancerous changes by inhibiting NF-κB DNA binding, inducing profuse levels of apoptosis, and inhibiting mutagenesis (Lee et al. 2008). Zhang et al. (2009) found DATS to significantly suppress cell proliferation of Saos-2 cells by blocking cell cycle progression and inducing apoptosis in a dose and time-dependent manner. Stan and Singh (2009) for the first time reported that DATS treatment suppressed androgen receptor (AR) function in prostate cancer cells. They found DATS treatment to inhibit synthetic androgen (R1881)-stimulated nuclear translocation of AR in LNCaP/C4-2 cells and proliferation of LNCaP cells. DAS may have value in treatment of joint inflammation because of its anti-inflammatory actions. DAS has been found to prevent IL-1beta and monosodium urate crystal-induced COX-2 upregulation in synovial cells and chondrocytes, and ameliorate crystal-induced synovitis potentially through a mechanism involving NF-κB (Lee et al. 2009a). Allylmethylsulfide (AMS), a volatile organosulfur from garlic has been shown to be a useful radioprotective agent by down-regulating the MAPKs and NF-κB signaling pathway that can be induced via X-ray irradiation (Lee et al. 2009b). Their results showed that AMS suppressed the activation of NF-κB and its dependent genes such as vascular cell adhesion molecule-1, inducible nitric oxide synthase, and cyclooxygenase-2 through inhibition of IκBalpha phosphorylation and activation of IκB kinase alpha/beta and mitogen-activated protein kinases (MAPKs). Ban et al. (2009) showed that thiacremonone, a sulfur compound isolated from garlic, exerted its anti-inflammatory and antiarthritic properties through the inhibition of NF-kappaB activation via interaction with the sulfhydryl group of NF-kappaB molecules, and thus could be a useful agent for the treatment of inflammatory and arthritic diseases. DATS-induced apoptosis in prostate cancer cells was found to be mediated in part by suppression of XIAP protein expression (Kim et al. 2011).

Garlic and AGE have been shown to have antiaging effects and could help in dementia and Alzheimer's disease. Studies on mice found AGE to prevent atrophic changes in the frontal brain, improve learning abilities and memory retention, and increase longevity in the senescence-accelerated mouse (Moriguchi et al. 1997; Nishiyama et al. 1996). *S*-allylcysteine significantly curtailed iron-(Fe^{2+}) and quinolinic acid (QA)-induced lipid peroxidation and scavenged the superoxide anion generated by 1 mM cyanide in rat brain homogenate. The assays demonstrated that it binds Fe^{2+} and Fe^{3+} and prevents redox cycling of iron, thus suggesting an additional method to reduce Fe^{2+}-induced lipid peroxidation (Dairam et al. 2008). This demonstrates a potential role for *S*-allylcysteine in the prevention or treatment of Alzheimer's disease. Garlic consumption by elderly subjects (mean age 70.69 ± 4.23) was shown to significantly lower plasma and erythrocyte MDA levels and increased activities of some antioxidant enzymes, suggesting decreased oxidation reactions due to garlic consumption (Avci et al. 2008). This reduced peroxidation process due

to garlic consumption may play a part in some of the beneficial effects of garlic in elderly subjects. Methionine sulfoxide reductase A and a dietary supplement *S*-methyl-L-cysteine found in garlic has been shown to prevent Parkinson's-like symptoms (Wassef et al. 2007). AGE and DADS have been shown to have beneficial effects against Cd-induced toxicity, and this was mediated via induction of cytoprotective enzymes in an NrF2-dependent manner (Lawal and Ellis 2011). The various allyl sulfides from garlic (DAS, DATS, and DADS) were found to have a beneficial effect in mouse liver as they decreased ROS and malondialdehyde levels and increased glutathione S-transferase activity (Iciek et al. 2012). Raw garlic homogenate was found to be effective in improving insulin sensitivity while attenuating metabolic syndrome and oxidative stress in fructose-fed rats (Padiya et al. 2011).

Combination therapy with S allyl cysteine (SAC) and clotrimazol (CLT) was shown to downregulate the apoptotic events in erythrocytes by antagonizing oxidative stress and Gardos channel that led to suppression of ceramide-initiated Fas aggregation in lipid rafts. Hence, combination therapy with SAC and CLT could be a very potential therapeutic option to enhance the life span of erythrocytes during Pb(2+) toxicity (Mandal et al. 2012). The investigation of serum superoxide dismutases, glutathione peroxidase, interleukin-2, and the increased indices of spleen and thymus indicated that the anticancer action of aged black garlic extract (ABGE) may be partly due to its antioxidant and immunomodulative effects (Wang et al. 2012).

Regulatory Status

GRAS 184.1317.

Standard

ISO 5560 (Dehydrated garlic), ISO 5567 (Dehydrated garlic-Determination of volatile sulphur compounds).

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Chapter 28
Geranium

Botanical Name: *Pelargonium graveolens* L'Her. ex Aiton.
Synonyms: Sweet-scented geranium, rose geranium.
Family: Geraniaceae.
Common Names: **French**: Geranium; **German**: Geranie; **Spanish**: Geranio; **Italian**: Geranio.

Introduction

History

Geranium oil (*Pelargonium graveolens* and *P. roseum*) has been used for centuries for skin care and for its spiritually uplifting signature. Geranium comes from various cultivars of *Pelargonium* species, which originate in Southern Africa. Pelargoniums and geraniums are generally known as geraniums due to the similar common names. The genera *Pelargonium* and *Geranium* were separated for the first time in 1789 (Hortus Kewensis). South Africa is the center of origin of the genus *Pelargonium* and the first pelargonium was *P. cucullatum* (L.) L'Herit collected from Table Mountain in 1672 by Paul Herman. The geraniums (*P. peltatum* L. and *P. zonale* (L.) L'Herit.) are believed to have been imported into the Netherlands in 1700 by William A. van der Stel and introduced to England in 1701 and 1710, respectively, and *P. graveolens* L'Herit. in 1794. Pelargoniums were exported to every country where Europe sent colonists. It reached Australia in the cabin of Arthur Bowes Smyth a surgeon on the Lady Penrhyn, part of the First Fleet. In the early nineteenth century, commercial cultivation began in Grasse, France. Plants from Grasse were later sent to Algeria in 1847 and to Reunion in the 1880s. In the mid-1930s, the plants reached USSR and Morocco for commercial cultivation. By the late nineteenth century, geranium was introduced into Israel and Egypt. Geranium oil has been produced in several East and Central African countries, principally

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Kenya. Reunion started production in 1870 and continues to produce oil. It reached the Tamil Nadu state in India around 1903, through the Frenchman Ernest Sens and later by Jacques Prioris. The Nigerian material was later planted in the Nilgiri Hills. Chinese geranium oil production also increased significantly in the Yunnan region. Geranium oil is also known as the "poor-man's rose."

Producing Regions

It is native to South Africa. Widely cultivated in Algeria, Egypt, China, France, Morocco, Russia, South Africa, Central America, and Europe. Essential oil comes mostly from, China, Egypt, Comores, Reunion, Morocco. The oils are distinguished by a country-of-origin prefix: Reunion, Egyptian, Moroccan, etc. The oil from Reunion is called Geranium Bourbon.

Botanical Description

An herbaceous perennial hairy shrub up to 1-m (3 ft) high. It has pointed leaves which are serrated at the edges. The inflorescence is axillary with small umbels of 3–7 flowers. The flowers are small and pink. The whole plant is very aromatic.

Essential oil is obtained by steam distillation of the leaves and flowering branchlets. The oil is yellowish to green, greenish-olive, brownish green mobile liquid. Yield 0.15–0.2%.

Parts Used

Essential oil, leaves.

Flavor and Aroma

Has a fruity-minty, rich sweet-herbaceous top note. The middle note is rich, sweet-rosy, quite tenacious. The dry out is sweet-rosy, herbaceous.

Active Constituents

Essential oil. The major constituents of the oil are geraniol (7–20%), citronellol (20–40%), linalool (5–15%), isomenthone, geranyl formate, citronellyl formate, 10-epi-γ-eudesmol (Egypt, Morocco, Algeria), and guaiadiene-6,9 (China). They also contain tannins, flavonoids, coumarins (Williams and Harborne 2002; Williams et al. 1997).

Preparation and Consumption

Its natural strength lies in the ability to revitalize tissue. Its aromatic influence helps release negative memories. The oil may be added to food or water as a dietary supplement. The reported uses are in baked goods, frozen dairy, soft and hard candy, gelatin and pudding, nonalcoholic beverages, and chewing gum (Fenaroli 1998).

Medicinal Uses and Functional Properties

Many *Pelargonium* species have been used as traditional medicine in Southern Africa with mainly antidysenteric properties (Watt and Breyer-Brandwijk 1962). Geranium (*Pelargonium graveolens*) has anticancer and anti-inflammatory properties and promotes wound healing. *Pelargonium reniforme* and *P. sidoides* extracts have strong antimicrobial, immunomodulatory, leishmanicidal, and interferon-like properties (Kolodziej 2002). Pelargonium oils and their constituents produce relaxation of smooth muscle through adenyl cyclase and increase in the concentration of second messenger, cAMP (Lis-Balchin and Hart 1997, 1998; Hart and Lis-Balchin 2002). Methanolic extracts of *Pelargonium* species and cultivars, and their teas, were found to have a contracticle effect initially, followed by a relaxation (Hart and Lis-Balchin 2002). Geranium oil has both a sedative and stimulant effect on the central nervous system (Lis-Balchin 2002). The essential oils of *P. grossularioides* and water-soluble and methanolic extracts were all found to be spasmogenic on guinea pig ileum and on rat uterus (Lis-Balchin et al. 1996b).

Geranium oil was found to inhibit all 12 fungi tested and 12 bacterial strains of the 22 tested (Patnaik et al. 1995). Lis-Balchin et al. (1996a, b) studies have also shown antibacterial activity against 25 different bacteria and 20 strains of *Listeria monocytogenes*, though there was some variability (Lis-Balchin et al 1996a; Lis-Balchin and Deans 1997). *Pelargonium*×*hortorum* leaves were reported as having most activity against *Candida albicans*, *Trichophyton rubrum*, and *Streptococcus mutans*, the organisms causing common dermal, mucosal, or oral infections in humans (Heisey and Gorham 1992). Flavonoids isolated from *P. radula* demonstrated strong inhibitory activity against *Staphylococcus aureus*, *Proteus rettgeri*, *Candida tropicalis*, and *Microsporum gypseum* (Pepeljnjak et al. 2005). The essential oil of *P. capitatum* was found to have antimicrobial activity against *Candida albicans* strains and antifungal activity (Guerrini et al. 2011).

Linalool a major constituent of geranium oil has a hypoglycemic effect in normal and streptozotocin-diabetic rats (Afifi et al. 1998) and a hepatic peroxisomal and microsomal enzyme induction in rats (Roffey et al. 1990). Elisabetsky et al. (1995a, b) suggested that the dose-dependent sedative effect of linalool on the central nervous system of rats could be caused by its inhibitory activity on glutamate binding in the cortex. The essential oil of geranium and its constituents have been shown to have good antimicrobial activity and insecticidal activities (Rosato et al. 2007, 2008; Jeon et al. 2009; Seo et al. 2009; Malik et al. 2011).

Antioxidant Properties

Pelargonium species, including the commercial geranium oil, have been reported to have antioxidative properties (Youdim et al. 1999; Fukaya et al. 1988; Dorman et al. 2000; Latte and Kolodziej 2004; Sun et al. 2005; Floryszak-Wieczorek et al. 2007; Piao et al. 2008; Arasimowicz et al. 2009; Koutelidakis et al. 2009; Adewusi and Afolayan 2010; Guerrini et al. 2011). Flavonoids and hydrolyzable tannins from *P. reniforme* showed higher radical scavenging activities than reference standard ascorbic acid (Latte and Kolodziej 2004). They concluded that the marked antioxidant effects of the polyphenols provide a clue for beneficial effects of *P. reniforme* in the treatment of liver disorders among several ethnic groups in areas of southern Africa. The essential oil and monomer as well as the residue and wastewater after distillation from buds, leaves, and stems of *P. graveolens* had strong antioxidant effect (Sun et al. 2005). The EtOAc fraction of *P. inquinans* had strong antioxidative activity and 1,2,3,4,6-penta-*O*-galloyl-beta-D-glucose (PGG) was the active component with an oxidative effect in this fraction (Piao et al. 2008). Koutelidakis et al. (2009) reported that *P. purpureum* exhibits antioxidant effects in vivo that may be observed not only in plasma but also in some organs. Plant extract of *P. reniforme* was shown to possess significant antioxidant activity and significant level of phenolic compounds which could be useful in treating alcoholic liver damage (Adewusi and Afolayan 2010).

Regulatory Status

GRAS 182.20 and GRAS 182.10.

Standard

ISO 4731 (Oil).

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Chapter 29
Ginger

Botanical Name:	*Zingiber officinale* Roscoe.
Synonyms:	*Amomum zingiber* L., *Zingiber zingiber* (L) Karst., Common ginger; Jamaican ginger; shunthi; ardraka.
Family:	Zingiberaceae.
Common Names:	**French**: gingembre; **German**: ingwer; **Italian**: zenzaro; **Spanish**: jengibre; **African**: tangwizi; **Hindi**: adrak; **Chinese**: kiang.

Introduction

History

The genus name *Zingiber* is probably derived from the Sanskrit *singabera* (horn shaped), via the Arabic *zanzabil*, and Greek *zingiberi*. The use of ginger predates any historical records. It is mentioned in the earliest Indian literature. It originated probably in India. The earliest Chinese record is in the Analects of Confucius (500 BC) "who was never without ginger when he ate." Ginger was introduced to Japan quite later. It reached the Middle East from India, but it is not clear whether Dynastic Egypt had it before 500 BC. It was certainly used during the time of Alexander the Great and is mentioned in *De Materia Medica* by Dioscorides, and later by Pliny. In the thirteenth century, ginger was introduced to Africa by the Arabs, and now it is a major crop in Africa. It was popular in Europe since the ninth century and is included in most herbals. Gingerbread was popular in England during the reign of Queen Elizabeth I. Around 2400 BC, a baker on the isle of Rhodes, near Greece, prepared the first gingerbread, and later it reached Egypt who savored and served it on ceremonial occasions. Marco Polo mentions ginger in the late thirteenth century. Vasco da Gama at the end of the fifteenth century mentions ginger being shipped to Europe from the Malabar Coast via Cairo. Tariff duties appear in the records of Marseilles

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in 1228 and in Paris by 1296. Portuguese introduced ginger to their West African colonies in the sixteenth century. The Spaniard, Francesco de Mendoza, carried rhizomes to Mexico shortly after Columbus, and ginger subsequently spread throughout Central America and the Caribbean islands. In the 1800s, ginger was sprinkled on top of beer or ale, then slowly stirred into the drink with a hot poker—thus the invention of ginger ale.

Producing Regions

It is native to Asia probably northeastern India. Widely cultivated in tropical and subtropical countries including Nigeria, India, Sri Lanka, Africa, Jamaica, China, Japan, and Australia. The Indian and Jamaican ginger are considered superior in quality.

Botanical Description

An herbaceous erect, leafy perennial herb up to 1-m (2–4 ft) high with palmately branched rhizome-bearing leafy shoots. It has tuber-like rhizomes with green reed like stalk and narrow spear-shaped leaves and white or yellow flowers on a spike direct from the root. Each flower has three yellowish orange petals with a purplish, lip-like structure. The plant propagates by the splitting of the rhizomes. The rhizome is harvested when a year old, washed and dried to a moisture content of less than 12%.

Parts Used

Rhizome (dried or fresh), ground ginger, essential oil, oleoresin. Ground ginger is light bone to tan. Fresh ginger is preserved and crystallized. The fresh form comes whole (unpeeled), sliced, chopped, crushed, or grated. Dried ginger is used sliced or powdered.

Flavor and Aroma

Warm, sweet, pungent, and aromatic. Fresh ginger has somewhat spicy, juicy, and refreshing lemon-like aroma. The flavor of ginger is characterized by its unique combination of lemon/citrus, soapy, and musty/earthy flavor notes. It is warming to taste. It is fiery and pungent.

Table 29.1 Nutrient composition and ORAC values of ginger ground

Nutrient	Units	Value per 100 g
Water	g	9.94
Energy	kcal	335
Protein	g	8.98
Total lipid (fat)	g	4.24
Carbohydrate, by difference	g	71.62
Fiber, total dietary	g	14.1
Sugars, total	g	3.39
Calcium, Ca	mg	114
Vitamin C, total ascorbic acid	mg	0.7
Vitamin B-6	mg	0.626
Vitamin B-12	mcg	0.00
Vitamin A, RAE	mcg_RAE	2
Vitamin A, IU	IU	30
Vitamin D	IU	0
Fatty acids, total saturated	g	2.599
Fatty acids, total monounsaturated	g	0.479
Fatty acids, total polyunsaturated	g	0.929
H-ORAC	μmol TE/100 g	9,154
L-ORAC	μmol TE/100 g	29,887
Total-ORAC	μmol TE/100 g	39,041
TP	mg GAE/100 g	669

Source: USDA National Nutrient Database for Standard Reference, Release 24 (2011)

Active Constituents

Dried rhizomes contain moisture 10.9%, protein 12%, crude fiber 7%, starch 46%, water extract 20%, alcohol extract 6%, ash 7%, vitamins (niacin and vit. A), minerals, and volatile oil 2%. The major constituents in the essential oil are zingiberene (40%) and ar-curcumene (20%). The warm pungent taste is caused by the nonvolatiles such as gingerols, shogaols, paradols, and zingerone which account for many of its health beneficial effects (Kundu et al. 2009). The nutritional constituents and ORAC values of ground ginger are given in Table 29.1.

Preparation and Consumption

Freshly ground ginger is used in the processed food industry, bakery products especially gingerbread and biscuits, preserves, desserts, mixed spices, and is an ingredient in some curry powders, pickles, sauces and chutneys, ginger beer, wine, and cordials. Dried ginger is used for sauces and soups. It is widely used in Oriental cooking. The Chinese use fresh, pickled, and preserved ginger for spicy, sweet

flavors with rice porridges, soups, and stir-fried vegetables. Fresh ginger is essential to Asian and Oriental cooking. Great for meat, fish, chicken, fruit sauces, and green salads. In England it is utilized in great quantities in the production of ginger ale and ginger beer. Europeans and North Americans traditionally preferred the dried, crystallized, or preserved forms.

Medicinal Uses and Functional Properties

Fresh or dried rhizomes or extracts are important ingredients of stomachics and tonics to treat dyspepsia and nausea (especially travel sickness). In China, the main use of fresh ginger is for treating fever, coughs, and nausea, while dried ginger is used against stomach pain and diarrhea (Iwami et al. 2011). Ginger is antibacterial, antifungal, antiparasitic, anthelmintic, and molluscicidal (Keskin and Toroglu 2011). It has hypoglycemic, cholesterol lowering, immune-stimulant, and anti-inflammatory properties. Ginger also has antiulcer and cholagogue effects. It stimulates peristalsis and the secretion of saliva and gastric juices.

The compounds, gingerols, shogaols, paradols, and zingerone, are some of the extensively studied phytochemicals of ginger and account for the antioxidant, anti-inflammatory, antiemetic, hepatoprotective, and gastroprotective activities (Atta et al. 2010; Al-Suhaimi et al. 2011; Nievergelt et al. 2011; Shim et al. 2011). A number of preclinical investigations with different assay systems and carcinogens have shown that ginger and its compounds possess chemopreventive and antineoplastic effects. The cancer preventive activities of ginger are supposed to be mainly due to free radical scavenging, antioxidant pathways, alteration of gene expressions, and induction of apoptosis, all of which contribute towards decrease in tumor initiation, promotion, and progression.

Ginger can be effectively used for the behavioral radioprotection and efficiently mitigating radiation-induced taste aversion (CTA) in both male and female species, because of its antioxidant, radioprotective, and neuromodulatory properties (Haksar et al. 2006). Gingerols were found to have antimicrobial activity against *Bacillus subtilis* and *E. coli* (Yamada et al. 1992) and Mycobacterium (Galal 1996; Hiserodt et al. 1998). The essential oil and different oleoresins showed good to moderate inhibitory activity against several fungi and bacteria (Singh et al. 2008). Ginger is involved in conditions such as arteriosclerosis (Kiuchi et al. 1992) and carcinogenesis (Shukla and Singh 2007; Manju and Nalini 2006; Krishnaswamy 2008). Ginger was found to be effective against gastric problems, have antiulcer activity (Yamahara et al. 1990; Yoshikawa et al. 1994), dysmenorrhea patient's abdominal pain (Yang et al. 2008), and chemotherapeutic effects (Kundu et al. 2009). Gingerol was found to inhibit skin cancer and thus have antitumor properties (Park et al. 1998). Ginger was shown to inhibit hypercholesterolema and check cholesterol biosynthesis (Tanabe et al. 1993). It reduced the release of prostaglandin and thromboxane in lung parenchyma, suggesting its role as anti-inflammatory (Aimbire et al. 2007). Ginger treatment of cultured ovarian cancer cells was found to significantly inhibit

growth in all cell lines, and 6-shogaol was the most active of all the different ginger components tested (Rhode et al. 2007). Furthermore, ginger treatment inhibited NF-κB activation and diminished the secretion of vascular endothelial growth factor and Interleukin-8. Sang et al. (2009) compared the anticarcinogenic and anti-inflammatory activities of three major gingerols and their corresponding shogaols. They found the shogaols ([6], [8], [10]) to possess stronger inhibitory effect on H-1299 human lung cancer cell and HCT-116 human colon cancer cells than the gingerols ([6], [8], [10]). Moreover, [6]-shogaol had stronger inhibitory effects than [6]-gingerol on arachidonic acid release and NO synthesis. Dietary ginger phytochemicals were shown to target cholesterol metabolism and fatty acid oxidation in mice, with antiobesogenic and also hypercholesterolemic consequences (Beattie et al. 2011). Chang et al. (2012) reported that zingerone, one of the active components of ginger can be recommended as a supplement to shrimp feed to increase growth, immunity, and disease resistance against the pathogen, *V. alginolyticus*. Ginger showed renoprotective effects in both models of renal failure and these protective effects could be attributed at least in part to their anti-inflammatory properties as evident by attenuating serum C-reactive protein levels and antioxidant effects as evident by attenuating lipid peroxidation marker, malondialdehyde levels, and increasing renal superoxide dismutase activity (Mahmoud et al. 2012).

Antioxidant Properties

Ginger contains up to 12 important compounds that provide as much as 40 times higher antioxidant activity than vit. E. Ginger has been found to have excellent antioxidant properties (Nair et al. 1998; Wang et al. 2003, 2010; Masuda et al. 2004; Rababah et al. 2004; Shin et al. 2005, 2011; Ninfali et al. 2005; Ajith et al. 2007; Asnani and Verma 2007; Suganthi et al. 2007; Chen et al. 2007; Ansari et al. 2006; Adhikari et al. 2007; Tao et al. 2008; Chohan et al. 2008; Suresh et al. 2010; Ghasemzadeh et al. 2010a, b; Hsu et al. 2010; Prakash and Srinivasan 2010; Shimoda et al. 2010; Shanmugam et al. 2010, 2011; Al-Suhaimi et al. 2011; Lee et al. 2011; Motawi et al. 2011; Onwuka et al. 2011; Ramudu et al. 2011; Wattanathorn et al. 2011; Singh and Kaur 2012). Gingerol, a component of ginger has been shown to extend shelf life of fermented meat sausage (Al-Jalay et al. 1987), meat (Ziauddin et al. 1995), dehydrated pork (Fuijo et al. 1969), and inhibit linoleic acid autoxidation (Kikuzaki and Nakatani 1993). Different gingerols and 6-shogaol from ginger were studied for their antioxidant and anti-inflammatory activities (Dugasani et al. 2010). They found 6-shogaol to possess the most potent antioxidant and anti-inflammatory properties, while 10-gingerol was the most potent among the gingerols. Ginger diarylheptanoids and a monoterpenoid protected lipid peroxidation in mouse liver hepatocytes exposed to oxidative stress (Tao et al. 2008). Ethanol was found to significantly decrease the enzymes SOD, CAT, GPx, GR, and glutathione (GSH) content and increase MDA levels in the heparic tissue in ethanol-treated rats. However, treatment of rats with 1% dietary ginger for 4 weeks reduced these

effects of ethanol suggesting a protective role of ginger (Mallikarjuna et al. 2008). Shati and Elsaid (2009) in their studies found a significant increase in NO and MDA level in liver and brain of mice and significant decrease in total antioxidant capacity, GPx activity in alcoholic group. There was also a significant increase in the liver function enzymes in alcoholic group. However, these changes in liver and brain tissues of mice were significantly ameliorated by water extract of ginger. Lindane administration to male albino rats was shown to enhance lipid peroxidation and reduce antioxidant defenses in rats on normal diet. But in these rats addition of ginger in the diet attenuated lipid peroxidation by modulating oxygen free radical scavenging enzymes and reduced glutathione and the enzymes GPx, GR, GST (Ahmed et al. 2008). El-Abhar et al. (2008) in their studies on ulcerative colitis (UC), found ginger extract to have a significant effect against acetic acid-induced ulcerative colitis in male Wistar rats by its anti-inflammatory and antioxidant properties. In ginger plus doxorubicin (DXN) treated rat groups, the MDA, GSH levels, and activities of the enzymes GST, SOD, CAT, GPx were restored compared to control groups, suggesting gingers nephroprotection due to decline of renal antioxidant status (Ajith et al. 2008). The essential oil and oleoresins of ginger were found to be better antioxidants than BHA by several different methods (Singh et al. 2008). Several compounds isolated from ginger were found to significantly decrease lipopolysaccharide-induced nitric oxide production and significantly reduce inducible nitric oxide synthase expression (Koh et al. 2009). Jung et al. (2009) in their studies found the hexane extract to attenuate mRNA expressions and protein levels of iNOS, COX-2, and proinflammatory cytokines. It thus exhibits anti-inflammatory properties because it can suppress the transcription of inflammatory mediator genes through the MAPK and NF-kB signaling pathways. El-Sharaky et al. (2009) found bromobenzene (BB) to significantly decrease the activities of antioxidant enzymes (SOD, GPx) and GSH level and enhance the activities of GR, GST, and Cyt P450. It also enhanced the production of NO products and activated COX-2 and caspase-3. However, prior to BB treatment, pretreatment with different doses of GE alleviated the toxic effects in three animal groups. Uz et al. (2009) found reactive oxygen species (ROS) to play a role in the ischemia/reperfusion (I/R)-induced renal injury and dietary ginger to play and exert renoprotective effects by radical scavenging and antioxidant activities. Asnani and Verma (2009) found significantly higher lipid peroxidation, and lowered levels of glutathione and ascorbic acid, and SOD, CAT, GPx in the liver of paraben-treated mice than control groups. However, the paraben-induced lipid peroxidation in mice liver was ameliorated by oral administration of an aqueous extract of ginger. Ginger essential oil was shown to have strong antioxidant activity by DPPH and FRAP methods (El-Ghorab et al. 2010). The phenolic constituent of ginger, (6)-paradol was shown to have potent chemopreventive, antilipid peroxidative, and antioxidant potentials as well as a modulating effect on phase II detoxification enzyme and reduced glutathione (GSH) in DMBA-induced hamster buccal pouch carcinogenesis (Suresh et al. 2010). Kim et al. (2010) from their studies found that zingerone (a major compound in ginger root) treatment exerts a beneficial efficacy by suppressing both oxidative stress and age-related inflammation through the modulation of several key proinflammatory genes and

transcription factors. The pungent ingredient [6]-gingerol of ginger exhibited preventive and/or therapeutic potential for the management of Alzheimer disease via the augmentation of antioxidant capacity. It effectively suppressed Aβ(25–35)-induced intracellular accumulation of reactive oxygen and/or nitrogen species and restored Aβ(25–35)-depleted endogenous antioxidant glutathione levels (Lee et al. 2011). The upregulation of heme oxygenase-1 expression by zerumbone was mediated through activation of Nrf2 signaling, which provides a mechanistic basis for the chemopreventive effects of this sesquiterpene on mouse skin carcinogenesis. It suppressed the intracellular accumulation of ROS (Shin et al. 2011). Ginger was found to exhibit a neuroprotective effect by accelerating the brain antioxidant defense mechanisms and downregulating the MDA levels to normal levels in diabetic rats (Shanmugam et al. 2011). The pesticides dichlorvos and lindane administration alone and in combination were found to increase the LPO and decrease the GSH level, SOD, CAT, GPx, GST, GR, QR activity, and protein. However, post-treatment with ginger juice decreased the LPO and increased the levels of GSH, SOD, CAT, GPx, GST, GR, QR activity, and protein in the brain of rats (Sharma and Singh 2012).

Regulatory Status

GRAS 182.10 and GRAS 182.20.

Standard

ISO 1003 (Specification), ISO 13685 (Ginger and its oleoresins).

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Chapter 30
Horseradish

Botanical Name: *Armoracia rusticana* P. Gaertn, et al.
Synonyms: *Cochlearia armoracia*, *Armoracia lapathifolia*.
Family: Brassicaceae or Cruciferae.
Common Names: **French**: grand raifort; **German**: Meerrettich, Kren; **Italian**: cren, rafano; **Spanish**: rabano picante.

Introduction

History

Horseradish is an ancient plant that has been used in European dishes since the Middle Ages. The Egyptians knew about horseradish as far back as 1500 BC. Early Greeks used horseradish as a rub for low back pain and an aphrodisiac. It is believed and said that horseradish was one of the bitter herbs (along with coriander, horehound, lettuce, and nettle) that the Jews ate during the feast of Passover. It is still used in the Passover Seder. Ancient herbalist Pliny mentions horseradish as being good for medicine, but not as food. Gerard (1975) says that it does not grow well with grapevines: "if the rootes heerof be planted neere to the vine, it bendeth backward from it as not willing to have fellowship with it." Gerard (1633) claimed that "boiled horseradish leaves mixed with wine and olive oil would reduce swelling and aching of the joints while the extract made from the crushed roots would expel intestinal worms." It has been used as a flavor accompaniment for beef, chicken, and seafood, by the Englishman, since the late 1600s. Legend has it that the Delphic oracle told Apollo, "The radish is worth its weight in lead, the beet its weight in silver, the horseradish its weight in gold." The German word "meerrettich" (sea radish) means "grows by the sea." Many believe the English mispronounced the German word "meer" and called it "mareradish." However, it became known as horseradish. The word "horse" (as applied in "horseradish") is believed to denote large size and

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coarseness. “Radish” comes from the Latin radix meaning root. Early settlers brought horseradish to North America and began cultivating it in the colonies. It was common in the northeast by 1806, and it grew wild near Boston by 1840. Commercial cultivation in America began in the mid-1850s, when immigrants started horseradish farms in the Midwest.

Producing Regions

Horseradish is native to Europe and Asia, but has become naturalized in North America, possibly from the Volga-Don area in Eastern Europe. Some consider it originated in Hungary or other parts of Eastern Europe, as far east as Russia and as far north as Finland. Cultivation dates back only to about Roman and Greek times, about 2,000 years ago (Simon et al. 1984; Brown 2002). It probably was introduced into Western Europe in the thirteenth century. Today it is found on all continents.

Botanical Description

Horseradish is a leafy, herbaceous perennial herb of the mustard family growing up to 1.2 m (4 ft) high. The top of the plant consists of a rosette of large paddle-shaped leaves and a flower stalk. It has large, long dark green leaves arising directly from a thick taproot. The flowers are small and white with a sweet honey scent on long flowering stalks of up to 1 m high (2–3 ft). Root sections are planted in the spring and harvested in autumn. The roots develop entirely underground and can grow to a meter (3 ft) in length. The roots and rhizomes are hardy and can be harvested as needed.

Parts Used

Root. Leaves. Fresh roots are sold sliced, grated, or shredded. The dried comes flaked, granulated, or powdered. The grated roots and rhizomes are used in making the horseradish sauce. Grated horseradish sauce is used in different dishes around the world.

Flavor and Aroma

Powerful, pungent, biting, sharp aroma. The flavor is strong, very hot, and very sharp. The immediate impact of aroma and flavor is due to the conversion of sinigrin by myrosinase.

Table 30.1 Nutrient composition of horseradish prepared

Nutrient	Units	Value per 100 g
Water	g	85.08
Energy	kcal	48
Protein	g	1.18
Total lipid (fat)	g	0.69
Carbohydrate, by difference	g	11.29
Fiber, total dietary	g	3.3
Sugars, total	g	7.99
Calcium, Ca	mg	56
Vitamin C, total ascorbic acid	mg	24.9
Vitamin B-6	mg	0.073
Vitamin B-12	mcg	0.00
Vitamin A, RAE	mcg_RAE	0
Vitamin A, IU	IU	2
Vitamin D	IU	0
Vitamin E (alpha-tocopherol)	mg	0.01
Fatty acids, total saturated	g	0.090
Fatty acids, total monounsaturated	g	0.130
Fatty acids, total polyunsaturated	g	0.339

Source: USDA National Nutrient Database for Standard Reference, Release 24 (2011)

Active Constituents

The fresh root is rich in glucosinolates (mustard oil glycosides) of which gluconasturtiin and sinigrin are the main compounds. Distillation of the dried and powdered root gives about 0.05–0.2 volatile oil. During drying, the glucosinolates are hydrolyzed by myrosinase to yield phenylethyl isothiocyanate and allyl isothiocyanate, respectively, that are present in the volatile oil. The active constituents are sinigrin (a glycoside, combined with water yields mustard oils), asparagines, and resin (Karnick 1994). Root also contains coumarins, phenolic acids, and ascorbic acid. The root is rich in the enzyme peroxidase and is a commercial source. It is very high in vitamin C. The nutritional constituents of ground prepared horseradish are given in Table 30.1.

Preparation and Consumption

It is a perfect accompaniment for rich or fatty foods. It can be used for beef, steaks, and venison or served with a strong fish like mackerel, tuna, or smoked trout. Horseradish is made into sauce with vinegar and cream that can be used with roast beef, cold chicken, or hard-boiled eggs. It is used as a condiment with beets in Eastern Europe. The British are known for their roast beef and horseradish sauce. As a spice, horseradish root is generally grated and mixed with salt, vinegar, and

other flavorings to make sauce or relish. The grated roots are used alone or in combination with apples, as a spice for fish. The leaves are used in salads and sandwiches. The plant is also used as an ingredient in ketchups and mustards. Horseradish is generally recognized as safe for human consumption as a natural seasoning and flavoring. French chefs use horseradish in most of their gourmet sauces by blending it with lemon juice and heavy cream. Wasabi (*Wasabi japonica*) is the Japanese answer to horseradish and is also known as the mountain hollyhock.

Medicinal Uses and Functional Properties

Horseradish has been traditionally used to treat bronchial conditions and urinary tract infections. Externally, it is applied as a counter-irritant to treat rheumatism and inflammation. It has antioxidant, antimicrobial, spasmolytic, cytotoxic, and skin irritant (hyperemic) properties, and this is attributed to the isothiocyanates. It is claimed to be used to treat general debility, arthritis, gout, urinary infections, respiratory infections, and fevers.

The fresh root is said to be antiseptic, diuretic, rubefacient, stomachic, stimulant, and vermifuge. It is applied externally as a poultice for infected wounds, inflammation of the pleura, arthritis, and inflammation of the pericardium (Phillips and Rix 1993; Brown 2002). The roots of horseradish are also used as a digestive stimulant, diuretic, to increase blood flow and also in rheumatism (Karnick 1994). Park et al. (2006) studied the fumigant activity of horseradish essential oil and reported that it had strong insecticidal activity against larvae of *L. ingénua*. Horseradish ethanol extracts had strong fungistatic activity against *Sclerotium rolfsii* Sacc., *Fusarium oxysporum* Schlecht., and *F. culmorum* (Tedeschi et al. 2011). Horseradish (*Armoracia rusticana*) was shown to modulate the adaptive response induced by zeocin in human lymphocytes and thus could play an important role in the field of medicine (Hudecova et al. 2012). Allyl isothiocyanate isolated from horseradish showed good insecticidal efficacy against the four stored-product pests, maize weevil *Sitophilus zeamais* (Motsch.), lesser grain borer *Rhizopertha dominica* (F.), *Tribolium ferrugineum* (F.), and book louse *Liposcelis entomophila* (Enderlein), with nongaseous residuals on stored products (Wu et al. 2009). Horseradish roots in a pilot scale study were found to make a complete removal of phenolic odorants (with a detection limit of 0.5 mg L^{-1}) from the swine slurry (Govere et al. 2007). Weil et al. (2005) reported for the first time the COX-1 enzyme and cancer cell growth inhibitory monogalactosyl diacylglycerides from wasabi and horseradish rhizomes.

Antioxidant Properties

Horseradish is high in glucosinolates which have strong antioxidant properties. Horseradish peroxidase (HRP), monophenol monooxygenase (tyrosinase), and catechol oxidase (laccase) are enzyme-based biosensors that are most commonly used for the detection of polyphenols and flavonoids content (Litescu et al. 2011). Kawaoka

et al. (2003) demonstrated that overexpression of the horseradish (*Armoracia rusticana*) peroxidase prxC1a gene stimulated the growth rate of tobacco (*Nicotiana tabacum*) plants. They also showed that the overexpression of the prxC1a gene in hybrid aspen resulted in higher peroxidase activity levels toward guaiacol and ascorbate in the cytosol. Growth rates and resistance to oxidative stress of transformed plants under greenhouse conditions also increased (Kawaoka et al. 2003).

Regulatory Status

GRAS 182.10.

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Chapter 31
Hyssop

Botanical Name: *Hyssopus officinalis* L.
Synonyms: Azob.
Family: Lamiaceae (Labiatae).
Common Names: **French**: hyssope; **German**: Ysop; **Italian**: Issopo; **Spanish**: Hisopo.

Introduction

History

The Greek *hyssopos* may have been derived from the Hebrew *ezob*, or holy herb, as it was used to purify temples and the ritual cleansing of lepers. It is mentioned in the Bible ("Purge me with hyssop and I shall be clean; wash me, and I shall be whiter than snow"—Psalm 51: 7); however, it is believed that it could have been savory or oregano or marjoram. But recent research suggests it could be the biblical plant, because the mold that produces penicillin grows on its leaf. This could have been the antibiotic protection when lepers bathed in hyssop. In Exodus 12: 22, Moses is quoted, describing the rite of Passover: "And ye shall take a bunch of hyssop, and dip it in the blood…." In 1 Kings 4: 33, about Solomon, "And he spake of trees, from the cedar tree that [is] in Lebanon even unto the hyssop that springeth out of the wall." It is also mentioned in the Bible in Leviticus 14: 4, 6, 49, 51, 52; Numbers 19: 6, 18; Hebrews 9: 19. In John 19: 29: "Now there was set a vessel full of vinegar: and they filled a spunge with vinegar, and put [it] upon hyssop, and put [it] to his mouth," Christ is given the hyssop when he makes his thirst known. Seventeenth-century herbalist Nicholas Culpeper called hyssop "a most violent purgative." M. Grieve in A Modern Herbal writes "it will improve the tone of a feeble stomach." A wine called *hyssopites* made from hyssop is mentioned by Pliny in the first century AD. The Benedictine monks used this herb in their liqueurs, in the tenth century.

D.J. Charles, *Antioxidant Properties of Spices, Herbs and Other Sources*,
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Producing Regions

Hyssop is native to southern and southeastern Europe. It grows wild in America, Europe, and Russia. It is found in India in the Himalayas from Kashmir to Kumaon. It is cultivated mainly in France, Hungary, Yugoslavia, and Albania.

Botanical Description

An erect, hardy, shrubby, evergreen perennial shrub up to 25–75-cm (9–26 in.) high, with short, branched, rhizomes, square stems, small opposite lance-shaped leaves, and attractive deep blue or violet flowers arranged in oblong, terminal clusters on long narrow spikes. The leaves are linear-oblong, lanceolate, obtuse, green, and fragrant, with oil bearing glands. It has a pleasant, aromatic flavor.

Parts Used

Fresh or dried leaves, flowers, essential oil.

Flavor and Aroma

Sweet, camphoraceous, spicy, and minty aroma. Warm, bitter aromatic, and mint-like taste. The essential oil has a warm, aromatic, sweet-camphoraceous aroma.

Active Constituents

Rich in flavonoids (6–9% diosmin) and phenolic acids (rosmarinic acid), diterpenoid lactones (marrubiin) and triterpenoids (oleanolic acid), essential oil (around 1%). Major constituents in the essential oil are pinocamphone (50%), iso-pinocamphone, and β-pinene (14%). Hyssop contains significant amounts of bitter and antioxidative tannins (Galambosi et al. 1993; Kerrola et al. 1994).

Preparation and Consumption

Hyssop goes well with vegetables, beans, dips, cheese spreads, salads, and meats. The leaves and flowers can be dried for use in teas. The flowers can be tossed in salads. The minty leaves and flowers can be used to flavor green salads, chicken soup, fruit soup, fruit salads, liqueurs, lamb stew, poultry stuffing, fish, and meat

products. It is also used in the preparation of perfumes and liquor. The essential oils are an important ingredient in the formulation of Benedictine and Chartreuse liqueurs.

Medicinal Uses and Functional Properties

Traditionally used to treat jaundice, dropsy, and respiratory ailments (coughs, bronchial inflammation, and nasal congestion). It is also used in eyewashes and as a gargle. It has antiseptic, spasmolytic, and stimulant properties. A tea of hyssop herb is effective in nervous disorders and toothache. The leaves are stimulating, stomachic, carminative, and colic, and the leaf juice is used to treat roundworms.

The essential oil of hyssop was found to have strong antimicrobial activity, and this activity was attributed to the linalool and 1,8-cineole in the essential oil (Mazzanti et al. 1998). The oil also exhibited high levels of virucidal activity against acyclovir-sensitive strain KOS and acyclovir-resistant HSV-1 clinical isolates and reduced plaque formation significantly (Schnitzler et al. 2007). Hyssop extracts contain caffeic acid, tannins, and other high-molecular-weight compounds that exhibit strong anti-HIV activity and could be used to treat patients with AIDS (Kreis et al. 1990). Gollapudi et al. (1995) found a polysaccharide (MAR-10) isolated from an aqueous extract of hyssop to contain strong HIV-1 activity and could be useful in the treatment of patients with HIV-1 infection. Miyazaki et al. (2003) found hyssop extracts to inhibit the digestion of complex carbohydrates, but not that of absorbable monosaccharide, and might be a useful supplement for hyperglycemia. The aqueous methanol extract of dried hyssop was found to contain alpha-glucosidase activity (Matsuura et al. 2004). *Hyssopus officinalis* L. probably regulates the differentiation of Th1, Th2, and Th17 on transcription level to play the role of anti-inflammatory (Wang et al. 2011). The essential oils of hyssop and coriander had limited effect (in the concentrations applied) on preserving vacuum-packed minced beef (Michalczyk et al. 2012).

Antioxidant Properties

It was reported that the active antioxidant components can be isolated from the alcoholic extract of *H. officinalis*. Dragland et al. (2003) evaluated a variety of herbs for their total antioxidant content to elucidate whether intake of herbs is a significant contributor to antioxidant intake. Hyssop leaves from different origins were used in this study. The total antioxidants varied from 30 to 49.8 mmol/100 g and were found to be intermediate among the culinary herbs tested in this study. Compounds quercetin 7-*O*-β-D-apiofuranosyl-(1 → 2)-β-D-xylopyranoside, quercetin 7-*O*-β-D-apiofuranosyl-(1 → 2)-β-D-xylopyranoside 3′-*O*-β-D-glucopyranoside, apigenin, apigenin 7-*O*-β-D-glucopyranoside, apigenin 7-*O*-β-D-glucuronopyranoside methyl

ester,luteolin,apigenin7-*O*-β-D-glucuronide,apigenin7-*O*-β-D-glucuronopyranoside butyl ester, luteolin 7-*O*-β-D-glucopyranoside, diosmin, and acacetin 7-*O*-α-l-rhamnopyranosyl-(1 → 6)-β-D-glucopyranoside, isolated from hyssop, and the extract of *H. officinalis* possessed good antioxidant activity (Wang and Yang 2010).

Regulatory Status

GRAS 182.10 and GRAS 182.20.

Standard

ISO 9841 (Oil).

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Chapter 32
Juniper

Botanical Name: *Juniperus communis* L.
Synonyms: Common juniper, Baccae juniperi.
Family: Cupressaceae.
Common Names: **French**: Baies de genievre, genievrier; **German**: Wacholderbeeren, Gewohnlicher Wacholder; **Italian**: ginepro; **Spanish**: enebro comun.

Introduction

History

The name "gin" comes from the word for Juniper in several European languages, including *genever* (Dutch) and *genievre* (French). Galen, a Greek physician, testified that the "fruit cleanses the liver and kidneys; it maketh gross tumors thin; it dries up hemorrhoids and induces menstruation; taken in large quantities it causes griping and gnawing of the stomach." Even today, juniper is used as a Christmas time decoration in some countries, in remembrance of a legend about Mary and the infant Jesus. When Mary and Joseph fled with the baby Jesus to Egypt, at one point they were almost overtaken. Trying desperately to hide, Mary could find only a small juniper tree. At the last moment the tree spread its limbs and Mary hid Jesus underneath the branches. The soldiers could only see an old man walking with a young woman, and did not stop to investigate. Thereafter, juniper was dedicated to the Virgin Mary. In rural Europe, there was a custom of hanging a branch of Juniper over the front door of the house to keep out witches. Juniper was burnt to keep away evil spirits, dispel the corruptions of the air that carried plague, drive off snakes and other poisonous creatures, purify the air in temples in preparation for ceremonies, and freshen the air in rooms. Dioscorides, in his *Materia Medica*, about 100 AD

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wrote “the juice expressed from the juniper berries was an excellent remedy for coughs, chest infirmities, stomach gas problems associated with mothers and stomach cramps.”

Producing Regions

Juniper is native to the northern hemisphere and grows in dry areas in Europe, Asia, Africa, and North America. It is widely distributed throughout the USA, central and north Europe, and temperate zones of Asia. Berries are wild harvested in several countries.

Botanical Description

An evergreen perennial shrub that may reach up to 5-m (15 ft) high, with bluish-green narrow needle-like leaves. Has an irregular reddish brown stem, and the leaves are terminated by a sharp thorn. The needles are straight, sharp, short and ridged, protruding at right angles to the branches. Inconspicuous male and female flowers on separate plants. The berries are round and blue-violet in color.

Parts Used

Berry (mature, dried female cone), essential oil. The berry is used whole, crushed lightly, or coarsely ground.

Flavor and Aroma

Has a very characteristic spicy, piney, acrid aroma. Sweet, aromatic, and spicy. Warm piney taste.

Active Constituents

Essential oil (0.5–1%). Major constituents in the oil are α-pinene (35%), myrcene (30%), β-pinene, sabinene, limonene, *p*-cymene, some sesquiterpenes (caryophyllene, elemene, cadinene) (Orav et al. 2010; Pepeljnjak et al. 2005). Sugar 30%, phe-

nolics (3–4%), catechol tannins 3–5%, flavonoids, and proanthocyanins. Hypolaetin-7-pentoside and quercetin-hexoside are the main flavonoid compounds (Miceli et al. 2009). Methanol and aqueous branch extracts of juniper had polyphenols, coumarins, lignans, steroids, alkaloids, and terpenes (Marino et al. 2010).

Preparation and Consumption

Berries are used in gin and also in alcoholic bitters. It is used to flavor marinade, pot roasts, liver pate, pickled meat, Sauerkraut, game, stews, and soups. The Germans make *Latwerge* that is used in many delicatessen-style sliced meats. In Europe, berries are used to marinate wild game and high-fat poultry, curing smoked meats, and to flavor sauerkraut and sauces. Extracts and oils are used in alcoholic and nonalcoholic beverages, frozen dairy desserts, baked goods, meat and meat products.

Medicinal Uses and Functional Properties

Traditionally used as diuretic and as urinary antiseptic, also as stomachic, carminative, and for dyspepsia. To treat flatulence, colic, snakebite, and intestinal worms.

Juniper has been shown to possess anti-inflammatory and diuretic effect and antioxidant, fungicide, anticholinesterase, antimicrobial, and antibacterial properties (Taviano et al. 2011; Ennajar et al. 2009, 2010, 2011; Ozturk et al. 2011; Marino et al. 2010; Neves et al. 2010; Lawrence and Palombo 2009; Martz et al. 2009; Miceli et al. 2009, 2011; Dzharullaeva 2009; Wei and Shibamoto 2007; Samoylenko et al. 2008; Al-Mustafa and Al-Thunibat 2008; El-Ghorab et al. 2008; Schepetkin et al. 2005; Lim et al. 2002; Acuna et al. 2002; Burits et al. 2001; Angioni et al. 2003; Filipowicz et al. 2003). The methanol extracts of juniper berries showed good antimicrobial activity against Gram-positive bacteria (Miceli et al. 2009). The antimycobacterial activity of *Juniperus communis* was attributed to a sesquiterpene longifolene and two diterpenes, characterized as totarol and trans-communic acid (Gordien et al. 2009). The volatile oils of juniper exhibited considerable inhibitory effects against 11 different strains of Gram-positive and Gram-negative bacteria (Wanner et al. 2010). Juniper berry essential oil showed similar bactericidal activities against Gram-positive and Gram-negative bacterial species, as well as a strong fungicidal activity against yeasts, yeast-like fungi, and dermatophytes (Pepeljnjak et al. 2005). The essential oil of *J. communis* had good repellant activity against ticks and mosquitoes (Carroll et al. 2011). Imbricatolic acid isolated from methanolic extract of *Juniperus communis* berries was shown to prevent cell cycle progression in CaLu-6 cells (De Marino et al. 2011).

Antioxidant Properties

Methanol extracts of juniper berries had high antioxidant activities as determined by the DPPH test, reducing power assay and TBA assay (Miceli et al. 2009). A positive correlation was found between the primary antioxidant activity and total phenolic content in different *Juniper* species (Taviano et al. 2011). Different extracts of leaves, ripe fruits, and unripe fruits of *Juniperus* species, including *J. communis*, were studied for the anticholinesterase and antioxidant activity by the ferrous ion-chelating, superoxide radical scavenging, and ferric-reducing antioxidant power (FRAP) assays. Total phenol and flavonoid contents of the extracts were also determined. They all showed good antioxidant activity, but the leaf extracts usually had higher antioxidant activity (Orhan et al. 2011).

Regulatory Status

GRAS 182.20.

Standard

ISO 7377 (Specification), ISO 8897 (Oil of juniper berry).

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Chapter 33
Lavender

Botanical Name:	*Lavandula angustifolia* Mill.
Synonyms:	*Lavandula officinalis* Chaix.; *Lavandula spica* L.; *Lavandula vera* DC.; common lavender; English lavender from France is often traded as French Lavender.
Family:	Lamiaceae (Labiatae).
Common Names:	**French**: Lavande; **German**: Lavendel; **Spanish**: Lavanda; **Italian**: Lavanda.

Introduction

History

Lavender (*Lavandula officinalis*) is native to the Mediterranean region and is cultivated in France, Spain, and elsewhere. It was used for aromatic purposes by the Romans in baths. It is effective to cure headaches, especially when related to stress, and clear depression associated with weakness and depression. Externally, lavender oil has been used as a stimulating liniment to help ease aches and pains of rheumatism. Lavender has several properties: carminative, relieves muscle spasms, antidepressant, antiseptic, antibacterial, and stimulates blood flow. Lavender is an aromatic flower used to make a delicious tea that calms the nerves. One teaspoon per pot of tea is the normal potency. Lavender oil is the most popular and most versatile essential oil associated with aromatherapy and traditional uses. The Latin name *Lavandula* is derived from the Latin word *lavare*, meaning "to wash," which comes from the ancient use of this plant to perfume water for bathing. The name *angustifolia* means narrow-leaved. *Lavandula* was known to the earliest botanical writers and the first written account is by Greek scholar Theophrastus (370–285 BC). Pure lavender has been highly regarded for the skin. The French scientist Rene Gattefosse was the first to discover these properties when he severely burned his arm in a laboratory accident. Lavender may also be used to cleanse cuts, bruises, and skin irritations. Its aromatic

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influences are health, love, peace, and higher consciousness. The oil can be diffused or applied topically. It is safe for use on small children; it may be added to food or water as a dietary supplement.

Producing Regions

Indigenous to the western Mediterranean region. Now cultivated all over the world. France, Spain, Australia, Bulgaria, Ukraine, England, Russia, Italy, and China are the major producers.

Botanical Description

It is an aromatic evergreen, perennial woody shrub, reaching up to 1-m (3 ft) height. It has pale green or silvery, narrow, linear leaves, with beautiful violet-blue or purple-blue flowers on attractive blunt spikes. The plant is highly aromatic. There are several species of *Lavandula*, plus a number of taxa and hybrids. The important species of lavender are *Lavandula* × *intermedia* (Lavandin), *Lavandula latifolia* (Spike lavender), and *Lavandula stoechas* (Spanish lavender).

Parts Used

Freshly cut and partially dried leaves, essential oil.

Flavor and Aroma

Lavender has a very floral, fruity, and herbaceous aroma. It has a sweet, floral-herbaceous, refreshing, pleasant balsamic-woody undertone.

Active Constituents

Essential oil (1–3%) containing more than 100 constituents including linalyl acetate, linalool, cis- and trans-β-ocimene, terpinen-4-ol, lavandulol, lavandulyl acetate, 1,8-cineole, limonene, etc.; flavonoids, triterpenoids, tannins (5–10%), and coumarins.

Preparation and Consumption

Lavender flowers and leaves are used in flavored vinegars, jellies, and sparingly in salads. Flowers and oils are used as flavorings in tea formulations. Lavender oil and absolute are used as natural food flavors. They are used in baked goods, soft candy, gelatin, frozen dairy, pudding, and alcoholic and nonalcoholic beverages (Fenaroli 1997). Lavender oils are used in colognes, *fougeres*, *chypres*, *abres*, and other floral perfumes and soaps.

Medicinal Uses and Functional Properties

Lavender is stated to be carminative, spasmolytic, and antidepressant. Lavender has antioxidant, antimicrobial, antibacterial, larvicidal, pharmacological, and other functions (Hohmann et al. 1999; Lis-Balchin et al. 1998; Lis-Balchin 1997, 2002; Lee and Shibamoto 2002; Broudiscou and Lassalas 2000; Hajhashemi et al. 2003; Nitzsche et al. 2004; Kovacheva et al. 2006; Ferreira et al. 2006; Marulanda et al. 2007; Tahraoui et al. 2007; Chohan et al. 2008; Field et al. 2008; Georgiev et al. 2009; Lodhia et al. 2009; Ozcan et al. 2009; Thring et al. 2009; Arzi et al. 2010; Blazekovic et al. 2010; Conti et al. 2010; Kasper et al. 2010; Pirali-Kheirabadi and Teixeira da Silva 2010; Sokovic et al. 2010; Yang et al. 2010; Zu et al. 2010; Barker and Altman 2011; Benabdelkader et al. 2011; Komes et al. 2011; Kunicka-Styczynska et al. 2011; Sienkiewicz et al. 2011; Spiridon et al. 2011; Vakilian et al. 2011; Woronuk et al. 2011; Alnamer et al. 2012; Amira et al. 2012). Linalool, a major constituent of lavender, was reported to relax the small intestine of mouse (Imaseki and Kitabatake 1962). The essential oil of lavender had a spasmolytic action on rabbit and guinea pig gut (Shipochliev 1968). Methanolic extracts of lavender dried flowers, fresh flowers, and fresh leaves had a spasmolytic action on the guinea pig ileum (Hart and Lis-Balchin 2002). Buchbauer et al. (1991, 1993) showed evidence for the sedative properties of lavender essential oil as it decreased the motility of test mice and stressed animals. Linalool inhaled for 1 h was found to induce sedation in mice without significant impairment in motor abilities (Linck et al. 2009). Lewith et al. (2005) found lavender to improve insomnia. Orally administered lavender capsules were found to have anxiolytic effects in humans under conditions of low anxiety (Bradley et al. 2009). Lavender oil promoted normalization of the level of total lipids and the ratio of total cholesterol to its α-fraction (Siurin 1997). The essential oil of *L. stoechas* showed good antimicrobial activities against different strains of bacteria, filamentous fungi, and yeasts (Benabdelkader et al. 2011). The aqueous lavender extract was shown to effectively reverse spatial learning deficits in rats with Alzheimer's disease (Kashani et al. 2011). A recent study found that lavender oil essence can be effective in reducing perineal discomfort following episiotomy (Sheikhan et al. 2012).

Antioxidant Properties

Phenolic components in the methanolic extracts of lavender were found effective in both enzyme-dependent and enzyme-independent lipid peroxidation systems (Hohmann et al. 1999). Lavender oil is found to relieve the pain associated with rheumatic and musculo-skeletal disorders (Billany et al. 1995). Smelling lavender essential oil was shown to enhance the free radical scavenging activity and decrease the stress hormone, cortisol, which protects the body from oxidative stress (Atsumi and Tonosaki 2007). Rosmarinic acid found in lavender has been shown to have antibacterial, antiviral, anti-inflammatory, and antioxidant activities (Petersen and Simmonds 2003). Kovacheva et al. (2006) evaluated the radical scavenging capacities of extracts and preparations from lavender plant cell culture with different rosmarinic acid content and compared them with pure rosmarinic and caffeic acids. Their results showed that extracts and preparations from lavender possessed strong radical scavengers. Nitzsche et al. (2004) showed that both rosmarinic acid and caffeic acid from lavender cell cultures had antioxidative activity. The antioxidant activity of *Lavandula* species (*L.*×*intermedia* and *L. angustifolia*) was found to be mainly due to the presence of rosmarinic acid. And there was a strong correlation between the antioxidant activity and polyphenol contents of the extracts (Blazekovic et al. 2010). Lavender essential oil was found to have strong DPPH radical scavenging activity (Yang et al. 2010). Spiridon et al. (2011) reported the antioxidant activities of oregano, lavender, and lemon balm. The phenolic acids identified in the analyzed species were ferulic, rosmarinic, *p*-coumaric, and caffeic, while predominant flavonoids were quercetin, apigenin, and kaempferol, which were present as glucosides.

Regulatory Status

GRAS 182.10 and GRAS 182.20.

Standard

ISO 3515 (Oil).

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Chapter 34
Lemon Balm

Botanical Name: *Melissa officinalis* L.
Synonyms: bee balm, balm, Melissa, Melissa balm.
Family: Lamiaceae (Labiatae).
Common Names: **French**: citronelle; **German**: zitronenmelisse; **Italian**: melissa; **Spanish**: balsamita maior.

Introduction

History

Lemon balm, called bosem in the Hebrew, means fragrance, and probably originated in the Middle East. It has been cultivated in the Mediterranean region for about 2,000 years. The Latin name *melissa* was coined in the Middle Ages from Greek *melissophyllon*, meaning "bee-leaf," because the plant is rich in nectar and commonly planted to feed bees; that name is akin to Latin *mel* "honey" and also the British term for orange rind jelly, *marmalade*. It is a popular spice in Mediterranean cooking, though it is more important as a medicinal herb than as a seasoning. *The London Dispensary* (1696) says, "An essence of Balm, given in Canary wine, every morning will renew youth, strengthen the brain, relieve languishing nature and prevent baldness." John Evelyn wrote, "Balm is sovereign for the brain, strengthening the memory and powerfully chasing away melancholy." Balm steeped in wine we are told again, "comforts the heart and driveth away melancholy and sadness." Gerard says, "It is profitably planted where bees are kept. The hives of bees being rubbed with the leaves of bawme, causeth the bees to keep together, and causeth others to come with them." The great Pliny said, "When they are strayed away, they do find their way home by it." He also said, "It is of so great virtue that though it be but tied to his sword that hath given the wound it stauncheth the blood". Gerard also said, "The juice of Balm glueth together greene wounds," and gives the opinion of Pliny and Dioscorides that "Balm, being leaves steeped in wine, and the wine drunk, and the

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leaves applied externally, were considered to be a certain cure for the bites of venomous beasts and the stings of scorpions." The Muslim herbalist Avicenna recommended lemon balm "to make the heart merry." Paracelsus claimed this herb could completely revitalize the body. The seventeenth century herbalist Culpeper says the herb "be kept in every gentlewomans house…. It causeth the Mind and Heart to become merry… and driveth away troublesome cares." The fourteenth century French King Charles V drank its tea every day to keep his health, as did the Prince of Glamorgan, who lived to be 108 years old. The seventeenth century Carmelite nuns made the famous Carmelite water, which combined lemon balm with lemon-peel, nutmeg, coriander, and angelica root. It was sold for centuries as *Eau de Melisse de Carmes*. The true Carmelite water is still sold in Germany as *Klosterfqu Melissengeist*.

Producing Regions

Lemon balm is native to the east Mediterranean region and west Asia. It is now cultivated in Middle East, North Africa, Egypt, Italy, Hungary, and the USA.

Botanical Description

It is a small plant up to 1 m (2 ft) high, with square stems. It has very aromatic, toothed leaves which emit a fragrant lemon odor when bruised. The flowers, white or yellowish, are in loose, small bunches from the axils of the leaves and bloom from June to October. The flowers consist of five fused sepals, five petals, two or four stamens, and four lobed ovaries. The seeds are very small, ovate, dark brown, or black in color. The plant dies down in winter, but the root is perennial.

Parts Used

Leaves (fresh or dried, whole or chopped).

Flavor and Aroma

Lemon balm has a sweet, lemon, fresh aroma. Fresh, lemony, sweet taste, with a slightly mint hint. The oil has a very pleasant fresh sweet lemony aroma.

Active Constituents

It has essential oil (0.1% average, with citral-geranial and neral, linalool, eugenol, citronellal, geraniol), tannins, bitter principle, resin, polyphenols, flavonoids, succinic acid,

and rosmarinic acid (Carnat et al. 1998; Saglam et al. 2004; Sari and Ceylan 2002; Capecka et al. 2005; Ivanova et al. 2005; Sanchez-Medina et al. 2007; Awad et al. 2009). The fresh herb has phenolics, L-ascorbic acid, and carotenoids. Polyphenolic compounds (rosmarinic acid, caffeic acid, and protocatechuic acid), essential oils (citral), monoterpenoid aldehydes, sesquiterpenes, flavonoids (luteolin), and tannins have been reported in lemon balm (Carnat et al. 1998; Guginski et al. 2009).

Preparation and Consumption

Lemon balm goes well with teas, vinegars, stewed fruits, jellies, puddings, and custards (Bozan 1995; Zeybek 1995). It can be added to fish, poultry, eggs, salads, and soups. It is also used as a garnish or added to salads for a lemony flavor. It is a common flavoring in fruit drinks, iced teas, and fruit-based desserts. It can be made into a sauce with virgin olive oil, garlic, ginger, fruits, and almonds.

Medicinal Uses and Functional Properties

Traditionally it has been used to heal wounds, sores, and bee and wasp stings, to relieve tension, calming nerves, and for headaches (Horrigan 2005). It was used as a drink to ensure longevity and aptly called "elixir of life" in Europe. It is used to treat asthma, stomach ailments, indigestion, menstrual cramps, and fevers (Herodez et al. 2003). It reduces sores from genital or oral herpes (Allahverdiyev et al. 2004). Aqueous and alcoholic extracts from the aerial part of *Melissa officinalis* are traditionally used in the treatment of fevers and colds, indigestion associated with nervous tension, hyperthyroidism, depression, mild insomnia, epilepsy, headaches, toothaches, and other ailments (Carnat et al. 1998; Herodez et al. 2003; Salah and Jager 2005; Dastmalchi et al. 2008; Howes and Perry 2011). Lemon balm has been shown to have antibacterial, antimicrobial, antimutagenic, antiviral, antifungal, antitumor, and antioxidant properties (Mimica-Dukic et al. 2004; Blomhoff 2004; Hamer et al. 2005; Uzun et al. 2004; Dragland et al. 2003; Bolkent et al. 2005; Kennedy and Scholey 2006; Apak et al. 2006; Mazzanti et al. 2008; Awad et al. 2009; Chung et al. 2010; de Ciriano et al. 2010; Lahucky et al. 2010; Komes et al. 2011; Lara et al. 2011; Obulesu and Rao 2011; Petrovic et al. 2011; Spiridon et al. 2011).

Rosmarinic acid in lemon balm appears to contribute for the antinociceptive property of the ethanolic extract (Guginski et al. 2009). Lemon balm was found to be the most effective plant against five food spoilage yeasts (Araujo et al. 2003). The essential oil of lemon balm inhibited all the yeast species and the fungitoxic effect was attributed to citral, the major constituent. It also inhibited some antibiotic resistant bacteria (Nascimento et al. 2000). The major compounds found to be the most powerful scavenging compounds in lemon balm were neral, geranial, citronellal, menthone, isomenthone, and β-caryophyllene (Mimica-Dukic et al. 2004). Lemon balm treatment is suggested for treating active Herpes simplex lesions or

preventing recurrences (Gaby 2006). Lemon balm essential oil was shown to be an efficient hypoglycemic agent, and this was probably due to the enhanced glucose uptake and metabolism in the liver and adipose tissue, and the inhibition of gluconeogenesis in the liver (Chung et al. 2010). Ethanol extract of lemon balm exerted an antigenotoxic effect on the blood cells of mice treated with the alkylating agent (MMS) in all doses (de Carvalho et al. 2011).

Antioxidant Properties

Ethanol extract of lemon balm was found to improve the oxidation stability of sunflower oil (Marinova and Yanishlieva 1997). Lemon balm possesses strong antioxidant activity due to its phenolic constituents rosmarinic acid and caffeic acid (Triantaphyllou et al. 2001; Labuda et al. 2002). Dragland et al. (2003) reported lemon balm to contain very high concentrations of antioxidants (>75 mmol/100 g) and suggested plant oxidants to be a better source of dietary antioxidants than many other food groups like fruits, berries, cereals, and vegetables. Lemon balm extract was found to decrease serum cholesterol and lipid levels in the hyperlipidemic animals (Bolkent et al. 2005). Essential oil of lemon balm was found to possess antioxidant activity and very effective against a series of human cancer cell lines (de Sousa et al. 2004). Lemon balm at a concentration of 1.5% w/w increased by 150% the antioxidant capacity of a salad portion (Ninfali et al. 2005). In the xanthine oxidase system, the extracts of lemon balm showed very efficient antioxidant result (Schempp et al. 2006). An aqueous extract of lemon balm had significant antioxidant capacity—0.99 mmol trolox equivalent (Apak et al. 2006). Ivanova et al. (2005) reported lemon balm extract to have 1,370.09 μM total phenols and an antioxidant capacity of 4.06 TEAC. Rosmarinic acid, a great antioxidant, was found in higher concentrations in tinctures made with dried plant material (Sanchez-Medina et al. 2007). The methanol extract of lemon balm was a potent in vitro inhibitor of rat brain GABA transaminase, an enzyme target in the therapy of anxiety, epilepsy, and related neurological disorders (Awad et al. 2009). The lyophilized extract of lemon balm showed strong antioxidant activity and high total phenolic content (de Ciriano et al. 2010). Lemon balm essential oil was found to have strong antioxidant activity (Chung et al. 2010). Extraction time was important in extracting the polyphenolic compounds and it also affected their antioxidant activities (Komes et al. 2011). *Origanum vulgare* and *Melissa officinalis* extracts were found to exhibit the most effective antioxidant capacity in scavenging DPPH radicals, while *Lavandula angustifolia* was less active (Spiridon et al. 2011).

Regulatory Status

GRAS 182.10 and GRAS 182.20.

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Chapter 35
Lemongrass

Botanical Names:	*Cymbopogon citratus* (DC. ex Nees) Stapf; *Cymbopogon flexuosus* (Nees ex Steud.) J. F. Watson.
Synonyms:	*Andropogon citratus* DC. ex Nees; West Indian lemongrass, lemongrass, fever grass.
Synonyms:	*Andropogon flexuosus* Nees ex Steud.; East Indian lemongrass, Cochin lemongrass.
Family:	Poaceae.
Common Names:	**French**: herbe de citron, verveine des Indes; **German**: Zitronengras, Lemongras; **Italian**: erba di limone; **Spanish**: hierba de limon; **Indian**: bhustrina, sera; **Indonesian**: sere, sereh; **Sinhalese**: sera; **Thai**: takrai; **Malay**: serai.

Introduction

History

The original use of lemongrass was probably as a food flavoring agent in Asia. The leaves are cooked with foods especially curries. They are perennial grasses native to tropical Asia. Fresh leaves crushed in water are used as a hair-wash and toilet water in India. Systematic cultivation and distillation of essential oil began in Kerala, India, in the 1880s. The genus name, *Cymbopogon*, comes from the Greek "kymbe", meaning "boat", and "pogon", meaning "beard". This reference is probably due to the shape of the grass's tiny flowers that emerge on branched stalks. The Romans, Greeks, and Egyptians have used lemongrass for centuries as a flavoring agent in medicines and as an aromatic in cosmetics. Indonesians have used it in cooking.

D.J. Charles, *Antioxidant Properties of Spices, Herbs and Other Sources*,
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Producing Regions

It is native to Asia and grows wild in tropical and subtropical regions. It is cultivated in India, the Caribbean, and Central America. East Indian lemongrass grows in eastern India, Cambodia, Singapore, and Sri Lanka. West Indian lemongrass grows in Madagascar, Guatemala, Comoro Islands, Brazil, Haiti, and Puerto Rico.

Botanical Description

They are tall, fast growing, herbaceous, perennial grasses up to 1.5 m (8 ft) high and very aromatic. They have sturdy stems and broad, aromatic leaves. The leaves are linear and lanceolate and the flowers are in inflorescence which are large and branched. The West Indian lemongrass is stem less with stiff tillers arising from short rhizomatous rootstock. Leaf blade is narrow, linear, and drooping with scabrous margin.

Parts Used

The various parts used include freshly cut and partially dried leaves, essential oil, and oleoresin. The inner stalk is used fresh, frozen, or dried. The fresh form is used whole, sliced, finely chopped, or pureed. The dried form is used ground, shredded, or whole.

Flavor and Aroma

It has a floral, very delicate, fresh grassy lemony aroma, lemony, with a slight hint of ginger. The essential oil has strong, lingering, fresh grassy lemon-like aroma.

Active Constituents

East Indian lemongrass oil—geranial up to 60%, neral up to 30%, geraniol up to 4%, limonene, linalool. West Indian lemongrass oil—geranial up to 60%, neral up to 30%, myrcene up to 20%, linalool. Lemongrass has been reported to have flavonoids and phenolic compounds, which consist of elimicin, catechol, chlorogenic acid, caffeic acid, hydroquinone, luteolin, isoorientin 2′-*O*-rhamnoside, quercetin, kaempferol, and apigenin (Guanasingh and Nagarajan 1981; Matouschek and Stahl 1991; Faruq 1994; Miean and Mohamed 2001).

Preparation and Consumption

Lemongrass features in Indian, Malaysian, Indonesian, and Sri Lankan dishes. It is used in major categories of food products, including meat, poultry, seafood, vegetable curries, candy, desserts, and baked goods. In Thai and Sri Lankan recipes, it is used with coconut milk in chicken and seafood. In Indonesia, lemongrass is combined with turmeric, chili peppers, and other spices to make bumbu, a seasoning, to flavor local sauces and soups. The stems are used in pickles and flavoring marinades. Dried leaves are used in teas. Lemongrass oil is used in flavoring major categories of food including alcoholic and nonalcoholic beverages, frozen dairy desserts, candy, gelatin, puddings, meat, and fish. Oleoresin is useful in foods, drinks, and baked goods.

Medicinal Uses and Functional Properties

The leaves and essential oil are used to treat dyspeptic disorders, colds, nervous conditions, and exhaustion. They have antimicrobial, sedative, spasmolytic, and carminative effects. It has also been shown to have antifungal, anti-inflammatory, antimutagenic, antimalarial, antinociceptive, larvicidal, and antibacterial effects (Viana et al. 2000; Cavalcanti et al. 2004; Tchoumbougnang et al. 2005; Wannissorn et al. 2005; Adeneye and Agbaje 2007; Lee et al. 2008; Viuda-Martos et al. 2010; Bassole et al. 2011; Cilek et al. 2011; Costa et al. 2011; Devi et al. 2011; Francisco et al. 2011; Khan and Ahmad 2011; Kumar et al. 2011; Mickiene et al. 2011; Avila-Sosa et al. 2012). Lemongrass tea, a popular Brazilian herbal medicine, was found to be toxic when administered to healthy volunteers (Leite et al. 1986). The essential oil from lemongrass was reported to have a promising anticancer activity and caused loss in tumor cell viability by activating the apoptotic process (Sharma et al. 2009). Costa et al. (2011) reported the safety of lemongrass intake at the doses used in folk medicine and indicated the beneficial effect of reducing the blood cholesterol level.

Antioxidant Properties

Lemongrass extract and essential oil have been reported to have strong antioxidant properties (Baratta et al. 1998; Rao et al. 2009; Tiwari et al. 2010; Viuda-Martos et al. 2010; Francisco et al. 2011; Henning et al. 2011; Shah et al. 2011; Quintans-Junior et al. 2011).The hepatoprotective effect of *C. citratus* extract was reported to be due to its antioxidant and free radical scavenging properties (Koh et al. 2012). Lemongrass was shown to be cardioprotective and antilipid peroxidative by increasing various antioxidants at a dose of 200 mg kg^{-1} body weight of rats, which was comparable with that of vitamin E (Gayathri et al. 2011). The results (Tiwari et al. 2010) suggest

the potential use of the cytoprotective, antioxidant, and anti-inflammatory properties of *C. citratus* in the form of dietary component and also in formulations against lung inflammatory diseases where oxidative stress plays an important role. Lemongrass (*C. citratus*) was found to have NO scavenging activity and also inhibited iNOS expression (Figueirinha et al. 2010). Lemongrass extract was found to decrease cerebral lipid peroxidation (TBARS) induced by iron sulfate, sodium nitroprusside, or 3-nitropropionic acid, and showed antioxidant effect by DPPH assay (Pereira et al. 2009). Isoorientin isolated from lemongrass was shown to be an effective inhibitor of in vitro LDL oxidation and thus could be useful in preventing or attenuating atherosclerosis (Orrego et al. 2009). Hydroalcoholic extract of lemongrass showed significant scavenging ability of DPPH, ABTS, hydroxyl, superoxide, and nitric oxide free radicals generated in vitro and also a moderate antilipid peroxidative effect. It also resulted in dose-dependent decrease in the yield of radiation-induced micronuclei, and decrease in the percentage of micronuclei compared with radiation alone groups. These results indicate antigenotoxic effect which may be partly due to the antioxidant capacity (Rao et al. 2009). Citral, a major compound found in lemongrass, significantly inhibited lipopolysaccharide-induced nitric oxide production, and also effectively inhibited the transcriptional activity and expression of iNOS. It also suppressed the DNA binding activity and nuclear translocation of NF-kappa B as well as I kappa B phosphorylation (Lee et al. 2008). Caffeic acid, chlorogenic acid, neochlorogenic acid, and luteolin 6-C-fucopyranoside were found to be strong free radical scavengers in the DPPH discoloration (Tapia et al. 2007). Rabbani et al. (2006) found citral from lemongrass to significantly inhibit the formation of micronuclei induced by nickel. It also showed good superoxide scavenging activity in citral treated groups, suggesting antioxidant action of citral to be responsible for the anti-clastogenic effect of citral against nickel chloride (Rabbani et al. 2006). Methanol extract, methanol/water extract, infusion, and decoction of lemongrass showed scavenging effect in the DPPH and superoxide anion assay and inhibited lipid peroxidation in erythrocytes, but were inactive toward xanthine oxidase (Cheel et al. 2005). Isoorientin and orientin isolated from lemongrass had similar activities toward DPPH and lipid peroxidation, while caffeic and chlorogenic acids isolated from lemongrass were active superoxide anion scavengers, and had strong effect toward DPPH. Caffeic acid from lemongrass inhibited lipid peroxidation (Cheel et al. 2005). Citral from lemongrass induced glutathione S-transferase in mouse skin, implying antioxidant role of citral, and providing new insights into skin cancer prevention (Nakamura et al. 2003). Organic lemongrass extract enriched in polyphenols caused relaxation action in the mesenteric preparation compared to aortic rings, and appeared to be mediated via NO-independent and non-prostanoid mechanisms (Abeywardena et al. 2002).

Regulatory Status

GRAS 182.20.

Standard

ISO 4718 (Oil of *C. flexuosus*), ISO 3217 (Oil of *C. citratus*).

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Chapter 36
Licorice

Botanical Name:	*Glycyrrhiza glabra* L.
Synonyms:	black sugar, licorice root, liquorice, sweet root, sweetwood, Russian licorice, Spanish licorice, Turkish licorice.
Family:	Fabaceae (Leguminosae).
Common Names:	**French**: regliss; **German**: Lakritze; **Italian**: liquirizia; **Spanish**: regaliz; **Hindi**: mulethi.

Introduction

History

A papyrus dating back from the time of Roman Empire and Assyrian tablets describes the therapeutic value of licorice, and the root has also been mentioned in the first Chinese herbal. Hippocrates, Theophrastus, and Pliny all referred to licorice. Theophrastus (372–287 BC) wrote: "Liquorice has the property of quenching the thirst if held in the mouth. The root contains a special sweetness which is safe for diabetics". The roots became popular chewing sticks in Italy, Spain, West Indies, and other places where the plant grows. The Greeks learned about the sweet root from the Scythians. Later, it became glycyrrhiza (*glykys*, meaning "sweet" and *rhiza*, "root"). It was widely cultivated in Italy in the fifteenth century, and also found its way into northern Europe. The Latin *liquiritia* turned into *lycorys* in Old French. The Dominican Black Friars introduced licorice into England, where lycorys extract was later sold as lozenges called "pomfrey cakes". The monestary gardens of Pontefract grew licorice, which later became the licorice confectionary center of Britain.

D.J. Charles, *Antioxidant Properties of Spices, Herbs and Other Sources*,
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Producing Regions

It is indigenous to southeastern Europe, Middle East, and northern India. It is extensively cultivated in Europe (Spain, Italy, France), Middle East (Iran, Iraq, Syria, Turkey), and Asia (China, India).

Botanical Description

It is a perennial herb or bushy herb up to 2 m (6 ft) high, with oblong leaves and small blue-violet flowers. The leaves are divided into several pairs of leaflets. The fruits are small, reddish pods. The rhizomes are grayish brown on the outside and yellow within, with a fibrous texture. There are several varieties and species of licorice-Spanish licorice (*G. glabra* L. var. *typica* Reg. et Herd.), Persian licorice (*G. glabra* L. var. *violacea* Boiss.), Russian licorice (*G. glabra* L. var. *glandulifera* Waldst. et Kit.), and Chinese licorice (*G. uralensis* Fisch.).

Parts Used

Dried root or rhizomes, or more commonly the hard black sticks formed from boiled root juice. Much of the licorice used in the USA is imported in an extract form, usually in sticks or solid blocks.

Flavor and Aroma

Medicinal and very highly aromatic. Very sweet taste, similar to anise, with slightly bitter and salty aftertaste.

Active Constituents

Glycyrrhizin (5–10%), flavonoids, polysaccharides, chalcones, asparagine, coumarins, saponins, sterols, tannins, starch (30%), sugars (14%), amino acids, amines, gums, and essential oils.

Preparation and Consumption

Licorice flavors candies, liqueurs, ice cream, chewing gum, and baked goods. Used as a tisane and to flavor syrups, dried fruit salads, and alcoholic drinks such as *raki* and *sambucca*. It is used in flavoring tobacco.

Medicinal Uses and Functional Properties

It is commonly used as a demulcent, expectorant, antitussive, and mild laxative. In Chinese traditional medicine, it is used to treat ulcers (gastric and duodenal), sore throat, malaria, abdominal pain, insomnia, tuberculosis, sores, abscesses, and food poisoning. It has been used in many countries to treat cancer. They are used extensively as ingredients in cough drops and syrups, tonics, laxatives, antismoking lozenges. It is also used as flavoring agents to mask bitter, nauseous, or other undesirable tastes in certain medicines. Licorice has an ancient reputation as an aphrodisiac, the Kama Sutra and Ananga Ranga contain numerous recipes for increasing sexual vigor which include licorice.

Flavonoids such as licoagrodin, licoagrochalcones, licoagroaurone and licochalcone C, kanzonol Y, glyinflanin B and glycyrdione A from licorice root have shown various pharmacological activities including antitumor, antiparasitic, antileishmanial, anti-ulcer, and antioxidative effects. Isoliquiritigenin a flavonoid isolated from the roots of licorice was found to relax the guinea pig trachea through a multiple of intracellular actions, including sGC activation, inhibition of PDEs, and associated activation of the cGMP/PKG signaling cascade, leading to the opening of large-conductance Ca^{2+}-activated K^+ channels (BKCa) and Ca^{2+} decrease through PKG-dependent mechanism and thus to tracheal relaxation (Liu et al. 2008). Glycyrrhizic acid (GA) and 18β-glycyrrhetinic acid (18βGA) from licorice root was found to significantly inhibit the production of lipopolysaccharide (LPS)-induced nitric oxide (NO), prostaglandin E(2) (PGE(2)), and intracellular reactive oxygen species (ROS). Both GA and 18βGA significantly reduced the protein and mRNA levels of iNOS and COX-2 in LPS-induced macrophages. They inhibited the activation of NF- B and the activities of phosphoinositide-3-kinase (P13K) p110δ and p110γ isoforms and then reduced the production of LPS-induced tumor necrosis factor-α (TNF-α), interleukin (IL)-6, and IL-1β in a dose-dependent manner. These results suggest that both GA and 18βGA may provide an anti-inflammatory effect by attenuating the generation of excessive NO, PGE(2), and ROS and by suppressing the expression of proinflammatory genes through the inhibition of NF-κB and P13K activity (Wang et al. 2011). Shetty et al. (2011) found 18α-glycyrrhetinic acid (AGA) to inhibit proliferation and growth of prostate cancer cell line DU-145 by inducing apoptosis. Both 18β-glycyrrhetinic acid (18βGA) and its derivative glycyrrhetinic acid-30-piperazine were found to have potent antimycobacterial properties against the drug-susceptible and drug-resistant *Mycobacterium bovis* (Zhou et al. 2011). GRA (18B-glycyrrhetinic acid from licorice root showed potent inhibitory effects on MCF-7 proliferation in a concentration- and time-dependent manner without affecting immortalized normal mammary epithelial cell line (MCF-10A). The growth inhibition of MCF-7 cells by GRA occurred through apoptosis. Their results suggested that GRA induces apoptosis in human breast carcinoma MCF-7 cells via caspase activation and modulation of Akt/FOXO3a pathway (Sharma et al. 2012). Liquiritigenin, a main compound of licorice, effectively attenuated the acute behavioral effects of cocaine exposure and prevented the induction

of selective neuroadaptive changes in dopaminergic signaling pathways in rats (Jang et al. 2011). Jhanji et al. (2011) demonstrated that isoliquiritigenin (ISL) from licorice extract had an antiangiogenic effect. Licorice as a dietary additive was found to be feasible for immune system enhancement (Katayama et al. 2011). Nettle and licorice extracts were found to stimulate cellular response and nonspecific resistance, with these effects being superior to those of pharmacopoeial *Echinacea purpurea* tincture (Borsuk et al. 2011). Oral administration of glycyrrhetinic acid, an active constituent of licorice, at a dose of 45 mg kg^{-1} body weight to hamsters treated with 7,12-dimethylbenz(a)anthracene was shown to completely prevent the tumor formation as well as restore the status of detoxification enzymes (Kowsalya et al. 2011). Glabridin, a flavonoid purified from licorice root, was reported to have good promise for use in preventing osteoclastogenesis by inhibiting RANKL-induced activation of signaling molecules and subsequent transcription factors in osteoclast precursors (Kim et al. 2012). The induction of mTOR-dependent autophagic and apoptotic cell death was found to be an important mechanism in cancer chemotherapy by isoliquiritigenin (ISL), a flavonoid isolated from licorice (Chen et al. 2012). The beneficial effects of licorice and its constituents for preventing/treating oro-dental diseases have been also reported (Messier et al. 2012).

Antioxidant Properties

Compounds extracted from the roots and leaves of licorice have been shown to have antioxidant properties (Gordon and An 1995; Vaya et al. 1997; Fuhrman et al. 1997; Haraguchi et al. 1998; Belinky et al. 1998a, b; Biondi et al. 2003; Murcia et al. 2004; Kang et al. 2005; Chin et al. 2007; Kim et al. 2008; Mekseepralard et al. 2010; Mukherjee et al. 2010; Shi et al. 2010; Sun et al. 2010; Franceschelli et al. 2011; Hasanein 2011; Kataya et al. 2011; Li et al. 2011; Ni et al. 2011; Ojha et al. 2011; Sakr et al. 2011; Sen et al. 2011; Siracusa et al. 2011; Veratti et al. 2011; Visavadiya and Narasimhacharya 2011; Wu et al. 2011; Yehuda et al. 2011; Yin et al. 2011; Zhang et al. 2011; Gabriele et al. 2012; Lateef et al. 2012). Retrochalcones isolated from the roots of licorice were shown to be effective in protecting biological systems against various oxidative stresses (Haraguchi et al. 1998). Hispaglabridin A, hispaglabridin B, glabridin, 4′-*O*-methylglabridin, isoprenylchalcone derivative, and isoliquiritigenin were found to be very potent antioxidants toward LDL oxidation with glabridin being the most abundant and potent antioxidant. These natural antioxidants may be beneficial to attenuate atherosclerosis as LDL oxidation is a key event in the formation of the early atherosclerosis lesion (Vaya et al. 1997). Licorice ethanolic extract and glabridin were shown to inhibit LDL oxidation by a mechanism involving scavenging of free radicals. Dietary supplementation of each E zero mouse with licorice or pure glabridin for 6 week resulted in a substantial reduction in the susceptibility of their LDL to oxidation along with a reduction in the atherosclerotic lesion area (Fuhrman et al. 1997). Belinky et al. (1998b) found that the antioxidant effect of glabridin on LDL oxidation resided mainly in the 2′hydroxyl and that the

hydrophobic moiety of the isoflavan is essential to obtain this effect. Glabridin has also been shown to inhibit NO production and inducible nitric oxide (iNOS) gene expression in murine macrophages by blocking NF-kappaB/Rel activation and that this effect was mediated at least partly by inhibiting the reactive oxygen species generation (Kang et al. 2005). Isoliquiritigenin (ILG) from licorice root was shown to inhibit LPS-induced NO and prostaglandin E(2) (PGE(2)) production. It was also found that the anti-inflammatory properties of ILG were caused by iNOS, cyclooxygenase-2 (COX-2), TNF-alpha, and IL-6 downregulation due to NF-kappaB inhibition via the suppression of IkappaB kinase (IKK), ERK1/2, and p38 phosphorylation in RAW 264.7 cells (Kim et al. 2008). Franceschelli et al. (2011) studied the antioxidant activity of licochalcone C at a concentration of 50 μM on THP-1 (human myelomonocytic leukemia) cells treated with proinflammatory stimuli such as LPS and IFN-γ. The results showed that treatment with licochalcone C attenuated the LPS-IFN-γ-induced inflammatory response by significantly decreasing the expression and activity of iNOS via nuclear factor kappa-B (NF-κB), by influencing extracellular O_2-production, and by modulating the antioxidant network activity of superoxide dismutase (SOD), catalase (CAT), and glutathione peroxidase (GPx) activity. They hypothesized that licochalcone C has antioxidant activity properties since it reduces the production of superoxide radicals and consequently reduces the activity of iNOS. Licorice was found to have cardioprotective potential against myocardial infarction of oxidative stress and favorable modulation of cardiac function (Ojha et al. 2011). Pretreatment of cisplatin-treated mice with GA prevented oxidative stress by restoring the levels of antioxidant enzymes at both doses. A significant dose-dependent decrease in DNA fragmentation, micronucleus formation ($p<0.05$), and the kidney toxicity markers BUN ($p<0.001$), creatinine ($p<0.01$), and LDH ($p<0.001$) and restoration of normal kidney histology were observed. These results clearly support the claim that the phytochemical GA has the potential to attenuate the side effects of anticancer drug overdose (Arjumand and Sultana 2011). Licorice extract was shown to restore the total antioxidant capacity of diabetic rats. Thus licorice may have a potential therapeutic effect for diabetes due to its antioxidant and antihyperglycemic properties (Kataya et al. 2011). Huo et al. (2011) reported a chemopreventive potential of licorice extract against liver oxidative injury. The cardioprotective potential of *G. glabra* against myocardial infarction by amelioration of oxidative stress and favorable modulation of cardiac function was shown in rats (Ojha et al. 2011).

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Chapter 37
Marjoram Sweet

Botanical Name: *Origanum majorana* L.
Synonyms: *Majorana hortensis*; knotted marjoram.
Family: Lamiaceae (Labiatae).
Common Names: **French**: Marjolaine; **German**: Majoran; **Italian**: Maggiorana; **Spanish**: Mejorana.

Introduction

History

Marjoram Sweet was known to the ancient Egyptians, Greeks and Romans and was grown in Egypt over 3,000 years ago. It was cultivated as a pot herb and used to flavor food. It was also prized as a miracle herb with the power to cure all diseases, especially colds and chills. The ancient Greeks and Romans crowned newlyweds with marjoram as a symbol of happiness. The Greeks called marjoram "joy of the mountains", and wore marjoram wreaths at weddings. The Greeks used it as a symbol of happiness, and believed that if placed or grown near the grave, the dead would enjoy eternal peace and happiness. They also believed that if the girl placed marjoram on her bed, Aphrodite would visit her in dreams and reveal the identity of her husband. Sweet marjoram to this day remains on the coat of arms of the ancient city of Marjora from which it gets its name. In Crete, it was worn by distinguished leaders as a badge of honor. It was used in houses to give a clean, pleasant smell, and in linen cupboards. It was popular in the Middle Ages as a medicinal herb, and as a culinary herb during the sixteenth century in England. According to Banckes's *Herbal*, marjoram would cure a cold if it was bound on the head; it was also good for bronchial coughs, asthmatic whooping coughs, and other respiratory ailments.

D.J. Charles, *Antioxidant Properties of Spices, Herbs and Other Sources*,
DOI 10.1007/978-1-4614-4310-0_37,

Producing Regions

Marjoram is native to the Mediterranean region and is now grown in Hungary, Germany, USA, France, Spain, Portugal, UK, North Africa, and west Asia. The oil is mostly produced in Morocco, France, Tunisia, Egypt, Bulgaria, Germany, and Hungary.

Botanical Description

It is a herbaceous plant up to 0.6 m (1–2 ft) high. It is a perennial bushy plant, but annual or biennial in Europe. It has oblique rhizome, hairy shrub like stalks, opposite dark green oval leaves, and white or red flowers in clustered bracts. The leaves are whole, larger ones being fragmented, oblate to broadly elliptical. The plant is highly aromatic. The dried herb is light green with a slight grayish tint.

Parts Used

The fresh leaves are used whole or chopped. They are used as garnish and in salads. The dried leaves are used whole, cut or ground. Essential oils and oleoresins. The aromatic seeds are employed in French confitures and confectionery.

Flavor and Aroma

It has a pleasant, aromatic, and spicy aroma. It has fresh, spicy, bitter and slightly pungent, camphor-like notes. It has delicate, sweet aroma of sweet basil and thyme and has fragrant, spicy, minty-sweet, slightly sharp, with bitter and camphoraceous undertones.

Active Constituents

The active constituents include Moisture 8%, protein 14%, fixed oil 5.6%, fiber 22%, ash 6–24%, and essential oil 1.8%. Other compounds are flavonoid glycosides, tannins, steroids, and vitamins (especially A and C). The major constituents of the essential oil are terpin-4-ol (20%), γ-terpinene (20%), sabinene hydrate (12–15%), α-terpineol, sabinene, and linalool. The major phenolic acids are sinapic, ferulic, coumarinic, caffeic, syringic, vanillic, and 4-hydroxybenzoic acid (Petr et al. 2008). The nutritional constituents (dried) and ORAC (fresh) values of marjoram are given in Table 37.1.

Table 37.1 Nutrient composition and ORAC values of marjoram dried

Nutrient	Units	Value per 100 g
Water	g	7.64
Energy	kcal	271
Protein	g	12.66
Total lipid (fat)	g	7.04
Carbohydrate, by difference	g	60.56
Fiber, total dietary	g	40.3
Sugars, total	g	4.09
Calcium, Ca	mg	1,990
Vitamin C, total ascorbic acid	mg	51.4
Vitamin B-6	mg	1.190
Vitamin B-12	mcg	0.00
Vitamin A, RAE	mcg_RAE	403
Vitamin A, IU	IU	8,068
Vitamin D	IU	0
Vitamin E (alpha-tocopherol)	mg	1.69
Fatty acids, total saturated	g	0.529
Fatty acids, total monounsaturated	g	0.940
Fatty acids, total polyunsaturated	g	4.405
Marjoram fresh		
H-ORAC	μmol TE/100 g	27,297
Total-ORAC	μmol TE/100 g	27,297
TP	mg GAE/100 g	964

Source: USDA National Nutrient Database for Standard Reference, Release 24 (2011)

Preparation and Consumption

It is used for its well-rounded herb note. Marjoram may be used in sausages, lamb, mutton, beef, pork, chicken, fish, sea food, tomato dishes, soups, stews, stuffing's, breads, salad dressings, and chowders. The widest use is in seasoning sausages and salamis. Marjoram is used in Italian, French, North African, Middle Eastern, and American cuisines and spice blends such as bouquet garni, fines herbs, and sausage and pickle blends. Marjoram is usually added towards the end of cooking. In European dishes it is added to fish sauces, butter-based sauces, salads, vinegar, eggplant, and mushroom sauces. In North Africa and Middle East, it is used in mutton, lamb, barbecues, vegetables, and seafood. In the USA, marjoram is mostly used in poultry seasonings, cheeses, sausages, soups, and salad dressings. The oil is used to flavor fats, oils, baked foods, meat products, processed vegetables, soups, vinegars, snack foods, and gravies.

Medicinal Uses and Functional Properties

It is considered antiseptic, antidiabetic, carminative, antispasmodic, stimulant, diaphoretic, and diuretic (Parry 1969; Rau et al. 2006) and is used as a tonic and cure for asthma, coughs, indigestion, rheumatism, headaches, and toothaches. It has also been used to treat cancers (Esiyok et al. 2004).

The MIC for the fungi *S. cerevisiae*, *C. paracrusei*, *C. krusei,* and *A. oryzae* was <4.0% (Ueda et al. 1982). Marjoram inhibited the fungi *A. fumigatus* and *A. niger* (Yadava and Saini 1991; Tiziana and Dorman 1998). Marjoram oil was most effective against *Acinetobacter calcoaceticus*, *Vibio natriegens,* and *S. aureus* (Tiziana and Dorman 1998). Marjoram extract was found to exhibit protective effect against hydroquinone-induced clastogenicity (Ghaly et al. 2008). Marjoram oil showed both bacteriostatic and bactericidal effects when applied to fresh sausage (Busatta et al. 2008). Essential oil of marjoram was shown to have antimicrobial activity against both Gram-positive and Gram-negative bacteria (Deans and Svoboda 1990; Barbosa et al. 2009). It was found to have a strong fumigant toxicity against Mediterranean flour moth (Karaborklu et al. 2011). Marjoram was shown to have strong antimicrobial activity (Ozcan et al. 2006; Leeja and Thoppil 2007; Sagdic et al. 2010).

Antioxidant Properties

Marjoram is also known to possess various therapeutic properties including antioxidant activity (Dapkevicius et al. 1997; Zheng and Wang 2001; Campanella et al. 2003; Dorman et al. 2004; Vagi et al. 2005; Tsai et al. 2007; Lopez et al. 2007; Yazdanparast and Shahriyary 2008; Al-Howiriny et al. 2009; Abdel-Massih et al. 2010; Celik et al. 2010; Viuda-Martos et al. 2010; Shati 2011; Mossa and Nawwar 2011; Hossain et al. 2012). Saito et al. (1976) reported higher antioxidant activity of marjoram at 0.02% against lard than tocopherol. In the egg yolk assay, the antioxidant activity of marjoram was found to be much higher than that of α-tocopherol and comparable with BHT at all concentrations tested (Tiziana and Dorman 1998). Nakatani (2000) studied the compounds from various herbs and spices for their antioxidant activity and isolated 26 active compounds from marjoram, rosemary, thyme, and oregano. Sweet marjoram aqueous extract was shown to have a remarkable capacity in retarding lipid oxidation, and these extracts were found to be rich in bound forms of phenolic compounds such as hydroxycinnamic acids and flavonoids (Triantaphyllou et al. 2001). Heo et al. (2002) found ursolic acid from marjoram to reduce the micromolar Abeta-induced oxidative cell death. Ursolic acid activity was assessed by MTT, lactate dehydrogenase, and trypan blue assay. El-Ashmawy et al. (2005) concluded from their study that marjoram plays an important role in ameliorating liver and kidney functions and genotoxicity induced by lead toxicity. They found the essential oil, alcoholic, and aqueous extracts of marjoram to significantly reduce the serum activities of alanine and aspartate transaminases, alkaline

phosphatase, urea, and creatinine and improved the kidney and liver histology in comparison with lead acetate treated group. The essential oil of marjoram was able to reduce the damaging effects of ethanol toxicity on male fertility, liver, and brain tissues (El-Ashmawy et al. 2007). Dearlove et al. (2008) studied the effect of polyphenolic substances of commercial culinary herbs including marjoram on fructose-mediated protein glycation. They found these extracts to be potent inhibitors of protein glycation and this is an example of the antidiabetic potential of these culinary herbs and spices. Marjoram ethanol extract was found to significantly decrease the incidence of ulcers, basal gastric secretion and acid output, and the concentration of malondialdehyde (Al-Howiriny et al. 2009). Marjoram extract was shown to alleviate the kidney and liver antioxidant activities and lower the LPO levels that were disrupted by Cd in albino rats. Marjoram showed both protective and curative effects on Cd-induced hepatotoxicity and nephrotoxicity (Shati 2011).

Regulatory Status

GRAS 182.10 and GRAS 182.20.

Standard

ISO 10620.

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Chapter 38
Mustard

Botanical Names: *Brassica juncea* (L.) Czernov. var. *rugosa* Bailey (Indian mustard, Chinese mustard, large-leaf mustard; brown or oriental mustard); *Brassica nigra* (L.) W.D.J. Koch (Black mustard); *Sinapis alba* L. (White mustard, yellow mustard).
Synonyms: *Synapsis juncea* L.; *B. rugosa* Prain.; *B. alba* (L.) Rabenh.; *B. alba* (L.) Boiss.; *B. hirta* Moench.
Family: Brassicaceae (Cruciferae).
Common Names: **French**: Moutarde, moutarde noir, moutarde blanc; **German**: rutensenf or sareptasenf, schwartzen senf, weiber senf or senfsaat; **Italian**: senape Indiana, senape negra, senape bianca; **Spanish**: mostaza de Indias, mostaza negra, mostaza sivestre; **Hindi**: rai, raya, laha, banarsi rai.

Introduction

History

The generally accepted name of mustard is believed to be derived from the Latin *mustum ardens*, meaning burning must, since the seed was sometimes ground with grape must. It is among the oldest recorded spices as seen in Sanskrit records dating to 3000 BC. Reference on Sumerian clay tablets of 2000 BC has a proverb: "When a poor man has died, do not try to revive him!/For when he had bread he had no salt/And when he had salt he had no bread./When he had meat he had no mustard/And when he had mustard he had no meat". Salt and mustard were the major Sumerian condiments. India was a major producer of mustard and still remains so today. The earliest reference to mustard in Chinese literature was related to *B. japonica*; apparently the true mustard was introduced much later from India along the Spice Road. A poultice of fennel, seeds of *Vitex*, *Juniperus excelsa*, tamarisk, tragacanth, *asafoetida*,

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Lolium and mint, mixed with flour, boiled in mustard water, and bandaged on the patient relieved pain. The Greeks and Romans ate the young green plants as a vegetable and mustard was used by the Europeans as a spice for thousands of years. The famous Greek philosopher, Pythagoras (503 BC), recommended a mustard poultice to treat scorpion stings, while another Greek, Hippocrates, some 100 years later, listed a number of internal and external medical uses for mustard seeds. Mustard seeds were used to entomb the kings in Egypt. The Roman Emperor Diocletian fixed the price of mustard seeds in AD 301, since it was such an important crop. There is an interesting story of the exchange between King Darius the third of Persia and Alexander the Great. King Darius sent a bag of sesame seeds to Alexander the Great symbolizing his vast army, who in turn replied with a bag of mustard seed to signify not only the equal number of his soldiers, but also their powerful energy. Mustard is mentioned in the Bible (Matthew 13: 31–32): 31 "The Kingdom of Heaven is like to a grain of mustard seed, which a man took, and sowed in his field:" 32 "Which indeed is the least of all seeds: but when it is grown, it is the greatest among herb and becometh a tree, so that the birds of the air come and lodge in the branches thereof". It is also mentioned in Luke 17: 6; Luke 13: 19; Mark 4: 31; Matthew 17: 20. In the tenth century it was grown by the monks of St Germain des Pres near Paris, France. Guests at the fete given by the French Duke of Burgundy in 1336 are reported to have consumed 70 gallons of mustard in one sitting. Dijon, in France, still remains to this day a market leader in specialized mustard preparations, and in 1634 the town was granted the exclusive right to make mustard. Today, Dijon mustard accounts for more than half the world's mustard. In 1777, M. Grey and M. Poupon produced a strong, canary-yellow paste to a secret recipe which included white wine—it is still produced in attractive jars and bottles. Mustard was introduced to England by the Romans, and Tewkesbury was the famous mustard center of England. It is referred to in Shakespeare's Henry IV Part 2, as: "His wit's as thick as Tewkesbury mustard". A set of Dame Alice de Bryene's household accounts for the year 1418–1419 shows that she used 84 pounds of mustard seed bought for one farthing per pound from Stourbridge Fair. A description of contemporary mustard preparation is given in *Delights for Ladies*, written by Sir Hugh Plat and published in the seventeenth century. In the eighteenth century, Mrs. Clements of Durham became famous for Durham Mustard. By the nineteenth century, Mr. Jeremiah Coleman became famous and rich with his Colman mustard, and produced the famous saying, "It's not the mustard that people eat that made Colman rich, but that left on the plate". From the eighteenth century onwards, different mustard types were produced and became very famous. Mustard seeds were a symbol of fertility for the ancient Indians and have been used by Africans, Chinese, Greeks, and Indians since ancient times.

Producing Regions

B. juncea or brown mustard probably originated in Africa, but is widely cultivated from Eastern Europe to China and Japan. In Asia, it is a very important vegetable and

oilseed crop. *B. nigra* or black mustard most probably originated in the region from W. Asia to Iran, it now occurs wild in the Mediterranean region, and throughout central Europe, the Middle East and the Ethiopian highlands. It is naturalized in the USA and parts of Britain. *S. alba* or white mustard is naturalized in England, the USA, and elsewhere. It is native to the Mediterranean region and W. Asia. It is grown commercially in eastern and northern Europe, and Canadian prairies. The major countries growing mustard are Nepal, India, Indonesia, Japan, Canada, USA, Russia, Great Britain, Italy, Czech Republic, Romania, Slovakia, Germany, and France.

Botanical Description

Brown mustard is an erect annual herb up to 1.5 m (3 ft) high, with grass-green variable leaves, small yellow flowers, and pungent brown seeds. Black mustard is a tall annual, branched herb up to 3 m (9 ft) high, with alternate mid-green pungent leaves, small yellow flowers, and small blackish seeds. White mustard is an annual herb up to 1.2 m (3 ft) high, with alternate, oval, mid to dull green leaves, yellow flowers, and pungent creamy seeds.

Parts Used

Seed (black, brown or uniform creamy) (whole or ground), oil. The seeds are used whole, crushed, ground, or as flour. It also comes in paste forms with water, vinegar, sugar, oil, spices, and herbs called prepared mustard. Mustard seed oil is pale yellow. Mustard leaves are called mustard greens and are used as prepared vegetable or are used in salads. The most common mustard green comes from the brown mustard.

Flavor and Aroma

Sharp, fresh, pungent. Fresh, pungent, slightly biting flavor. The white or yellow mustard is largest and has delicate flavor and is the least burning. The brown mustard seed has a nutty, sweet, and mellow flavor. The black mustard seed has the sharpest flavor and a nutty aftertaste.

Active Constituents

All three types have almost similar composition. Average seed contains moisture 8%, protein 29%, fat 28%, carbohydrates 19%, fiber 11%, ash 5% (Ca, P, Fe),

Table 38.1 Nutrient composition and ORAC values of mustard seed ground

Nutrient	Units	Value per 100 g
Water	g	5.27
Energy	kcal	508
Protein	g	26.08
Total lipid (fat)	g	36.24
Carbohydrate, by difference	g	28.09
Fiber, total dietary	g	12.2
Sugars, total	g	6.79
Calcium, Ca	mg	266
Vitamin C, total ascorbic acid	mg	7.1
Vitamin B_6	mg	0.397
Vitamin B_{12}	mcg	0.00
Vitamin A, RAE	mcg_RAE	2
Vitamin A, IU	IU	31
Vitamin D	IU	0
Vitamin E (alpha-tocopherol)	mg	5.07
Fatty acids, total saturated	g	1.989
Fatty acids, total monounsaturated	g	22.518
Fatty acids, total polyunsaturated	g	10.088
H-ORAC	μmol TE/100 g	28,759
L-ORAC	μmol TE/100 g	498
Total-ORAC	μmol TE/100 g	29,257
TP	mg GAE/100 g	1,844

Source: USDA National Nutrient Database for Standard Reference, Release 24 (2011)

β-carotene, thiamine, riboflavin, niacin, essential oil 1% (mainly allyl isothiocyanate—90%), and glucosinolate sinigrin. Sinigrin on hydrolysis by myrosinase yields allyl isothiocyanate, glucose, and potassium bisulfate. The nutritional constituents and ORAC values of ground mustard seed are given in Table 38.1.

Preparation and Consumption

Tender green plants as well as green pods are eaten as vegetables or salads. Mustard greens have a radish-like biting taste. The British enjoy brown mustard with roast beef and ham. The Japanese use the oriental brown variety as a dip for raw fish. In the Caribbean, yellow or brown mustard is used with fruits and chili peppers for tasty sauces, marinades and stews. In Indian cooking, whole brown or black mustard seeds are "popped" or "tarkared" in heated ghee or oil, and then added to sauces, chutneys, pickles, curries, *sambhars* and *dhals*, to bring out the nutty flavor and aroma. Ground mustard or mustard flour is used in seafood, cocktail sauces, barbecue, sauces, cheese dishes, spice cakes and cookies, devilled eggs, baked beans, ham dishes, pork roast, ham salad, salad dressings, chowders, and bisques.

In Bengali fish dishes and curries, ground mustard provides flavor and consistency. Whole yellow mustard seeds are used in pickled condiments, while the paste form is popular for salad dressings and hot sauces.

A variety of famous mustard blends are available: American ballpark-style mustard is from the white seeds and blended with sugar and wine or vinegar, colored with turmeric. It flavors hot dogs, ham, and barbecue relishes.

Bordeaux mustard is made from black seeds, blended with unfermented wine. The seeds are not husked, thus giving a strong, aromatic, dark brown mustard often flavored with tarragon. This is good with sausages, cold meats, and in beer-flavored stews.

Dijon mustard is light in color and made from husked black seeds or brown seeds blended with wine, salt, and spices. This mustard is used in classic French mustard sauces, salad dressings, and mayonnaise. It is sharp and salty, pungent, hot, but less than English mustard. Is used in classic French cuisine with steak and other grilled or roasted meats, especially rabbit.

The famous French brands are Amora, Grey-poupon, Dijon, and Louti from Bordeaux.

English mustard is hot and made from white seeds and sometimes mixed with wheat flour and turmeric for color. This accompanies beef, ham, gammon, or bacon, pork (especially sausages); it is an ingredient in Welsh rarebit and spicy sauces for fish and vegetables and also an ingredient in piccalilli relish.

German mustard is generally a smooth blend of vinegar and black mustard, varying in strength. It is slightly dark, sweet–sour, and flavored with herbs and spices. Uses same as Bordeaux mustard.

Meaux mustard is yellow brown in color, made with the partly crushed, partly ground black seed mixed with vinegar, producing crunchy hot mustard for bland foods.

Medicinal Uses and Functional Properties

It has been used as a laxative, for the treatment of asthma, and to induce vomiting or relieve coughs. Mustard is considered diuretic, appetizer, emetic, rubefacient, and stimulant. It relieves congestion, neuralgia, and spasms. Used externally for treating rheumatism, arthritis, and lumbago. The consumption of low amounts of isothiocyanates (ITC)-containing mustard was found to quickly and effectively modulate the cytoprotective factors in peripheral blood mononuclear cells and/or blood. The fact that these observations were confirmed by two cytogenetic biomarkers for cancer risk implies that even short-term intake of ITC-containing vegetables might indeed be associated with reduced cancer risk (Lamy et al. 2012). Sinigrin, a major glucosinolate present in Indian mustard (*Brassica juncea* L.) seeds, acts as the precursor of the anticancer compound allyl isothiocyanate, and shows a wide range of biological activities (Wang et al. 2011). In an orthotopic rat bladder cancer model, oral allyl isothiocyanate (AITC)-rich mustard seed powder (MSP-1) at 71.5 mg kg^{-1} (sinigrin dose of 9 μmol kg^{-1}) inhibited bladder cancer growth by

34.5% ($P<0.05$) and blocked muscle invasion by 100%. Moreover, the anticancer activity was associated with significant modulation of key cancer therapeutic targets, including vascular endothelial growth factor, cyclin B1, and caspase 3. On an equimolar basis, the anticancer activity of (AITC) delivered as MSP-1 appears to be more robust than that of pure AITC. MSP-1 was thus shown to be an attractive delivery vehicle for AITC and it strongly inhibits bladder cancer development and progression (Bhattacharya et al. 2010).

Antioxidant Properties

Mustard seed and leaves have been reported to have antioxidant properties (Kim et al. 2002, 2003; Yokozawa et al. 2002, 2003; Choi et al. 2002; Gagandeep et al. 2005; Tiku et al. 2008; Benson and Devi 2009; Jung et al. 2009; Lee et al. 2010; Gill et al. 2011; Khattak 2011; Yuan et al. 2011). A new kaempferol 7-*O*-triglucoside (7-*O*-beta-D-glucopyranosyl-(1→3)-[beta-D-glucopyranosyl-(1→6)]-glucopyranoside) isolated from the leaves of mustard was found to be a scavenger of 1,1-diphenyl-2-picrylhydrazyl radical (Kim et al. 2002). The radical scavenging isorhamnetin 7-*O*-glucoside isolated from mustard leaves showed the peroxynitrite and DPPH scavenging activities with IC50 values of 2.07 ± 0.17 and 13.3 μM (Choi et al. 2002). Yokozawa et al. (2002) showed that isorhamnetin diglucoside is metabolized in vivo by intestinal bacteria to isorhamnetin and that isorhamnetin plays an important role as an antioxidant. The BuOH fraction of mustard leaf was found to control glucose metabolism and reduce lipid peroxidation as well as the level of oxygen radicals, ameliorating the damage caused by oxidative stress in diabetes (Kim et al. 2003). An EtOAc fraction from mustard leaves was found to have strong inhibitory effects, which was concentration-dependent, on the formation of advanced glycation end products and free radical-mediated protein damage in an in vitro system, indicating that this fraction has a potential protective role against diabetes and/or its complications (Yokozawa et al. 2003). Mustard seeds were suggested to have strong cancer chemopreventive potentials and their ability to enhance antioxidant defence system and then in turn to provide protection against the toxic effects of carcinogens (Gagandeep et al. 2005). Mustard leaf extract was found to have protective effect against chromosomal damage and this was associated with modulation of lipid peroxidation as well as an increase in GSH and GSH-dependent enzyme glutathione S-transferase (GST). These findings suggested that the intake of mustard leaf could lead to protection against in vivo genotoxicity and oxidative stress (Tiku et al. 2008). Mustard oil was found to have a protective role against atherogenic index (AI) and lipid peroxidation under both normal and stress conditions in rats (Benson and Devi 2009). Three kaempferol glycosides, kaempferol-3-*O*-(2-*O*-sinapoyl)-beta-D-glucopyranosyl-(1→2)-beta-D-glucopyranoside-7-*O*-beta-D-glucopyranoside (1), kaempferol-3-*O*-beta-D-glucopyranosyl-(1→2)-beta-D-glucopyranoside-7-*O*-beta-D-glucopyranosyl-(1→6)-beta-D-glucopyranoside (2), and kaempferol-3-*O*-(2-*O*-sinapoyl)-beta-D-glucopyranosyl-(1→2)-beta-D-glucopyranoside-7-*O*-beta-D-glucopyranosyl-(1→6)-beta-D-glucopyranoside (3), isolated from mustard

leaves, were tested for antioxidant activities by measuring the scavenging activities on DPPH and ONOO(−). Compounds 1 and 3 showed good antioxidant activities toward both DPPH and ONOO(−), while compound 2 showed only a weak activity toward ONOO(−) and no DPPH activity (Jung et al. 2009). Lee et al. (2010) found mustard leaf kimchi ethanolic extracts to exhibit a strong protective effect against lipid oxidation in raw ground pork. Mustard leaves were shown to have good scavenging effect on DPPH radical with good phenolic content (Khattak 2011). A suspension of mustard seed extract was found to suppress oxidized-LDL-induced macrophage respiratory burst in vitro, to prevent growth, and to induce apoptotic death of SW480 cells (a human colon cancer cell line), while no such effects were found for normal 3T3 cells. A diet enriched with mustard seeds was shown to decrease plasma levels of the lipid peroxidation product malonaldehyde in mice exposed to the colon cancer-inducer azoxymethane (AOM). Such a diet also dose-dependently enhanced the activity of several antioxidant enzymes, such as superoxide dismutase (SOD), catalase, and GSH-peroxidase and, moreover, reduced AOM-mediated formation of colon adenomas by about 50% (Yuan et al. 2011). Sengupta and Ghosh (2012) reported that compared with native mustard oil, the capric acid-enriched mustard oil improved blood lipids, enhanced antioxidant protection, and reduced lipid peroxidation in male albino rats.

Regulatory Status

GRAS 182.10, GRAS 182.20 and GRAS 184.1527.

Standard

ISO 1237 (Specification), ISO 17059 (Oilseeds).

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Chapter 39
Myrtle

Botanical Name: *Myrtus communis* L.
Synonyms: Corsican pepper, wax myrtle.
Family: Myrtaceae.
Common Names: **French**: Myrtle commun; **German**: Myrte; **Spanish**: Mirto; **Italian**: Mirto; **Hindi**: vilayatimehndi; **Arabic**: hadass.

Introduction

History

Myrtle (*Myrtus communis*) is native to the Mediterranean region and is mainly cultivated for the extraction of its essential oil. Used in ancient Greece, the astringent, tonic, and antiseptic properties of its leaves are used to heal wounds, or internally to remedy disorders of the digestive and urinary systems. The oil is antiseptic and anti-catarrhal, and is used to treat chest ailments. Myrtle branches, berries, and leaves have been used since Biblical times. It is used in the Eastern Mediterranean islands of Sardinia, Corsica, and Crete and western Asia to flavor smoked or roasted meats. The myrtle was held as the emblem of honor and authority, and worn by the Athenian judges in the exercise of their functions. The wreaths of the Grecian and Roman victors, in the Olympian and other festivities, were made from myrtle leaves. It is alluded to in the Scriptures, and Jews used it as a token of peace, and entered into bridal decorations. In the Mohammedan tradition it was among the pure things carried by Adam out from the Garden of Eden. The leaves, berries, and twigs have been employed in flavoring food and wines, and the leaves are said to furnish a good tea.

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Producing Regions

Native to the Mediterranean region and western Asia. It is widely cultivated elsewhere, especially common in Morocco, Tunisia, and Algeria. Tunisia is the major supplier of the oil, with Spain, France, and Italy producing small quantities.

Botanical Description

An evergreen shrub or small tree, generally 3–7-m (9–25 ft) high. It has stiff branches and reddish twigs, with dark glossy green leaves. The attractive flowers are white or pinkish and very fragrant. Fruits are round, reddish-blue to violet berries. The whole plant is very aromatic.

Parts Used

Myrtle seeds are purple black berries and used whole or coarsely ground. The leaves are used whole or chopped. Essential oil is obtained by steam distillation of the fresh leaves. The oil is yellow to greenish-yellow mobile liquid.

Flavor and Aroma

Leaves have refreshing, fragrant, and orange like aroma. Myrtle berries have sweet, with rosemary-like and juniper-like flavors. Has a strong camphoraceous-spicy, sweet-herbaceous top note. The middle note is fresh, sweet-herbaceous, camphoraceous. The dry out is not at all tenacious.

Active Constituents

Essential oil (0.2–0.8%). The major constituents of the oil are myrtenol, myrtenyl acetate, α-pinene, 1,8-cineole, limonene, α-terpinyl acetate, and linalool. Myrtle is rich in volatile oils, phenolic acids such as gallic and ellagic acids, flavonoids, fatty acids, tannins, and anthocyanin pigments (Martin et al. 1990).

Preparation and Consumption

The leaves of myrtle are used in salads, stews, roast meats, and stuffings. They are also used to wrap roast pork or wild game before cooking. Italians wrap meats with myrtle branches and then roast, smoke, or broil them. The leaves are stuffed in

meats and removed before eating. The berries have been used to flavor wine and in desserts, sweet dishes, and liqueurs. The wood, leaves, and branches give the meats a very fragrant note.

Medicinal Uses and Functional Properties

Myrtle is antiseptic, astringent, and expectorant. Myrtle oil has been researched for normalizing hormonal imbalances of the thyroid and ovaries as well as balancing the hyperthyroid. Myrtle oil has many reported benefits for the skin such as helping with acne and oily skin. Research has also shown it to help the respiratory system with chronic coughs and tuberculosis. It is suitable to use for children's coughs and chest complaints and may help support the immune function in fighting colds, flu, and infectious disease. Apply the oil topically, diffuse, or use in a humidifier. In folk medicine, myrtle has been used as anti-inflammatory drug. Myrtle is a culinary spice and flavoring agent for alcoholic beverages in the Mediterranean region.

Myrtle has been shown to have antioxidant, anti-inflammatory, antimicrobial, insecticidal, and apoptotic activities (Conti et al. 2010; Mahboubi and Ghazian 2010; Sumbul et al. 2010; Djenane et al. 2011; Karaborklu et al. 2011; Amira et al. 2012). The tested materials (volatile oil, alcoholic and aqueous extracts, myricetin 3-*O*-β-glucopyranoside, myricetin 3-*O*-α-rhamnopyranoside, and gallic acid) of myrtle were found to have significant antihyperglycemic, anti-inflammatory, and antinociceptive effects as compared with control groups and reference drugs (Nassar et al. 2010). The extracts of myrtle exhibited antinociceptive activity against acetic acid-induced writhing and also showed significant activity against acute inflammation which was dose dependent for aqueous extracts. The ethanolic (0.05 $g\,kg^{-1}$) and aqueous extracts (0.005, 0.015, and 0.03 $g\,kg^{-1}$) demonstrated anti-inflammatory effects against chronic inflammation. The aqueous and ethanolic extracts of the aerial parts of *Myrtus communis* L. showed antinociceptive effects and these may be mediated by opioid receptors (Hosseinzadeh et al. 2011). The essential oil of *Myrtus communis* reduced leukocyte migration to the damaged tissue and exhibited anti-inflammatory activity. The oil also inhibited cotton pellet-induced granuloma and serum TNF-alpha and IL-6 in mice (Maxia et al. 2011).

Antioxidant Properties

Myrtle has been shown to possess antioxidant, antibacterial, and antifungal activities (Vacca et al. 2003; Romani et al. 2004; Hayder et al. 2004; Montoro et al. 2006; Sepici-Dincel et al. 2007; Sacchetti et al. 2007; Sanjust et al. 2008; Yoshimura et al. 2008; Aidi Wannes et al. 2010; Mimica-Dukic et al. 2010; Serce et al. 2010; Kiralan et al. 2012; Messaoud and Boussaid 2011; Mothana et al. 2011; Amira et al. 2012). Semimyrtucommulone from myrtle was found to be a novel dietary antioxidant lead (Rosa et al. 2003). Myrtucommulone A and semimyrtucommulone from myrtle

showed powerful antioxidant properties, protecting linoleic acid against free radical attack in simple in vitro systems, inhibiting its autoxidation and its $FeCl_3$- and EDTA-mediated oxidation. Two industrial red myrtle liqueurs showed antioxidant capacity values comparable to those of red wine, expressed as mM of Trolox (Vacca et al. 2003). Hydroalcoholic extracts, ethylacetate extract, and aqueous residues after liquid–liquid extraction exhibited dose-dependent inhibition of oxidation induced by copper ions, and also reduced the formation of conjugated dienes (Romani et al. 2004). Hayder et al. (2004) found an aqueous extract, total flavonoids oligomer fraction (TOF), hexane, chloroform, ethyl acetate and methanol extracts, and essential oil from myrtle leaves to significantly decrease the SOS response induced by AFB1 (10 μg/assay) and Nifuroxazide (20 μg/assay). The aqueous extract, the TOF, and the ethyl acetate and methanol extracts also showed free radical scavenging activity towards the DPPH radical. Myricetin-3-*o*-galactoside and myricetin-3-*o*-rhamnoside from myrtle leaves inhibited xanthine oxidase activity, lipid peroxidation, and scavenged the free radical DPPH. They induced an inhibitory activity against nifuroxazide, aflatoxin B1, and H_2O_2 induced mutagenicity. Moreover, these two compounds from myrtle leaves modulated the expression patterns of cellular genes involved in oxidative stress, in DNA damage repair, and in apoptosis (Hayder et al. 2008). The compounds myrtucommulone A and semi-myrtucommulone from myrtle were found to be great dietary antioxidants during the thermal, solvent-free degradation of cholesterol, and also significantly preserved LDL from oxidative damage induced by Cu^{2+} ions at 2 h of oxidation (Rosa et al. 2008). Amensour et al. (2009) studied the total phenolic content and antioxidant activity of the methanolic, ethanolic, and aqueous extracts of myrtle leaves and berries. Overall the leaf extracts had higher total phenol content and showed higher antioxidant activities than the berry extracts. They also found a positive correlation between the phenolic content and antioxidant activity. The methanol extracts of different myrtle plant parts (leaf, flower, and stem) showed better antioxidant activity than the leaf and flower essential oils (Aidi Wannes et al. 2010).

Regulatory Status

Food additive. FDA 121.1163.

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Chapter 40
Nigella

Botanical Name:	*Nigella sativa* L.
Synonyms:	*Nigella cretica* Miller; *Nigella indica* Roxb. ex Fleming; *Nigella arvensis* Auct. Terr., nigella seed, small fennel, black cumin, black caraway seed.
Family:	Ranunculaceae.
Common Names:	**French**: nigelle, cumin noir; **German**: schwarzkummel; **Italian**: nigella; **Spanish**: neguilla, pasionara; **Turkish**: kolonji; **Hindi**: kala zira.

Introduction

History

The genus name "*Nigella*" is believed to have been derived from the Latin *nigellus* or *niger*, meaning "blackish," and "*sativa*" from "to sow." As black cumin it has been reported in ancient Greek, Hebrew, and Roman texts as a condiment and component of herbal medicines. It is believed to have been introduced into Britain in 1548. In southeast Asia, the seeds of nigella have been mainly used as a medicinal. Nigella is a minor cultivated crop from Morocco to northern India, in sub-Saharan Africa especially Ethiopia, where it has reportedly been used as a fish poison, and in Russia, Europe, and North America. *Nigella sativa* L. is the most important spice in this genus, while *N. arvensis* is of minor importance, and *N. damascena* L. is the famous blue-flowered ornamental "love-in-the-mist." The seeds have been found in the tomb of Tutankhamun in Egypt. The great Greek physician, Dioscorides of the first century AD, recorded that seeds were taken to treat headaches, catarrh, toothache, intestinal worms, as a diuretic, and to increase breast milk.

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Producing Regions

It is native to the Mediterranean region through West Asia up to northern India, and is domesticated. Nigella is found wild in India and has been used as a condiment since ancient times. India is the largest producer and exporter of Nigella seeds. Bangladesh, Nepal, Sri Lanka, Iraq, and Pakistan are the other producing countries.

Botanical Description

Nigella is an erect, herbaceous annual herb up to 60 cm (1.5 ft) high, with a well-developed yellow-brown taproot. The stem is profusely branched, becoming hollow with age, and light to dark green. The leaves are feathery, and normally green in color, but become brown or red with age. The flowers are pale green when young, light blue when mature. The fruit is a capsule, yellow or brownish when mature. The seeds are small, pitted and wrinkled, and an oily white interior.

Parts Used

Nigella seed (dark brown to black) (whole or ground), essential oil.

Flavor and Aroma

Strong, pungent, carrot like. Aromatic, oily, pungent, peppery, and nutty. Sharp, slightly bitter, peppery, and nutty taste.

Active Constituents

Moisture 4%, protein 22%, fat 41%, fiber 8%, carbohydrate 17%, ash 4.5%, essential oil 0.5%. Other compounds are alkaloids (nigellicines and nigeledine), sterols, tannins, vitamins, glucosides. Major constituents of the essential oil are *p*-cymene, thymoquinone, α-pinene, β-pinene, and others. The major quinines are thymoquinone, dithymoquinone, thymohydroquinone (Tesarova et al. 2011). Some important constituents are thymoquinone, thymohydroquinone, dithymoquinone, thymol, carvacrol, nigellimine-*N*-oxide, nigellicine, nigellidine, and alpha-hederin (El-Fatatry 1975; Randhawa and Alghamdi 2011).

Preparation and Consumption

Nigella is used to flavor meat and meat products, vegetable dishes, pickles, stews, and soups. It is an ingredient in curries, fruit pies, sauces, vinegar, and alcoholic beverages. It is an essential constituent in the famous Middle East "*choereg*" rolls. Crushed nigella seed is mixed with dough before baking to give it a gray to almost black color to the bread. Widely used in Indian cuisines, particularly in lamb dishes such as korma. The seeds are sprinkled on the naan bread before baking. It is one of the ingredients in *panch phoran*. It is also added to dhal (lentil) as well as chutneys and vegetables. In Iran and North India, nigella is used to enhance the flavor of vegetable dishes.

Medicinal Uses and Functional Properties

It is considered carminative, diuretic, emmenagogue, analgesic, antidiabetic, antipyretic, antineoplastic, antibacterial, antimicrobial, anti-inflammatory, sudorific, stimulant, expectorant, and anthelmintic, and has other reported properties (Salomi et al. 1991; Houghton et al. 1995; Daba and Abdel-Rahman 1998; Worthen et al. 1998; Prajapati et al. 2003; El-Abhar et al. 2003; Ali and Blunden 2003; Mahmood et al. 2003; Ali. 2004; el-Aziz et al. 2005; Kanter et al. 2006a; Bamosa et al. 2010; Banerjee et al. 2010; Halamova et al. 2010; Keyhanmanesh et al. 2010; Li et al. 2010; Abusnina et al. 2011; Ali and Meitei 2011; Hayat et al. 2011; Khosravi et al. 2011; Korany and Ezzat 2011; Rogozhin et al. 2011; Vaillancourt et al. 2011). It has been used to treat chronic conditions including cardiovascular disease and immunological disorders. It has also been used in the treatment of diabetes, hypertension, and dermatological conditions. A decoction is traditionally used to treat headache, rheumatic pains, asthma, coughs, nausea, and in India to induce abortion. Crushed seeds in vinegar are applied in skin disorders such as ringworm, eczema, and baldness. In Egypt, the tea Druce is used to treat diabetes. It has insect repellant properties. Thymoquinone, the major active component of the medicinal herb *Nigella sativa* has been described as a chemopreventive and chemotherapeutic compound.

A few pharmacological effects of N. sativa seed, its oil, various extracts, and active components include anti-inflammation, immuno-modulatory, immunosuppressive, immune stimulation, hypoglycemic, antihypertensive, antiasthmatic, antimicrobial, antiparasitic, antioxidant, and anticancer (El-Fatatry 1975; Hanafy and Hatem 1991; Morsi 2000; Islam et al. 2004; Roy et al. 2006; Mbarek et al. 2007; Norwood et al. 2007; Salem 2005; Yildiz et al. 2010; Attia et al. 2011; Bakathir and Abbas 2011; Boskabady et al. 2011; El-Najjar et al. 2011; Gilhotra and Dhingra 2011).

Alcoholic extracts of the seed was shown to have antibacterial activity against *E. coli* and *M. pyogenes* var. *aureus* (Pruthi 2001). *Nigella sativa* reduced the superoxide dismutase values in all the treated rabbits, suggesting its role in the prevention of liver fibrosis in rabbits (Turkdogan et al. 2001). NS treatment was found to be beneficial in spinal cord tissue damage in rats (Kanter et al. 2006b). Thymoquinone

(NS) and epigallocatechin-3-gallate (green tea) were found to have similar chemotherapeutic effects on cancer cells as 5-fluorouracil (Norwood et al. 2006). NS was found to be very effective (in vitro) in influencing the survival of MCF-7 breast cancer cells, thus promising a great alternative in cancer chemoprevention and treatment (Farah 2005). The fixed oil from NS seeds had an in vitro antisickling activity (Ibraheem et al. 2010). *Nigella sativa* and its constituent thymoquinone have been found to have strong anticancer activity (Randhawa and Alghamdi 2011). Thymoquinone was reported to have potential implication in breast cancer prevention and treatment, and that the antitumor effect may also be mediated through modulation of the PPAR-γ activation pathway (Woo et al. 2011). Lei et al. (2012) provided molecular evidence both in vitro and in vivo to support their conclusion that thymoquinone can activate caspase-3 and caspase-9 and thus result in the chemosensitization of gastric cancer cells to 5-FU-induced cell death.

Antioxidant Properties

Nigella sativa (NS) extracts and essential oil have been shown to possess strong antioxidant activity (Houghton et al. 1995; Nagi et al. 1999; Burits and Bucar 2000; Mansour et al. 2001; Badary et al. 2003; Kanter et al. 2003; Ramadan et al. 2003; Farah et al. 2005; Ilhan et al. 2005; Mohamed et al. 2005; Ozugurlu et al. 2005; Kanter et al. 2005a–c; Cemek et al. 2006; Sayed-Ahmed and Nagi 2007; Al-Enazi 2007; Bourgou et al. 2008; Al-Johar et al. 2008; Yildiz et al. 2008; Barron et al. 2008; Hasani-Ranjbar et al. 2009; Ragheb et al. 2009; Abdelmequid et al. 2010; Abdel-Zaher et al. 2010; Assayed 2010; Butt and Sultan 2010; El-Beshbishy et al. 2010; Coban et al. 2010; Ismail et al. 2010; Mousavi et al. 2010; Rastogi et al. 2010; Terzi et al. 2010; Yaman and Balikci 2010; Alici et al. 2011; Ashraf et al. 2011; Attia et al. 2011; Okeola et al. 2011; Hussain et al. 2011; Tesarova et al. 2011; Sultan et al. 2012). The anti-oxidant/anti-inflammatory effect of thymoquinone has been reported in various disease models, including encephalomyelitis, diabetes, asthma, and carcinogenesis. Moreover, thymoquinone could act as a free radical and superoxide radical scavenger, as well as preserving the activity of various antioxidant enzymes such as catalase, glutathione peroxidase, and glutathione-S-transferase, the induction of chemoprotective enzymes probably through increasing transcription. The anticancer effect(s) of thymoquinone are mediated through different modes of action, including anti-proliferation, apoptosis induction, cell cycle arrest, ROS generation, and anti-metastasis/anti-angiogenesis. Additionally, thymoquinone has been shown to exhibit anticancer activity through the modulation of multiple molecular targets, including p53, p73, PTEN, STAT3, PPAR-γ, activation of caspases, sustained expression of CD62L, and generation of ROS. The antitumor effects of thymoquinone have also been investigated in tumor xenograft mice models for colon, prostate, pancreatic, and lung cancer (Ravindran et al. 2010; El-Sayed 2011; Salem et al. 2011; Woo et al. 2012). Thymoquinone, a major component of

Nigella seeds shows protective action against CCl_4-induced hepatotoxicity because of its antioxidant properties (Nagi et al. 1999). Thymoquinone was shown to protect against renal I/R-induced damage through an antioxidant mechanism as well as the decrease of CYP3A1 and SSAT gene expression (Awad et al. 2011). Badary and Gamal (2001) found thymoquinone to be a powerful chemopreventive agent against MC-induced fibrosarcoma tumors and this could be due to its antioxidant activity and interference with DNA synthesis coupled with enhancement of detoxification process. Ashraf et al. (2011) reported that the protective effects of Nigella may not only be due to thymoquinone, but perhaps due to other antioxidants also. Treatment with Nigella extract was shown to decrease the elevated glucose and MDA concentrations, increase the lowered GSH and ceruloplasmin concentrations, and prevent lipid-peroxidation-induced liver damage in diabetic rats (Meral et al. 2001). Mabrouk et al. (2002) showed that supplementation of diet with honey and Nigella had a protective effect against MNU-induced oxidative stress, inflammatory response and carcinogenesis in Sprague Dawley rats. Khan et al. (2003) found Nigella could suppress $KBrO_3$-mediated renal oxidative stress, toxicity and tumor promotion response in rats, and is a potent chemopreventive agent. Kanter et al. (2003) reported that *Nigella sativa* decreased lipid peroxidation and liver enzymes, and increased the antioxidant defense system activity in CCl_4-treated rats. Prior treatment with thymoquinone or Nigella seed oil was shown to have a protective effect against the negative impacts of hyperhomocysteinemia (HHcy) in rats (El-Saleh et al. 2004). NS was found to have a therapeutic effect in diabetes by decreasing oxidative stress and preserving pancreatic beta-cell integrity in STZ-induced diabetes in rats (Kanter et al. 2004). Treatment of rats with Nigella seeds was found to suppress Fe-NTA-induced oxidative stress, hyperproliferative response, and renal carcinogenesis in Wistar rats (Khan and Sultana 2005). Abdel-Wahhab and Aly (2005) reported nigella oil to be more effective than clove oil in restoring the hematological and biochemical changes induced by aflatoxin in rats. The essential oil of black cumin has been shown to possess radical scavenging properties (Burits and Bucar 2000). Kaleem et al. (2006) reported the antidiabetic activity of nigella ethanol extract because of its antioxidant effects. They found the ethanol extract to reduce the elevated levels of blood glucose, lipids, plasma insulin and improve the levels of lipid peroxidation products and the antioxidant enzymes, reduce glutathione and glutathione peroxidase in liver and kidney in experimental diabetic rats. Bayrak et al. (2008) found NS essential oil to have potent FR scavenger and antioxidant properties, and a promising agent for protecting tissues from oxidative damage and preventing organ damage due to renal ischemia/reperfusion (I/R). The NS essential oil was found to improve the functional and histological parameters and attenuate the oxidative stress induced by cyclosporine A, thus preventing renal dysfunction and morphological abnormalities associated with CsA administration in rats (Uz et al. 2008). Ebru et al. (2008) in their study found NS essential oil pre-treatment to reduce CsA injury in rat heart, and this was demonstrated by normalized cardiac histopathology, decreased lipid peroxidation, improved antioxidant enzyme status, and cellular protein oxidation. Radad et al. (2009) for the

first time reported the potential of thymoquinone from NS to protect primary dopaminergic neurons against MPP(+) and rotenone relevant to Parkinson's disease. The alcohol and hexane extract of NS seeds showed antimicrobial and antioxidant activity (Mehta et al. 2009). Chandra et al. (2009) demonstrated that chronic highly active antiretroviral therapy (HAART) increased serum insulin levels by dysregulating both insulin production by beta-cells and insulin action at the periphery. This could be prevented by dietary supplementation with NS oil. The suppressed insulin production was restored in cells coexposed to NS oil or thymoquinone. Hamdy and Taha (2009) reported that NS essential oil and thymoquinone corrected STZ-diabetes-induced alterations in CK-MB and brain monoamines due to their antioxidant properties. Nigella seed extract was shown to act as free radical scavenger and protect TAM-induced liver injury in rats (El-Beshbishy et al. 2010). Oral feeding of ethanol extract of nigella resulted in increased survival in mice exposed to whole body irradiation (7.5 Gy) and this was attributed to the prevention of radiation-induced oxidative damage (Rastogi et al. 2010). NS acts in the kidney as a potent scavenger of free radicals to prevent the toxic effects of GS both in the biochemical and histopathological parameters (Yaman and Balikci 2010). Abdel-Zaher et al. (2010) reported that nigella oil through inhibition of morphine-induced NO overproduction and oxidative stress, appears to have a therapeutic potential in opioid tolerance and dependence. Nigella seed oil was shown to prevent oxidative stress and attenuate the changes in the biochemical parameters induced by gamma-HCH in male rats (Attia et al. 2011). Ezz et al. (2011) reported the promising anticonvulsant and potent antioxidant effects of curcumin and Nigella sativa oil in reducing oxidative stress, excitability, and the induction of seizures in epileptic animals and improving some of the adverse effects of antiepileptic drugs. N. sativa oil has been shown to have a therapeutic potential in tramadol tolerance and dependence through blockade of NO overproduction and oxidative stress induced by the drug in mice (Abdel-Zaher et al. 2011). Nigella fixed oil and essential oil were found to be effective in reducing the abnormal values of enzymes, lactate dehydrogenase (LDH), CPK, and CPK-MB. Similarly, liver enzymes were also reduced. However, their results revealed that the essential oil supplementation was more effective in ameliorating the multiple organ toxicity in oxidative stressed animal modeling. Therefore, the essential oil was more effective in reducing the extent of potassium bromate-induced multiple organ toxicity (cardiac and liver enzymes imbalance) and thus would be more helpful in reducing the extent of myocardial and liver necrosis (Sultan et al. 2012).

Regulatory Status

GRAS 182.10.

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Chapter 41
Nutmeg

Botanical Name:	*Myristica fragrans* Houtt.
Synonyms:	*Myristica moschata* Thunb.; *Myristica officinalis* L. f.; *M. aromatica* Swartz; *M. amboinensis* Gand.; myristica.
Family:	Myristicaceae.
Common Names:	**Arabic**: jus alteeb; **Dutch**: notemuskaat; **Farsi**: djus hendi; **French**: Muscade; **German**: Muskatnuss; **Hindi**: jaiphal; **Italian**: Noce Moscata; **Spanish**: Nuez Moscada; **Indonesian**: jati-pala; **Russian**: muskatniy oreek; **Sinhalese**: sadhika; **Swedish**: muskotnot; **Thai**: luk jan.

Introduction

History

The English nutmeg is from the Latin *muscus*, via French *mugue* and medieval English *notemuge*; mace is from *maccis*. The Sanskrit *Susruta Samhita* about 600 AD has nutmeg named as *jai phal* and mace as *jai kosa* (mace is the fleshy outer covering of the nutmeg). Nutmeg is of Indonesian origin from the Spice Islands, but was brought to India by Arab traders and from there to Europe. The Hindu traders introduced nutmeg to Java (nutmeg is known as *jati-phala* and mace as *jati-kosa*), and then from there to Malaysia (*buah pala*). Theophrastus is credited with attributing the spice *comacum* to nutmeg because of its dual properties (Enquiry into Plants, 372–287 BC). Pliny the Elder, 350 years later in his *Historia Naturalis* called it a nut. Kazwini around AD 1300 was the first to reveal the source of nutmeg as Moluccas. The first European record is from AD 540 by Actius of Constantinople. In 1191 when Emperor Henry VI entered Rome for his coronation, the streets were fumigated with nutmegs and other stewing aromatics. The English chronicler wrote

D.J. Charles, *Antioxidant Properties of Spices, Herbs and Other Sources*,
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about nutmeg "And notemuge to put in ale, whether it be moist or stale" and in thirteenth century England mace was sold for 4s and 7d per pound almost equal to the price of one sheep or half cow. Vasco da Gama landed on India's west Coast in 1498 and by 1512 the Portuguese had reached the Moluccas and dominated the nutmeg trade for the next century. Garcia da Orta visited the Moluccas in the sixteenth century and wrote this about nutmeg "The tree supplying nutmeg and mace is like a pear tree in both trunk and foliage. In these islands its fruit is sparse and wild, and they eat its fruit with betel leaf and make no other use of it" (da Orta 1563). In the early seventeenth century, the Dutch replaced the Portuguese as the dominant player and monopolized the trade for the next 200 years. The Dutch East India Company in 1735 burnt tons of surplus nutmeg to maintain a high price. The French Pierre Poivre brought nutmeg to Mauritius, then Ile de France in December 1753. Later Captain Provost of the *L'Etoile du Matin* collected nutmeg seeds and clove on the island of Begy, and brought to Ile de France (Ly-Tio-Fane 1958). Plants were moved to the Seychelles and Reunion (Ile de Bourbon). Around 1818 nutmeg was introduced to Zanzibar from Mauritius or Reunion. During the British occupation of the Moluccas (1796–1802), the Honorable East India Company sent their botanist Mr. Christopher Smith to collect seedlings of nutmeg and clove to establish the spice in Penang and other countries under British control. It was introduced into Sri Lanka in 1804. Nutmeg was taken to the Caribbean island of St. Vincent in 1802 and then to Grenada in 1843. Grenada still continues to be a leading producer of nutmeg.

Producing Regions

Nutmeg is native to the Banda Islands (Moluccas) in Indonesia, but is also cultivated in South India, Sri Lanka, Sumatra and Malaysia. It is commercially cultivated in Indonesia, Malaysia (East Indian) and Caribbean, Grenada (West Indian), and to a smaller extent in Sri Lanka (East Indian). The East Indian nutmeg is superior in flavor to the West Indian.

Botanical Description

It is a dioecious evergreen tree spreading up to 15–20-m (49–66 ft) high, with dark green leaves, yellowish flowers without petals and large yellowish fruit. All parts of the tree are aromatic. The fleshy fruit is produced by the female trees and later splits into two at maturity. The large, hard seed is the nutmeg which is grayish brown and varies in size up to 3 cm long and 2 cm wide. It is oval in shape, a little wrinkled up but smooth to touch. It is surrounded by bright red aril that forms a thin, net-like fleshy layer. The dried aril is the spice mace.

Parts Used

Nutmeg and mace are used as spices mainly the whole seed dried and powdered. Nutmeg is used ground, grated, or crushed. Essential oil of nutmeg and mace (obtained by steam distillation or steam and water distillation) is also used often. The oleoresins are also used.

Flavor and Aroma

It has a sweet, spicy, aromatic nutty aroma more like camphor and penetrating. It has a very distinctive spicy, bitter sweet taste resembling clove with a terpeny, citrus-like aroma and flavor, but sweeter than mace.

Active Constituents

Nutmeg has moisture 40% with volatile essential oil 11%, nonvolatile ether extract 33.60%, starch 30%, glucose 0.1%, fructose 0.07%, sucrose 0.72%, protein 7.16%, crude fiber 11.7%, total ash 2.57%, acid-insoluble ash 0.20%, polyphenols, total tannins 2.50%, and true tannins 1%. The main components of the essential oil are sabinene, α-pinene, β-pinene, and myristicin. The seeds contain up to 75% fatty oil known as nutmeg butter. The nutritional constituents and ORAC values of nutmeg are given in Table 41.1.

Preparation and Consumption

Mainly used in the Food Processing Industry as a spice and in ground forms. It is mainly used with sweet, spicy dishes like pies, puddings, custards, cookies and spice cakes. Nutmeg with its oleoresins is used in meat dishes like Middle Eastern lamb, Italian mortadella sausages, Scottish haggis, vegetable dishes like broccoli, beans, cabbage, eggplant, onions, spinach and brussels sprouts. Ketchup, pickles, and chutneys are also seasoned with nutmeg. It is indispensable to eggnog and a number of mulled wines and punches. Fish, seafood, and a number of soups are flavored by nutmeg but should be used very sparingly. It is an ingredient of the Moroccan spice blend *ras el hanout*. Nutmeg provides intense sweet, spicy aroma to cakes, sweet rolls, pumpkin pies, ice creams, chocolate and lemon desserts. It is a favorite spice of the Dutch and French.

Table 41.1 Nutrient composition and ORAC values of nutmeg ground

Nutrient	Units	Value per 100 g
Water	g	6.23
Energy	kcal	525
Protein	g	5.84
Total lipid (fat)	g	36.31
Carbohydrate, by difference	g	49.29
Fiber, total dietary	g	20.8
Sugars, total	g	28.49
Calcium, Ca	mg	184
Vitamin C, total ascorbic acid	mg	3.0
Vitamin B-6	mg	0.160
Vitamin B-12	mcg	0.00
Vitamin A, RAE	mcg_RAE	5
Vitamin A, IU	IU	102
Vitamin E (alpha-tocopherol)	mg	0.00
Vitamin D	IU	0
Fatty acids, total saturated	g	25.940
Fatty acids, total monounsaturated	g	3.220
Fatty acids, total polyunsaturated	g	0.350
H-ORAC	μmol TE/100 g	12,600
L-ORAC	μmol TE/100 g	42,625
Total-ORAC	μmol TE/100 g	69,640
TP	mg GAE/100 g	567

Source: USDA National Nutrient Database for Standard Reference, Release 24 (2011)

Medicinal Uses and Functional Properties

Nutmeg is often used to treat flatulence, nausea, vomiting, stomach cramps, diarrhea as it has carminative and stimulative properties. In Ayurvedic Medicine it is used to treat mild fever, asthma, and to reduce the catarrh of the respiratory tract. As nutmeg has pronounced antimicrobial and anti-inflammatory activities, it is used in the relief of aches, pains like arthritis and rheumatism. The essential oil is also known to have a spasmolytic activity and relieves stomach cramps and flatulence. The addictive and hallucinogenic effects are ascribed to myristicin and elemicin.

Nutmeg seed extracts, active compounds, and oil have been reported to exhibit anti-inflammatory, antimicrobial, antibacterial, antiobesity, larvicidal, and molluscicidal activities (Lee et al. 1999; Chung et al. 2006; Narasimhan and Dhake 2006; Cho et al. 2007; Chaubey 2008; Ma et al. 2009; Senthilkumar et al. 2009; Nguyen et al. 2010; Cuong et al. 2011; Lee and Park 2011). Myristicin, an active aromatic compound in nutmeg, has been known to have anti-cholinergic, antibacterial, and hepatoprotective effects.

The dihydroguaiaretic acid (DHGA) isolated from the aryls of nutmeg showed an inhibitory activity against the complex formation of the fos-jun dimmer and the DNA consensus sequence with an IC50 value of 0.21 μmol. NDGA also inhibited

fos-jun dimmer action showing IC50 values of 7.9 nmol. In in-vitro assay DHGA suppressed leukemia, lung cancer, and colon cancer (Park et al. 1998). Morita et al. (2003) found that nutmeg showed the most potent hepatoprotective activity. Myristicin, the major component of nutmeg essential oil, was found to possess extraordinary potent hepatoprotective activity. They concluded that the hepatoprotective activity of myristicin might be due in part to the inhibition of TNF-alpha release from macrophages. Hexane extract of nutmeg significantly decreased acetylcholinesterase activity as compared with their respective vehicle-treated control groups (Dhingra et al. 2006). Narasimhan and Dhake (2006) showed that the constituents isolated from nutmeg exhibited good antibacterial activity and suggested the potential use of natural compounds instead of synthetic preservatives. Chirathaworn et al. (2007), in their in vitro study, reported that the role of nutmeg as an anticancer agent is contained in myristicin which showed cytotoxic and apoptotic effects in human neuroblastoma SK-N-SH cells with an accumulation of cytochrome and activation of caspase-3 in the cytosol. Myristicin was reported to have anti-inflammatory properties related to its inhibition of NO, cytokines, chemokines, and growth factors in dsRNA-stimulated macrophages via the calcium pathway (Lee and Park 2011). Meso-dihydroguaiaretic acid (MDA), an anti-oxidative and anti-inflammatory compound from nutmeg was shown to inhibit insulin-induced lipid accumulation in human HepG2 cells by suppressing expression of lipogenic proteins through AMPK signaling, and thus suggesting it to be a potent lipid-lowering agent (Lee et al. 2011). Lignans (macelignan, machilin F, nectandrin B, safrole, licarin A, licarin B, myristargenol, and meso-dihydroguaiaretic acid) isolated from *Myristica fragrans* were shown to have anabolic activity in bone metabolism (Lee et al. 2009).

Antioxidant Properties

Nutmeg and the active compounds have been found to show antioxidative properties (Duan et al. 2009; Sohn et al. 2007; Akinboro et al. 2011). Argenteane is a dilignan antioxidant isolated from nutmeg's mace, and it has similar activity as vitamin E (Calliste et al. 2010). Mace lignan isolated from nutmeg was found to significantly reduce the cell growth inhibition and necrosis caused by t-BHP. Furthermore, macelignan ameliorated lipid peroxidation as demonstrated by a reduction in MDA formation in a dose-dependent manner, and also reduced intracellular ROS formation and DNA damaging effect caused by t-BHP (Sohn et al. 2007). The lignans present in the aqueous extract of fresh nutmeg mace showed antioxidant, radioprotective, and immunomodulatory effects in mammalian cells. Mace lignans protected the splenocytes against radiation-induced intracellular ROS production in a dose-dependent manner (Checker et al. 2008). Murcia et al. (2004) found strong antioxidant activity of nutmeg and also irradiated nutmeg. Nutmeg was suggested as a great radioprotector, because nutmeg treatment effectively protected against radiation-induced biochemical alteration as reflected by a decrease in LPO level and

ACP activity, and an increase in GSH and ALP activity (Sharma and Kumar 2007). Low-density lipoprotein (LDL) antioxidant lignans were extracted from nutmeg and found to be very effective (Kwon et al. 2008). Nutmeg was found to exert some level of protective ability against peroxynitrite-mediated biomolecular damage. This indicated that the phenolics present in the spice contributed to such spice-elicited protection against peroxynitrite toxicity (Ho et al. 2008). Maeda et al. (2008) evaluated the antioxidative activity of phenylpropanoid compounds extracted from nutmeg. The antioxidant activity was evaluated using the 1,1-diphenyl-2-picrylhydrazyl radical-scavenging method, superoxide dismutase assay, ferric thiocyanate assay, and radical-scavenging effect assay with electron-spin resonance. They found high antioxidant activity in the monoterpenoid extracts. Nutmeg extract had high total phenolic content, was strongly inhibitory of TBARS formation and had strong DPPH scavenging activity (Kong et al. 2010). Regular use of nutmeg along with other spices may prevent postprandial rise in glucose levels through inhibition of intestinal alpha-glucosidase and may maintain blood glucose level through insulin secretagogue action (Patil et al. 2011). Akinboro et al. (2011) reported that argenteane, or phenolic compounds, acting as antioxidant may be responsible for the observed antimutagenic effect of this extract against CP-induced chromosomal aberrations.

Regulatory Status

GRAS 182.10 and GRAS 182.20.

Standard

ISO 6577.

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Chapter 42
Onion

Botanical Name:	*Allium cepa* L.
Synonyms:	Bulb onions, multiplier onions, shallots, potato onion, tree onion, palandu.
Family:	Liliaceae (Amaryllidaceae or Alliaceae).
Common Names:	**French**: oignon; **German**: Zwiebel; **Italian**: cipolla; **Spanish**: cebolla; **Hindi**: pyaj.

Introduction

History

Onion is one of the oldest vegetables known to mankind dating back to 3,500 years. Onion plant is the most often depicted plant in Egyptian tomb paintings. An inscription on the Great Pyramid of Cheops indicates "100 talents of silver had been spent on onions, garlic, and radishes with which the slave labor were reimbursed, in lieu of money, for their part in building the pyramid in 2500 BC." It is the plant that the Greeks and Romans had a love–hate relationship with, both praising its healing properties and damning its odor. It is also the plant that Alexander the Great fed to his troops to give them strength and vigor for battle. The ancient Egyptians loved onion and one of the varieties evoked as a deity and worshipped. The Egyptians ate it raw. Onion was one of the staple foods for the slaves who built the Giant Pyramid. Later the Israelites mourned the loss of Egyptian onions on their way to the Promised Land. It is mentioned in the Bible (Numbers 11: 5). The English name onion is believed to have been derived from the Roman name *unionem* or *unio*, referring to its single bulb. Romans introduced onion to Britain, and Emperor Nero took it for cold, coughs, and sore throats. It was regarded as an aphrodisiac and a symbol of fertility.

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Producing Regions

Onion is native to western Asia and the Mediterranean. It has long been cultivated worldwide and with many different varieties. The USA, Egypt, Japan, Hungary, Czechoslovakia, France produce dehydrated onions.

Botanical Description

Onion is a perennial or biennial herb that grows from a bulb up to 1.2 m (3 ft) high. Stems are erect and carry an umbel of flowers. The leaves are narrow, basal, hollow cylindrical, and blue-green in color. Flowers are white or pink or purple, small in globe-shaped umbels. The fruit is a capsule containing black seeds. There are many different varieties of onions, the most common ones being the white globe, yellow globe, and red globe.

Parts Used

Fleshy bulb (fresh or dry, frozen, chopped onions, powder, charred powder, flakes, onion salt, onion juice), essential oil. Fresh onion comes chopped, sliced, or diced. Dried onion comes granulated, powdered, minced, chopped, ground, or toasted.

Flavor and Aroma

It has a pungent, sweet aroma. It has a pungent bitter taste and flavor.

Active Constituents

The activity and pungent smell is due to several sulfur-containing compounds—mainly sulfoxides, but also cepaenes (α-sulfinyl-disulfides). Sulfoxides (such as trans-*S*-(1-propenyl)-L-(+)-cysteinesulfoxide, an isomer of alliin) are present in the intact bulb, but they are converted by enzymatic action (by alliinase) into various sulfides that spontaneously form disulfides. These compounds can easily form disulfide bonds with SH-groups of proteins and thus alter their biological activities. Other constituents present are phenolic acids (caffeic, sinapic), flavonoids, sterols, saponins, sugars, vitamins, pectins, anthocyanins, and essential oils Singh et al. (2004).

Table 42.1 Nutrient composition and ORAC values of onion powder

Nutrient	Units	Value per 100 g
Water	g	5.39
Energy	kcal	341
Protein	g	10.41
Total lipid (fat)	g	1.04
Carbohydrate, by difference	g	79.12
Fiber, total dietary	g	15.2
Sugars, total	g	6.63
Calcium, Ca	mg	384
Vitamin C, total ascorbic acid	mg	23.4
Vitamin B-6	mg	0.718
Vitamin B-12	mcg	0.00
Vitamin A, RAE	mcg_RAE	0
Vitamin A, IU	IU	0
Vitamin D	IU	0
Vitamin E (alpha-tocopherol)	mg	0.27
Fatty acids, total saturated	g	0.219
Fatty acids, total monounsaturated	g	0.202
Fatty acids, total polyunsaturated	g	0.310
H-ORAC	μmol TE/100 g	3,858
L-ORAC	μmol TE/100 g	431
Total-ORAC	μmol TE/100 g	4,289
TP	mg GAE/100 g	861

Source: USDA National Nutrient Database for Standard Reference, Release 24 (2011)

Quercetin is one of the major compounds (Rodriguez Galdon et al. 2008; Lu et al. 2011). The nutritional constituents and ORAC values of onion powder are given in Table 42.1.

Preparation and Consumption

White onions are the most pungent and strong, yellow onions are slightly milder and sweeter, red (purple) onions are the mildest and also the sweetest. Onions add color, flavor, and crunchiness to foods. The dry or fresh onion is used raw, sauteed, steamed, broiled, boiled, pickled, marinated, stuffed, cooked and pureed, baked, deep fried in batter, and caramelized. Onions are great in cheese spreads, savory pies, stuffings, soups, stocks, casseroles, salads, breads, pates, meat loaves, steamed vegetable combinations, and stir fries. They can be added to sauces, soups, and stews. Yellow onions turn a rich, dark brown when cooked and give French Onion Soup its tangy sweet flavor. It is essential in soups, stocks, marinades, all types of meat and chicken dishes; in salads, pickles, and chutneys. It is an important ingredient in all cuisines worldwide. In India and China, onion is a major ingredient in lots of dishes. Dehydrated onions are used in a variety of dishes like baked goods, pickles,

relishes, condiments, meat seasonings, Dutch loaf, German bologna, salad dressing mixes. Yellow onions are good for soups, sauces or stews for long cooking. Sweet is good for baked, battered, and fried food. The red onions are used raw in sandwiches and salads.

Medicinal Uses and Functional Properties

Onion is used in the treatment of appetite loss and prevention of age-related changes in blood vessels (arteriosclerosis). Onions and juice may be used to treat minor digestive disturbances and is used to overcome the immediate effects of insect stings. Juice mixed with sugar or honey is a traditional treatment for colds and cough. The treatment of dysentery, wounds, scars, keloids, asthma, and diabetes are among the many traditional uses.

Onion is known to have anticancer, antimicrobial, hypoglycemic, anti-platelet aggregation, anti-asthmatic, antiallergic, lipid- and blood pressure-lowering effects (Williamson and Manach 2005; Sengupta et al. 2004; Colli and Amling 2009; Yu et al. 2010; Taj Eldin et al. 2010; Gorinstein et al. 2011; Jung et al. 2011; Kim et al. 2011; Mantawy et al. 2011; Viry et al. 2011; Zhou et al. 2011). Onion bulbs have been found to be a rich source of dietary flavonoids. Different flavonoids have been characterized and quercetin and its glycosides are the most important ones (Boyer et al. 2005; Wong and Rabie 2008; Slimestad et al. 2007). Higher concentrations of quercetin occur in the outer dry layers of onion bulb (Smith et al. 2003). There are a few studies on the antidiabetic effects of onion skin extract in vivo (Nemeth and Piskula 2007; Kanter et al. 2007). Clinical trials hitherto focused mainly on garlic (*A. sativum*) but there is good clinical evidence of efficacy of onions in treating appetite loss and preventing arteriosclerosis. Onion acts as stimulant, diuretic, expectorant, lowers blood sugar, cholesterol (Augusti 1990). Onion oil contains heart stimulant, and increases coronary flow (Augusti 1990). Onion is useful in preventing oral infections and toothache (Chevallier 1996). Essential oil of onion was shown to be potent inhibitor of yeast growth (Kim et al. 2004). They were also found to be antibacterial. Oral administration of onion extract was shown to prevent cadmium-induced renal dysfunction (Ige et al. 2009). Quercetin an active constituent of onion, also possesses antimicrobial property (Geoghegan et al. 2010). Onion extract and quercetin play a role in the anti-scar effect in skin through up-regulation of MMP-1 expression, implying this agent is a promising material for reducing scar formation (Cho et al. 2010). Crude *Allium cepa* was shown to produce hypoglycemic effects, and thus could be used as a dietary supplement in management of type 1 and/or type 2 diabetes mellitus (Taj Eldin et al. 2010). Treatment with onion and garlic methanol extracts was found to prevent loss in body weight, decrease plasma glucose level, and significantly ameliorate the hyperalgesia, TBARS, serum nitrite, and GSH levels in diabetic mice. The onion extract had higher total phenolic content (Bhanot and Shri 2010). Quercetin and ethyl alcohol extract of onion skin were found to have blood glucose lowering potential via the α-glucosidase inhibition

(Kim et al. 2011). Zhou et al. (2011) reported that in a meta-analysis, consumption of high levels of Allium vegetables (onions, garlic, shallots, leeks, chives, and so forth) reduced the risk for gastric cancer.

Antioxidant Properties

The antioxidant activity of onion and onion scales has been studied in several models and assays (Pratt 1965; Gazzani et al. 1998; Cao et al. 1996; Vinson et al. 1998; Yang et al. 2004; Shon et al. 2004; Eguchi et al. 2005; Ly et al. 2005; Yamamoto et al. 2005; Blomhoff 2005; Ramos et al. 2006; Stratil et al. 2006; Slimestad et al. 2007; Huang et al. 2009; Murota et al. 2007; Meyers et al. 2008; Zielinska et al. 2008; Dini et al. 2008; Takahashi and Shibamoto 2008; Gorinstein et al. 2008; Javadzadeh et al. 2009; Khaki et al. 2009; Pellegrini et al. 2009; Veda et al. 2008; Singh et al. 2009; Roldán-Marín et al. 2009; Azuma et al. 2010; Chang et al. 2010; Benitez et al. 2011; Cazzola et al. 2011; Lynett et al. 2011; Shim et al. 2011; Stankevicius et al. 2011). Onion bulbs are a rich source of flavonoids and contribute to the overall intake of flavonoids (Lee et al. 2008). Quercetin, a bioflavonoid found in several fruits and vegetables, including onions, has antioxidant and anti-inflammatory activity and prevents cancer (Shaik et al. 2006; Hung 2007), reduces the risk of coronary heart disease and stroke (Edwards et al. 2007; Terao et al. 2008; Mennen et al. 2004). Quercetin was shown to reduce blood pressure in hypertensive subjects (Edwards et al. 2007). Hubbard et al. (2004) studied the relationship between the ingestion of dietary quercetin and platelet function. Ingestion of quercetin was found to inhibit platelet aggregation and the collagen-stimulated tyrosine phosphorylation of total platelet proteins. Their study implicates quercetin as a dietary inhibitor of platelet cell signaling and thrombus formation. Meyers et al. (2008) reported that onion-fed mice demonstrated the greatest increases in GSH:GSSG ratios and the greatest decreases in protein-mixed disulfide levels of all diets compared. Rutin, a flavonoid in onions, was found to reduce the level of nitrite in LPS-stimulated BALD/c mice, while the elevated levels of TNF-alpha in LPS-stimulated animals was lowered (Guruvayoorappan and Kuttan 2007). Galluzzo et al. (2009) reported quercetin to kill HeLa cells through an ERalpha-dependent mechanism involving caspase- and p38 kinase activation and hence has great potential as chemopreventive actions on cancer growth. Rassi et al. (2005) reported both quercetin and rutin to increase nuclear ERbeta protein and decrease ERalpha protein of osteoclast progenitors. In addition rutin was shown to reduce RANK protein, while quercetin promoted apoptosis by cleavage of caspase-8 and caspase-3. Their results suggest the anti-resorbing properties of flavonols to be mediated by ER proteins through inhibition of RANK protein or the activation of caspases. Both red and white varieties of onion were found to preserve the bioactive compounds and antioxidant potentials, and hinder the rise in plasma lipid levels and decrease in plasma antioxidant activity of rats fed cholesterol (Gorinstein et al. 2010). Polyphenols present in a large variety of dietary products including onion, was shown, under gastric

conditions to reduce nitrite to *NO that in turn exerts a biological impact as a local relaxant (Rocha et al. 2009). Yamamoto et al. (2005) found the Welsh green onions to reduce superoxide generation by suppressing the angiotensine II production and the NADH/NADPH oxidase activity, increase the NO availability in the aorta, and thus lower blood pressure in rats fed with HFS diet.

Methanolic extracts of outer scales and edible portions of onion were shown to reduce cerebral infarct size and attenuate impairment in short memory and motor coordination, and this was accompanied by a decrease in mitochondrial TBARS (Shri and Singh 2008). Onion flesh or onion peel was shown to enhance the antioxidant status in aged Sprague Dawley rats and could be beneficial for the elderly in lowering lipid peroxide levels (Park et al. 2007). Quercetin-supplemented diets were shown to lower blood pressure and attenuate cardiac hypertrophy in rats with aortic constriction (Jalili et al. 2006). Nishimura et al. (2006) in their experiment found onion extracts and di-*n*-propyl trisulfide to have high ameliorative effect of memory impairment. They further found that the hippocampus lipid hydroperoxide in senescence-accelerated mouse P8 was decreased by the administration of di-*n*-propyl trisulfide. These results they report suggest that di-*n*-propyl trisulfide present in onions ameliorates memory impairment in SAMP8 mouse through its antioxidant effect. Onion peel hydroalcoholic extract was shown to reduce aortic contractions in rats possibly through inhibition of calcium influx but not involving NO, cGMP, endothelium, and prostaglandins (Naseri et al. 2008). This hypotensive effect could be due to quercetin in the extract and possibly the antioxidant activity, and inhibition of vascular smooth muscle cells Ca^{2+} influx.

The effect of methanolic extract of onion on ischemic injury in heart-derived H9c2 cells in vitro and in rat hearts in vivo was studied by Park et al. (2009). They found the extract to attenuate ischemia/hypoxia-induced apoptosis in heart-derived H9c2 cells, through an antioxidant effect. Onion extract and quercetin has been shown to protect against neuronal damage from transient cerebral ischemia (Hwang et al. 2009). They reported quercetin and onion extract to decrease protein levels of 4-hydroxy-2-nonenal (a marker for LPO) in the ischemic CA1. Vijayababu et al. (2006) found quercetin to be a p53-independent effector of apoptosis in prostate cancer cells via its modulation of the Bax/Bcl-2 protein ratio because there was an increased level of IGFBP-3 associated with increased proapoptotic proteins and apoptosis in response to quercetin. Kumari and Augusti (2007) found that both gugulipid and SMCS cause reduction of endogenous lipogenesis, increase catabolism of lipids and subsequent excretion of metabolic by-products through the intestinal tract.

Onion, a rich source of flavonoids, has been shown to favorably modulate the process of carcinogenesis (Krishnaswamy (2008). Onion has been found to reduce the incidence of cancers in several tissues in epidemiological studies (Gao et al. 1999; Dorant et al. 1996). The chemopreventive effects of onion (Wu et al. 2006) are mediated by the enhancement of the activity of specific mixed-function oxidases that depress the activation of carcinogens (Chun et al. 2001), increased synthesis of GSH that directly protects cells from damage by free radicals (Banerjee et al. 2002; Bose et al. 2002; Scharf et al. 2003), induction of cell cycle arrest and apoptosis in cancer cells (Sun et al. 2004), and induction of phase II enzymes which enhance

detoxification and excretion of potential carcinogens and reduction of the formation of DNA adducts (Munday et al. 2003). In their study on quercetin, Hung (2007) found it to inhibit A549 lung carcinoma cell proliferation and this was associated with the activation of extracellular-regulated kinase (ERK). Wenzel et al. (2004) found quercetin from onions to alter the levels of a variety of proteins involved in growth, differentiation, and apoptosis of colon cancer cells. This explains the anti-cancer activities of quercetin. Apigenin, a flavone, abundantly present in onions has been shown to have cancer chemopreventive effects in an organ-specific format and could be used for the development of cancer chemopreventive agent (Patel et al. 2007). Onion extracts have also been used in the prevention and treatment of hypertrophic scars (Zurada et al. 2006). Hubbard et al. (2006) reported that those who preferentially consume high amounts of quercetin-containing foods like onion have a reduced risk of thrombosis and potential CVD risk. They found collagen-stimulated platelet aggregation to be greatly inhibited after ingestion of high-quercetin soup in a time-dependent manner. Al-Fayez et al. (2006) demonstrated that quercetin from onion and apples regulates COX-mediated and PGE-2 production and their ability to attenuate prostanoid levels could be contributing to their chemopreventive efficacy. Wu et al. (2006) in their research on onion oil found it to have chemopreventive action by inducing cell cycle arrest and apoptosis in tumor cells.

Onion extract was found to be significant for glucose concentration and body weight for its antidiabetic effects. Thus onion intake is effective for lowering plasma glucose concentrations and body weight (Kook et al. 2009). Oral administration of onion was found to reduce the serum uric acid levels in hyperuricemic rats and inhibited xanthine dehydrogenase (XDH) and xanthine oxidase (XO) activities (Haidari et al. 2008).

El-Demerdash et al. (2005) investigated the effects of onion on the biochemical parameters, enzyme activities, and lipid peroxidation in alloxan-induced diabetic rats. They found the levels of glucose, urea, creatinine, and bilirubin to be significantly increased in the plasma of alloxan-diabetic rats compared to the control group. The activities of AST, ALT, LDH and AlP, AcP were significantly increased in plasma and testes of alloxan-diabetic rats, while these activities decreased in the liver compared to the control group, the brain LDH was increased. The concentration of TBARs and the activity of glutathione S-transferase in plasma, liver, testes, brain, and kidney were increased in alloxan-diabetic rats. The altered parameters were restored to normal levels with repeated doses of onion juice. These results clearly show the antioxidant and antihyperglycemic effects of onion juice (El-Demerdash et al. 2005).

Onion was shown to attenuate the Cd-induced oxidative damage in rat liver possibly via lipid peroxidation and enhanced antioxidant defense system (Obioha et al. 2009). Ola-Mudathir et al. (2008) studied protective role of onion on Cd-induced testicular damage and spermiotoxicity. They found the aqueous extracts of onion to offer protection against Cd-induced testicular oxidative damage and spermiotoxicity by reducing lipid peroxidation and increasing antioxidant defense in rats. Suru (2008) studied the protective effects of onion on Cd-induced kidney damage in male Wistar rats. The levels of renal LPO and GST were reduced while the levels of renal

GSH, SOD, CAT, and Na^+/K^+-ATPase were decreased in rats that received Cd alone. Treatment with onion extract resulted in a significant dose-dependent restoration of these parameters. Izawa et al. (2008) reported the protective effects of onion and quercetin against the male reproductive toxicity induced by diesel exhaust particles (DEP). Haleagrahara et al. (2009) studied the effect of quercetin on stress-induced changes in oxidative biomarkers in the hypothalamus of rats and found the antioxidant action of quercetin to be beneficial in the prevention and treatment of stress-induced oxidative damage in the brain. They found forced swimming stress to produce a severe oxidative damage in hypothalamus of rats but treatment with quercetin significantly attenuated these stress-induced changes. Mastrangelo et al. (2006) studied whether quercetin can afford protection from chromosome breaks induced by atrazine. They found quercetin to significantly reduce the frequency of total aberrations induced by atrazine. Their results suggest that quercetin may protect against the genotoxic effects of atrazine. Lines and Ono (2006) showed that FRS 1000, a beverage containing flavonoids from onion peels improved male sexual function. This was because FRS 1000 strongly inhibited phosphodiesterase 5A (PDE 5A) which is important for treatment of erectile dysfunction. They also found that quercetin was the flavonoid responsible for this activity. Murota et al. (2004) showed that quercetin-4′-glucoside, present in onion serves as a favorable antioxidant source for suppressing iron-induced oxidative stress in the intestinal tract. The dried skin of red onion possesses ingredients with potential for skin-whitening cosmetics with anti-tyrosinase activity (Arung et al. 2011a). Of the three phenolic compounds, quercetin was found to have the highest antioxidative activity (Xue et al. 2011). In enhanced meats (pork loin, belly cuts), onion showed strong antioxidant effect equal to sodium ascorbate and also showed strong antimicrobial effect by inhibiting the growth of total bacteria (Park et al. 2008). Irradiation increased the TBARS values of control ground beef, but addition of 0.5 % onion reduced oxidative changes during storage (Yang et al. 2011). Quercetin-3′-*O*-beta-D-glucoside from the methanol extract of dried skin of *A. cepa*, inhibited melanin formation in B16 melanoma cells and mushroom tyrosinase. In addition, it exhibited strong antioxidant activity of 3.04 μmol TE/mmol. Thus quercetin-3′-*O*-beta-D-glucoside could be useful for treating hyperpigmentation and for protecting against oxidative stress (Arung et al. 2011b).

Regulatory Status

GRAS 182.20.

Standard

ISO 5559 (Dehydrated onion).

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Chapter 43
Oregano

Botanical Name:	*Origanum vulgare* L ssp. *hirtum* (Link) Ietswaart.
Synonyms:	*Origanum heracleoticum* auct. Non L.; European oregano; joy of the mountain; common marjoram; origanum.
Family:	Lamiaceae (Labiatae).
Common Names:	**French**: Origan; **German**: Echter Dost; **Italian**: Origano; **Spanish**: Oregano.

Introduction

History

The genus *Origanum* provides the source of well-known oregano spices—Greek and Turkish types. The name Oregano is derived from the Greek words *oros*, a mountain and *ganos*, joy. Thus it is often called locally "Joy of the mountains". The Greeks and Romans used oregano but actually which species was never clear to them and this confusion began early in its history. During the Middle Ages in Poland, oregano was used against a number of diseases. The eighteenth-century herbalist K'Eogh described oregano as having "a hot dry nature". It is good against pains of the stomach and heart and also useful for coughs, pleurisy, and obstructions of the lungs and womb, and it also comforts the head and nerves. The herbalist John Gerard in the sixteenth century recommended a decoction of the leaves to "easeth such as are given to overmuch sighing". The Greeks and Romans used oregano more for medicinal purposes than culinary uses. In the first century, Greek physician Dioscorides described more than one oregano as medicine. Oregano came to North America with various colonists and escaped from gardens to grow wild. The oreganos quickly became part of standard medicine in the United States. It was not until WW II that oregano gained importance as a flavoring. The serviceman returning

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from the Mediterranean brought the taste of oregano, and once pizza became embedded in American consciousness, oregano became all-American.

Producing Regions

Oregano is native to Europe and central Asia. Now cultivated all over the world, including the USA, Asia, South America, Europe to central Asia (*O. vulgare*), Mediterranean region (*O. majorana*), Middle East (*O. syriacum*), and Crete (*O. dictamnus*). Oregano, and to a lesser extent marjoram, are commercially grown as spices (oregano gives the characteristic flavor to pizza). Dittany and related species have been developed as ornamental garden plants. The herb is still a popular medicine in Greece and especially in Crete, where it is said to be endemic. The oil is produced mainly in Russia, Bulgaria, Hungary, and Italy.

Botanical Description

A hardy, bushy, herbaceous perennial plant up to 90-cm (35 in.) high, with creeping roots, branched woody stems, and opposite leaves. It has erect flower-bearing stalks, dark green, hairy ovate leaves, and purple or white flowers that form terminal spikes. Each flower produces four small seed-like structures. It is very similar to marjoram or sweet marjoram (*O. majorana*) and the two species (both popular culinary herbs) are often confused. Several species have been used in folk medicine, including *O. compactum*, *O. dictamnus*, *O. heracleoticum*, *O. onites*, and *O. syriacum*. *O. syriacum* is the hyssop of the Bible (mentioned at the Crucifixion). *O. dictamnus*, the dittany of Crete (or *dictamon* in Greek), has wooly leaves and large floral bracts. In Greek mythology, it is the herb that was used by Aphrodite to heal the wounds of the Trojan hero Aeneas.

Parts Used

Dried leaves (whole or ground) (light to dark green), essential oil. The dark green leaves are available whole, chopped, or minced. The dried light green leaves are available whole, flaked, or ground. Essential oil is obtained by steam distillation of the dried flowering herb. The oil is a yellow to dark-brown mobile liquid. Yield 1–2%.

Flavor and Aroma

Strongly aromatic, camphoraceous aroma. Aromatic, slightly bitter and pungent flavor. The pungent flavor has some green, musty, hay, and minty notes. It imparts a slightly astringent mouth feel.

Table 43.1 Nutrient composition and ORAC values of oregano dried

Nutrient	Units	Value per 100 g
Water	g	9.93
Energy	kcal	265
Protein	g	9.00
Total lipid (fat)	g	4.28
Carbohydrate, by difference	g	68.92
Fiber, total dietary	g	42.5
Sugars, total	g	4.09
Calcium, Ca	mg	1,597
Vitamin C, total ascorbic acid	mg	2.3
Vitamin B-6	mg	1.044
Vitamin B-12	mcg	0.00
Vitamin A, RAE	mcg_RAE	85
Vitamin A, IU	IU	1,701
Vitamin D	IU	0
Vitamin E (alpha-tocopherol)	mg	18.26
Fatty acids, total saturated	g	1.551
Fatty acids, total monounsaturated	g	0.716
Fatty acids, total polyunsaturated	g	1.369
H-ORAC	μmol TE/100 g	165,712
L-ORAC	μmol TE/100 g	22,582
Total-ORAC	μmol TE/100 g	175,295
TP	mg GAE/100 g	3,789

Source: USDA National Nutrient Database for Standard Reference, Release 24 (2011)

Active Constituents

Carvacrol, thymol, *p*-cymene, γ-terpinene, sabinene, linalool, borneol, β-bisabolene, and β-caryophyllene are the major constituents found in the essential oil. Oregano contains proteins, vitamins, acids, tannins, resin, sterols, flavonoids, and bitter principle. Five antioxidant phenolic compounds, rosmarinic acid derivative, caffeic acid, protocatechuic acid, phenyl glucoside, and 2-caffeyloxy-3-[2-(4-hydroxybenzyl)-4, 5-dihydroxy]-phenyl propionic acid were reported (Kikuzaki and Nakatani 1989). The polar constituents are apigenin, luteolin, chrysoeriol, diosmetin, quercetin, eriodictyol, cosmocide, vicenin-2, caffeic acid, rosmarinic acid, *p*-menth-3-ene-1,2-diol 1-*O*-β-glucopyranoside, thymoquinol 2-*O*-β-glucopyranoside, thymoquinol 5-*O*-β-glucopyranoside, thymoquinol 2,5-*O*-β-diglucopyranoside, 12-hydroxyjasmonic acid and its β-glucopyranoside, lithospermic acid B, epi-lithospermic acid B, and 10-epi-lithospermic acid (Koukoulitsa et al. 2006b). The nutritional constituents and ORAC values of dried oregano are given in Table 43.1.

Preparation and Consumption

It is best known in tomato sauce having a hot peppery aroma. Oregano leaves are used in Italian, Greek, Brazilian, Mexican, Spanish, and Colombian cuisines. It is used in meat, sausages, salads, stewings, dressings, and soup. Great in cheese and egg combinations, including omelets, frittatas, quiches, and savory flans. Must in pizzas and spaghetti sauces. It adds depth and enhances flavor to yeast breads, marinated vegetables, roasted bell peppers, mushrooms, roasted and stewed beef, pork, poultry, game, onions, black beans, zucchini, potatoes, eggplant, and shellfish. Its flavor combines well with those of garlic, thyme, parsley, and olive oil. The ancient Egyptians and Greeks used it to flavor fish, meats, vegetables, and wine.

Medicinal Uses and Functional Properties

Oregano, sweet marjoram, and dittany are mainly used to treat bronchitis, catarrh, cold, flu, colic, and dyspepsia. These herbs or their dilute oils are sometimes used topically for mouth hygiene, to treat nasal congestion, wounds, and itching skin. The essential oils of oregano and marjoram are used in aromatherapy. The essential oils are known to be antibacterial, antifungal, antiviral, spasmolytic, and anti-inflammatory. Modern herbalists recommend leaf infusions for indigestion, coughs, headaches, and to promote menstruation. It has been described as a tonic and stimulant. An infusion helps to prevent seasickness. *Origanum vulgare* has been used as a stimulant, diaphoretic, carminative, and nerve tonic and as a cure for asthma, coughs, indigestion, rheumatism, toothaches, headaches, spider bites, and coronary conditions. In China it is also used to treat fevers, vomiting, diarrhea, jaundice, and itchy skin.

Oregano extracts possess strong antifungal potential and strong inhibitory effects against both Gram-positive and Gram-negative bacteria (Biondi et al. 1993; Schmitz et al. 1993; Izzo et al. 1995). The carvacrol/thymol chemotypes of oregano have been shown to have high inhibitory activity against fungal growth, conidial germination, and production of *Penicillium* species (Daferera et al. 2000). The phenolic compounds in essential oils are also involved in the inhibition of yeast sporulation (Baricevic and Bartol 2002). Oregano extract was found to be effective in enhancing mental well-being in humans ((Mechan et al. 2011). Oregano extract ointment was shown to decrease the bacterial contamination and subsequent infection on post-surgical wounds and had equivalent overall scar appearance compared to petrolatum (Ragi et al. 2011). Oregano essential oil showed the strongest antibacterial activity among the oils tested, and carvacrol was the most potent among the tested components (Sokovic et al. 2010). The phenolic glucoside, origanoside isolated from oregano, was demonstrated to cause depigmentation and thus could be useful for novel food additives and skin-whitening cosmetics (Liang et al. 2010). The use of oregano essential oil to inhibit surface fungi did not affect the sausage drying process, pH, water activity, or color changes during ripening (Chaves-Lopez et al. 2012). Yin et al. (2012) suggest that carvacrol may induce apoptosis by direct activation of the

mitochondrial pathway, and the mitogen-activated protein kinase pathway may play an important role in the antitumor effect of carvacrol. Their results have identified, for the first time, the biological activity of carvacrol in HepG2 cells and this should lead to further development of carvacrol for liver disease therapy.

Antioxidant Properties

Oregano extracts and compounds isolated from oregano have been found to have antioxidant, antifungal, antibacterial, and antimicrobial properties (Deighton et al. 1993; Martinez-Tome et al. 2001; Zheng and Wang. 2001; Exarchou et al. 2002; Botsoglou et al. 2003, 2010; Dragland et al. 2003; Matsuura et al. 2003; Oussalah et al. 2004; Blomhoff 2004; Ivanova et al. 2005; Faleiro et al. 2005; Shan et al. 2005, 2011; Bozin et al. 2006; Hazzit et al. 2006; Rodríguez-Meizoso et al. 2006; Bhale et al. 2007; Lopez et al. 2007; Seidel et al. 2007; Jimenez-Alvarez et al. 2008; Lin et al. 2008a, b; Pezo et al. 2008; Lopez-Lazaro 2009; Raudonis et al. 2009; Ryan et al. 2009; Chou et al. 2010a, b; Dambolena et al. 2010; Kintzios et al. 2010; Lahucky et al. 2010; Li et al. 2010; Mechergui et al. 2010; Ozkan et al. 2010; Pennisi et al. 2010; Rababah et al. 2010; Scramlin et al. 2010; Camo et al. 2011; Conforti et al. 2011; Colindres and Brewer 2011; Duan et al. 2011; El Babili et al. 2011; Huang et al. 2011; Karakaya et al. 2011; Kaurinovic et al. 2011; Kim et al. 2011; Miron et al. 2011; Park 2011; Park et al. 2011; Spiridon et al. 2011; Terenina et al. 2011). Oregano has been used as stabilizers of edible oils or of finished meat products (Baricevic and Bartol 2002). Oregano supplements protected chickens against stress-induced increases in TBA-reactive substances (TBARS), in different muscles (Young et al. 2003). Treatment with oregano oil significantly retarded lipid oxidation in both breast and thigh meat patties of turkey at all storage times compared with controls (Govaris et al. 2004). Botsoglou et al. (2004) indirectly provided evidence that antioxidant compounds present in oregano essential oils were absorbed by the rabbit and increased the antioxidant capacity of tissues. Oregano extracts containing rosmarinic acid (RA) yielded higher than expected amylase inhibition than purified RA, suggesting the involvement of other phenolic compounds or phenolic synergies (McCue and Shetty). Dry leaves of oregano showed high antioxidant activity in olive oil and improved the organoleptic quality of olive oil, as assessed by Mediterranean consumer acceptability studies (Antoun and Tsimidou 1997; Charai et al. 1999). A significant increase in the oxidative stability of fried chips, measured as the rate of peroxide formation during storage at 63°C, was achieved by addition of ground oregano or its petroleum ether extracts (Lolos et al. 1999). Five polar constituents from oregano were found to inhibit aldose reductase, the first enzyme of the polyol pathway implicated in the secondary complications of diabetes (Koukoulitsa et al. 2006a). Oregano showed nitric oxide (NO)-suppressing activity, and this is because of the inhibition of inducible nitric oxide synthase (iNOS) expression (Tsai et al. 2007). Oregano had a strong dose-dependent protective effect on the copper-induced low-density lipoproteins (LDL) oxidation (Kulisić

et al. 2007). Carvacrol from oregano essential oil protected the liver against defects caused by ischemia and reperfusion, and carvacrol was not hepatotoxic (Canbek et al. 2008). Srihari et al. (2008) found oregano supplementation to have a modulatory role on tissue lipid peroxidation and antioxidant profile in colon cancer-bearing rats, and this suggests a possible anti-cancer property of oregano. The protective effect of dietary oregano on the alleviation of carbon tetrachloride-induced (CCl_4) oxidative stress in rats was studied by Botsoglou et al. (2008), and they found that dietary oregano effectively improved the impaired antioxidant status in CCl_4-induced toxicity in rats. Aristatile et al. (2009a) found carvacrol to afford a significant hepatoprotective and hypolipidemic effect against D-galactosamine-induced hepatotoxicity in rats. The anticataract effect of oregano extract was based on direct or indirect antioxidant mechanisms (Dailami et al. 2010). Oregano was shown to act as an effective quencher of oxidative attackers with antimelanogenesis properties (Chou et al. 2010a). Cooking hamburgers with spice mixture containing oregano significantly decreases the malondialdehyde suggesting potential health benefits for atherogenesis and carcinogenesis (Li et al. 2010). Carvacrol was shown to afford a significant hepatoprotective and antioxidant effect against D-GalN-induced rats (Aristatile et al. 2009b). Carvacrol and thymol were shown to be the main antioxidant components of the oregano essential oil (Terenina et al. 2011). The aqueous-methanolic extract of oregano showed antiurolithic activity, and this was possibly mediated through inhibition of CaOx crystallization, antioxidant, renal epithelial cell protective and antispasmodic activities (Khan et al. 2011).

Regulatory Status

GRAS 182.20.

Standard

ISO 7925.

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Chapter 44
Black Pepper

Botanical Name: *Piper nigrum* L.
Synonyms: Piper; pepper, kalimirch; peper; pimento, maricha.
Family: Piperaceae.
Common Names: **French**: Poivre; **German**: Pfeffer; **Italian**: Pepe; **Spanish**: Pimienta negra; **Hindi**: kali mirch.

Introduction

History

Black pepper is one of the oldest and best-known spices in the world, and is rightly called "King of Spices." The history of pepper is really the history of spice trade. The word "pepper" comes from the Sanskrit "*pippali*," name of the Indian long pepper. Pepper accounts for almost 35% of all the spices traded annually on the international market. Throughout recorded history, pepper has been called the most prestigious spice. The pepper vine is native to the hills of western India, from where it went all over the world. Two peppers, the black pepper and long pepper were recognized by Theophrastus (372–287 BC). The Greek physician Dioscorides, in the first century AD mentions black and white pepper. Hippocrates, around 400 BC, mentioned about the use of pepper in assisting the gastric juices to function. In the Roman Empire, pepper was a very important article of commerce. During Biblical times, pepper was worth 4 denarii per pound. Plato declared, "while pepper was small in quantity it was great in virtue." The Emperor Marcus Aurelius imposed a customs tax on long pepper and white pepper, but exempted black pepper. In the spice trading, it has been used as an exchange medium like money, and, at times, has been valued so highly that a single peppercorn dropped on the floor would be hunted like a lost pearl. In classical times, "tributes" were paid in pepper, and both Attila the Hun and Alaric I the Visigoth demanded pepper as a substantial part of

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Rome's ransom. Horace, the Roman poet told his gardener that he would "rather see pepper grown in my garden than wine grapes." The harvesting and processing of pepper on the Malabar Coast is accurately described in *Topographia Christiana* (c. 545 AD) by Cosmos Indicopleustes after his visit to India and Sri Lanka. Peppercorns were very expensive and accepted in lieu of money in dowries, taxes, and rents, in the Middle Ages. The statutes of King Ethelred in tenth-century England required German spice traders to pay tribute, including 10 lb pepper, to trade with London merchants. Pepper was included in most early European herbals and medical treatises. Pepper was taken to Java by the Hindu traders around 500 AD. Marco Polo visited Java in 1280 and describes pepper cultivation in his *Description of the World*, 1298. Since the Middle Ages, pepper was the core of the European spice trade, with Genoa and Venice dominating the market. Vasco da Gama arrived at Calicut on the Malabar Coast of India on May 20, 1498, and subsequently established in 1503, an export price for pepper at Cochin, a price the Portuguese maintained for decades. In the century 1500–1600, Portugal imported from Malabar the equivalent of 2 million kg annually. Garcia da Orta describes pepper in his Colloquies on the Simples and Drugs of India, in 1563. The Italian traveler, Varthema (1465–1519), in his *Itinerario de Ludovico de Varthema Bolognese* of 1510, gives a detailed picture of Calicut plantations in the sixteenth century. Barbosa gives a vivid account of the plant and Calicut pepper trade in his *Coasts of East Africa and Malabar*. The Dutch controlled much of the pepper trade in the seventeenth century, but could never monopolize as they did with clove and nutmeg. Their end coincided with the American entry in 1797 by Captain J. Carnes of Salem, Massachusetts. Early in the nineteenth century the British organized pepper plantations in Malaysia and later Sarawak.

Producing Regions

Native to the hills of western India. Now cultivated extensively in tropical countries. The major pepper producing countries are India, Indonesia, Malaysia, Vietnam, China, Sri Lanka, Brazil, Mexico, Madagascar, and Singapore.

Botanical Description

A perennial, glabrous woody climber up to 10-m (30 ft) high. It has ovate, alternate leaves that are dark shiny green above and pale and glandular below. The pepper plants have dimorphic branching, having two different types of branches. From the axils of leaves, lateral shoots grow, and they have sympodial habit of growth, having short internodes and no adventitious roots. The inflorescence is a pendant spike on lateral branches, bearing small yellowish-green to whitish-yellow flowers. The

fruit is the spice called peppercorns. Black pepper is the dried, unripe berry. The corns are wrinkled and spherical, about 5 mm (1/8 in.) in diameter. Malabar and Tellicherry pepper are considered superior quality because of the size and maturity, with only 10% of the largest corns being graded as Tellicherry. White pepper is the same as the black, but is allowed to ripen more fully on the vine. The outer shell is then removed by soaking the berries in water until the shells fall off or are held under flowing spring water, yielding a whiter, clean pepper. White pepper is less pungent, has a mellow flavor, and is low in fiber but high in starch. Green pepper is from the same fruit from mature but green peppers.

Parts Used

Peppercorns dried (whole or ground), essential oil, oleoresin. It is available as whole, decorticated, cracked, coarse, medium, regular, or fine grind. The essential oil is obtained by steam distillation of the crushed, dried nearly ripe berries. The oil is water-white to pale greenish-gray mobile liquid. Yield 1–4%.

Flavor and Aroma

Black pepper has a penetrating, aromatic, woody, pungent aroma. It has lemony and clove tones. Very pungent and fiery, with woody-piney flavor.

Active Constituents

The berry contains moisture 9–12%, protein 11–13%, starch 25–45%, fiber 9–17%, and ash 3–6%. Another analysis gave moisture 8.7–14.1%, total N 1.55–2.6%, N in nonvolatile ether extract 2.70–4.22%, volatile ether extract 0.3–4.2%, nonvolatile ether extract 3.9–11.5%, alcohol extract 4.4–12%, starch 28–49%, crude fiber 8.7–18%, crude piperine 2.8–9%, piperine 1.7–7.4%, total ash 3.6–5.7%, and acid insoluble ash 0.03–0.55%. The essential oil contains α-pinene, β-pinene, β-caryophyllene, limonene, sabinene, and δ-3-carene as the major constituents. The major alkaloids are piperine, brachymide B, guineesine, retrofractamide A, sarmentine, sarmentosine, and tricholein (Parmar et al. 1997). Piperinic acid exists in four isomeric forms: piperine, isopiperine, isochavicine, and chavicine. Quercetin, isoquercetin, isorhamnetin 3-β-D-rutinoside, kaempferol 3-arabinoside, kaempferol-3-*o*-β-galactoside, and quercetin-3-*o*-β-D-rutinoside are the major flavonols (Parmar et al. 1997). There are also several lignans-cubebin. The nutritional constituents and ORAC values of black pepper are given in Table 44.1.

Table 44.1 Nutrient composition and ORAC values of black pepper

Nutrient	Units	Value per 100 g
Water	g	12.46
Energy	kcal	251
Protein	g	10.39
Total lipid (fat)	g	3.26
Carbohydrate, by difference	g	63.95
Fiber, total dietary	g	25.3
Sugars, total	g	0.64
Calcium, Ca	mg	443
Vitamin C, total ascorbic acid	mg	0.0
Vitamin B-6	mg	0.291
Vitamin B-12	mcg	0.00
Vitamin A, RAE	mcg_RAE	27
Vitamin A, IU	IU	547
Vitamin D	IU	0
Vitamin E (alpha-tocopherol)	mg	1.04
Fatty acids, total saturated	g	1.392
Fatty acids, total monounsaturated	g	0.739
Fatty acids, total polyunsaturated	g	0.998
H-ORAC	μmol TE/100 g	10,205
L-ORAC	μmol TE/100 g	23,323
Total-ORAC	μmol TE/100 g	34,053
TP	mg GAE/100 g	287

Source: USDA National Nutrient Database for Standard Reference, Release 24 (2011)

Preparation and Consumption

Black pepper is used all over the world. Pepper is used for flavoring, masking odor, pungency, and color. It is important in the cuisines of China, Southeast Asia, India, USA, UK, Greece, Italy, and France. It has been used for thousands of years on and for every food product. It is great in both vegetarian and nonvegetarian cooking. It is suitable for dishes of meat, poultry, seafood, milk, egg, grains, vegetables, fruit, beans and seeds, and beverages. It is also best ground directly on the food. It is used to flavor all kinds of savory dishes. It is an essential ingredient of most curry powders (masala powder) all over the world. In Europe, pepper is added during and after cooking to foods like soups, steaks, cheeses, vinegars, pickles, and salads. Whole peppercorns are used in stocks and pickling mixtures and in some salamis and sausages; essential spice in pastrami; in classic French *sauce au poivre* (grilled steaks). White pepper is used in white sauces. Green peppercorns can be mashed with garlic, onion, cinnamon, or to make spiced butter or with cream to make a fresh and attractive sauce for fish.

Medicinal Uses and Functional Properties

In Ayurveda, pepper is used in the treatment of epileptic fits and to bring about sleep. It stimulates the taste buds causing reflex stimulation of gastric secretions, thus improving digestion and treating gastrointestinal upsets and flatulence. It also calms nausea and raises body temperature, making it valuable for treating fevers and chills.

It has stomachic, carminative, antioxidant, antibacterial, antimicrobial, immunomodulatory, larvicidal, antibiotic, anti-inflammatory, antitumor, antipyretic, and diaphoretic properties (Nakatani et al. 1986; Reddy and Lokesh 1992; Krishnakantha and Lokesh 1993; Sharma et al. 2000; Ramasarma 2000; Dorman and Deans 2000; Calucci et al. 2003; Karthikeyan and Rani 2003; Pradeep and Kuttan 2003; D'Souza et al. 2004; Vijayakumar et al. 2004; Lambert et al. 2004; Gulcin 2005; Kaleem et al. 2005; Selvendiran et al. 2006; Vijayakumar and Nalini 2006; Natarajan et al. 2006; Agbor et al. 2007; Choi et al. 2007; Saxena et al. 2007; Srinivasan 2007; Waje et al. 2008; Dearlove et al. 2008; Duessel et al. 2008; Topal et al. 2008; Kapoor et al. 2009; Pathak and Khandelwal 2009; Vasudevan et al. 2009; Ee et al. 2010; Fu et al. 2010; Hlavackova et al. 2010; Liu et al. 2010; Majdalawieh and Carr 2010; Mehmood and Gilani 2010; Bae et al. 2011; Duangjai et al. 2011; Hwang et al. 2011; Jantan et al. 2011; Jin et al. 2011; Li et al. 2011; Kamaraj et al. 2011; Park et al. 2011; Keskin and Toroglu 2011; Krchnak et al. 2011; Mishra et al. 2011; Rahman et al. 2011).

The essential oil of black pepper showed inhibitory effects against 25 different genera of bacteria (Dorman and Deans 2000). Piperine from black pepper has been shown to stimulate the digestive enzymes of pancreas, thus enhancing the digestive capacity and significantly reducing gastrointestinal food transit time. Piperine, a component of black pepper has been shown to increase the bioavailability of epigallocatechin-3-gallate (EGCG) a component of tea, in mice (Lambert et al. 2004). Piperine was found to offer significant in vitro antiproliferative effects on cultured human colon cancer cells (Duessel et al. 2008). Piperine was found to inhibit LPS-induced endotoxin shock through inhibition of type 1 IFN production (Bae et al. 2010). It could also have a protective role against acute pancreatitis (Bae et al. 2011). Piperine has also been shown to have potential as a potent anticancer drug in therapeutic strategies for fibrosarcoma metastasis (Hwang et al. 2011).

Antioxidant Properties

Pepper has antioxidant activity and this is attributed to the tocopherols and polyphenol contents in pepper. Black pepper lowers lipid peroxidation in vivo and protects against oxidative damage by quenching free radicals and reactive oxygen species. In a number of situations of oxidative stress it has shown to beneficially influence cellular thiol status, antioxidant molecules, and antioxidant enzymes. Piperine was shown to protect the plasmid DNA from degradation by gamma-radiation (Sharma et al. 2000). Male Wistar rats fed with high fat diet were found to have significantly

higher levels of thiobarbituric acid reactive substances (TBARS), conjugated dienes (CD), and lowered activities of superoxide dismutase (SOD), catalase (CAT), glutathione peroxidase (GPx), glutathione-S-transferase (GST), and reduced glutathione (GSH) in liver, heart, kidney, intestine, and aorta as compared to the control rats. However, the supplementation of diets with black pepper or piperine, lowered CD and TBARS levels and maintained the levels of GSH, and the enzymes SOD, CAT, GPx, GST compared to those of control rats (Vijayakumar et al. 2004). Vijayakumar and Nalini (2006) found that supplementation with piperine markedly protected erythrocytes from oxidative stress by significantly improving the antioxidant status in high fat diet fed antithyroid drug-treated Male Wistar rats. Black pepper was found to have the highest antioxidant activity and phenolic content among the food groups such as cereals, legumes, oil seeds, oils, green leafy vegetables, spices, roots, and tubers commonly consumed in India (Saxena et al. 2007). Different fractions of the petroleum ether extract of pepper fruits were found to have strong antioxidant activity using different methods (Singh et al. 2008). The essential oil and oleoresins (ethanol and ethyl acetate) of pepper showed strong antioxidant capacity and antioxidant activity in comparison with BHA and BHT, but lower than PG (Kapoor et al. 2009). Pepper extracts were shown to have strong antioxidant and antiatherogenic effect against atherogenic diet intoxication (Agbor et al. 2012). The extracts of black pepper at 200 μg mL^{-1} and its compounds at 25 μg mL^{-1} inhibited LPO by 45–85%, COX enzymes by 31–80%, and cancer cells proliferation by 3.5–86.8% (Liu et al. 2010).

Regulatory Status

GRAS 182.10 and GRAS 182.20.

Standard

ISO 959-1 (Black pepper), ISO 959-2 (White pepper), ISO 10621 (Dehydrated green pepper), ISO 11162 (Peppercorns in brine), ISO 5564 (Piperine content).

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Chapter 45
Peppermint

Botanical Name: *Mentha*×*piperita* L.
Synonyms: brandy mint; balm mint.
Family: Lamiaceae (Labiatae).
Common Names: **French**: Menthe poivree; **German**: Pfefferminz; **Italian**: Menta piperita; **Spanish**: Mentha pimienta.

Introduction

History

English botanist John Ray (1628–1705) published his *Historia Plantarum* in 1704 and described *Mentha palustris*. The genus name *Mentha* is derived from the Greek word "*Mintha*," the name of a mythical nymph who metamorphosed into this plant; the species name *piperita* is from the Latin "*piper*," alluding to pepper and its aromatic and pungent taste (Tyler et al. 1988). By 1721 peppermint was listed in the London Pharmacoepia as a digestive aid and flavoring agent (Tyler et al. 1988; Briggs 1993). French and Latin apothecaries stated peppermint was wholesome for the stomach. Mint leaves have been used in medicine for thousands of years according to the Roman, Greek, and Egyptian era records (Evans 1991; Briggs 1993). Peppermint uses by the Greeks and Romans was written by Roman naturalist Pliny the Elder (ca. 23–79 CE). Pliny recommended its applications to the forehead to eliminate headaches. Dioscorides suggested its use as an effective contraceptive. In the Middle Ages, it was used in very different ways. It was grown in Roman monastery gardens and the Jews called it the sage of Bethlehem.

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Producing Regions

Peppermint is native to India. It is cultivated in central and southern Europe, North and South America, Asia, almost worldwide. It is found growing wild throughout Australia, North America, and Europe. Peppermint growing in northern regions, including Black Mitcham peppermint, are superior quality. The United States is the leading producer of peppermint essential oil, growing in Oregon, Idaho, Indiana, Washington, and Wisconsin.

Botanical Description

A perennial herbaceous plant that grows up to 1-m (3.3 ft) high with underground runners by which it is easily propagated. It has erect green stalk and leaves. The leaves are opposite, petiolate, ovate, pointed, and smoother on the upper surface. The lower surface contains more glandular trichomes. The inflorescence is verticillate and the flowers are small, purple, in terminal obtuse spikes. The plant is propagated by cuttings.

Parts Used

Leaves (dried or fresh), essential oil, peppermint extract. The fresh form is eaten raw, pureed or cooked. Dried form is sold whole, chopped, as flakes. The essential oil is obtained by steam distillation of the flowering plant. The oil is a pale yellow to pale olive-green mobile liquid. Redistilled oils are generally colorless. Yield 1–3%.

Flavor and Aroma

Minty, strongly mentholic, herbaceous, very aromatic, and cooling. The taste is spicy, minty cool, sweet, fragrant, and slightly pungent. The aftertaste is herbaceous, minty, and cooling. The presence of essential oils in the leaves and other parts of the plant gives it a very appealing aroma.

Active Constituents

Essential oil, flavonoids, phytols, tocopherols, azulenes, rosmarinic acid, carotenoids, and tannins (Bradley 1992; Bruneton 1995; Leung and Foster 1996; Wichtl and Bisset 1994). The major constituents are luteolin, hesperidin, rutin; caffeic, chlorogenic, and

Table 45.1 Nutrient composition and ORAC values of peppermint fresh leaf

Nutrient	Units	Value per 100 g
Water	g	78.65
Energy	kcal	70
Protein	g	3.75
Total lipid (fat)	g	0.94
Carbohydrate, by difference	g	14.89
Fiber, total dietary	g	8.0
Calcium, Ca	mg	243
Vitamin C, total ascorbic acid	mg	31.8
Vitamin B-6	mg	0.129
Vitamin B-12	mcg	0.00
Vitamin A, RAE	mcg_RAE	212
Vitamin A, IU	IU	4,248
Vitamin D	IU	0
Fatty acids, total saturated	g	0.246
Fatty acids, total monounsaturated	g	0.033
Fatty acids, total polyunsaturated	g	0.508
H-ORAC	μmol TE/100 g	13,978
Total-ORAC	μmol TE/100 g	13,978
TP	mg GAE/100 g	690

Source: USDA National Nutrient Database for Standard Reference, Release 24 (2011)

rosmarinic acids; α- and γ-tocopherols; and α- and β-carotenes. The major constituents of essential oil are menthol (29–50%), menthone (16–25%), menthyl acetate (5%), isomenthone, menthofuran, and piperitone. The nutritional constituents and ORAC values of fresh leaves of peppermint are given in Table 45.1.

Preparation and Consumption

It is the most widely used herb. It is a popular flavor found in desserts, beverages, ice cream, liquors, sauces, confectionary, candies, and after dinner mints. The crushed leaves can be used in jellies, beverages, sherbets, soups, sauces, stews, meat, fish, and vegetables. The oil is used to flavor chewing gum, candy, and mints.

Medicinal Uses and Functional Properties

The drug is used to treat digestive disorders and to mask the unpleasant taste of other herbs. It is specifically employed in case of spastic complaints (including irritable bowel syndrome), ailments of the gall bladder and bile duct, and catarrhs of the respiratory tract. Peppermint tea is considered a stimulant and has antiseptic properties.

It is effective in treating headaches, common colds, sore throats, insomnia, fever, and nervous tension. The oil is antimicrobial, antiviral, anti-inflammatory and mildly anesthetic, and can be used topically to relieve pain, including headache (but not migraine) and mucosal inflammations of the mouth. The British Herbal Compendium reported carminative, spasmolytic and choleretic activities and indicates peppermint leaf for dyspepsia, flatulence, intestinal colic and biliary disorders (Bradley 1992).

Peppermint is one of the most widely used single ingredient herbal teas. Peppermint is used in traditional and conventional medicine and this is because of the presence of monoterpenoids in essential oils from peppermint and different phenolic compounds. The peppermint essential oil is known to act as antimicrobial, antispasmodic, carminative, choleretic, antiviral agents, and as natural antioxidants (Iscan et al. 2002; Yadegarinia et al. 2006; Schmidt et al. 2009; Toroglu 2011; Zong et al. 2011). Phenolic compounds and essential oils of mint have a wide range of pharmacological activity: antioxidant, anthelmintic, antiulcer, cytoprotective, hepatoprotective, cholagogue, chemopreventive, antispasmodic, anti-inflammatory, and antidiabetogenic (Katikova et al. 2001; Dragland et al. 2003; Blomhoff 2004; Ka et al. 2005; Kaliora and Andrikopoulos 2005; Samarth et al. 2006a, b; Schempp et al. 2006; Germann et al. 2006; Mckay and Blumberg 2006; Sharma et al. 2007; Buyukbalci and El 2008; Mimica-Dukic and Bozin 2008; Dorman et al. 2009; López-Lázaro 2009; de Sousa et al. 2010; Lopez et al. 2010; Kratchanova et al. 2010; Neves et al. 2010; Yang et al. 2010; Yi and Wetzstein 2010; Keskin and Toroglu 2011; Ahmad et al. 2012; Gao et al. 2011; Carvalho et al. 2012).

Peppermint essential oil was tested for its antimicrobial properties against 21 human and plant pathogenic microorganisms and was found to strongly inhibit plant pathogenic microorganisms, whereas human pathogens were only moderately inhibited. Menthol, the major constituent of peppermint essential oil, was found to be responsible for the antimicrobial property of the oils (Iscan et al. 2002). The essential oil of peppermint exhibited very strong antibacterial activity particularly against *E. coli* strains. It also showed significant fungistatic and fungicidal activity and minimal fungicidal concentration values that were considerably lower than those of the commercial fungicide bifonazole (Mimica-Dukic et al. 2003). Yadegarinia et al. (2006) found the essential oil of peppermint to possess excellent antimicrobial activities against *E. coli*, *Staphylococcus aureus*, and *Candida albicans*.

Antioxidant Properties

Katikova et al. (2001) studied the effect of peppermint leaf extract on the indicators of cytolysis, lipid peroxidation, and antioxidant system of serum in laboratory rats with acute toxic hepatitis. The extract exhibited antioxidant effects and this was proven by the reduction of the final and intermediate products of lipoperoxidation, the absence or decline of the level of endogenous alpha-tocopherol content and glutathione-dependent enzymes. Peppermint oil reduced DPPH to 50% and also exhibited high OH radical scavenging activity (Mimica-Dukic et al. 2003). Menthone and

isomenthone, the two constituents from peppermint essential oil, were found to be the most powerful scavenging compounds. Water-soluble extracts from different *Mentha* species were screened for their potential antioxidative properties and *M. piperita* "Frantsila" was found to be the best (Dorman et al. 2003). The level of activity identified was strongly associated with the phenolic content. The antioxidant capacity (two assays) and the total phenolics, ascorbic acid and carotenoid contents in fresh and air-dried herbs were studied and reported. The highest antioxidant capacity, expressed as inhibition of LA peroxidation (TAA), was found for extracts from both dried and fresh oregano. The activity for peppermint was lower. The content of total soluble phenolics was very high in dried peppermint (Capecka et al. 2004). Eriocitrin, a polyphenolic compound isolated from an aqueous extract of peppermint, was found to be a powerful antioxidant and a free radical scavenger (Sroka et al. 2005). Samarth et al. (2006a) reported that an extract of peppermint is chemopreventive and antigenotoxic when given subsequent to an initiating dose of benzo[a]pyrene in newborn Swiss albino mice. They suggested that the chemopreventive action and antigenotoxic effects may be due to the antioxidative properties of the peppermint extract. Peppermint oil had greater antioxidant activity than myrtle oil both by DPPH assay and the carotene/linoleic acid systems (Yadegarinia et al. 2006). Samarth et al. (2006b) evaluated the radiomodulatory influence of peppermint leaf extract on hepatic antioxidant status and lipid peroxidation in Swiss albino mice and based on their findings suggested that the antioxidant and free radical scavenging activities of peppermint leaves were the likely mechanism of radiation protection. Dorman et al. (2009) determined the iron(III) reductive, iron(II) chelating and free radical scavenging abilities of seven different extracts of peppermint and also quantified the phenolic and flavonoid content. They found strong activities for the seven different extracts against different chelating, reductive, and radical scavenging assay. Peppermint oil possessed antiradical activity with respect to DPPH and hydroxyl radicals, exercising stronger antioxidant impact on the hydroxyl radical (Schmidt et al. 2009). Peppermint was found to have a significant radioprotective effect and this could be due to the amount of phenolic compounds, the content of flavonoids and flavonols in the peppermint extract which have strong antioxidant and radical scavenging activity (Samarth and Samarth 2009). Methanolic extracts of peppermint produced significant ($p<0.05$) protection of PC12 cells against oxidative stress (Lopez et al. 2010). Peppermint grown in greenhouse showed higher total phenolic content and antioxidant capacity (YEAC) than those grown under field conditions (Yi and Wetzstein 2010). The methanolic extract of peppermint and other mint species were found to have significant antioxidant activity and polyphenol content (Kratchanova et al. 2010; Ahmad et al. 2012). Peppermint (organic and conventional) showed significant antioxidant activity and good phenolic content (Junli Lv et al. 2012).

Regulatory Status

GRAS 182.10 and GRAS 182.20.

Standard

ISO 5563.

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Chapter 46
Pomegranate

Botanical Name: *Punica granatum* L.
Synonyms: anar, anardana.
Family: Punicaceae.
Common Names: **French**: grenade; **German**: Granatapfel; **Italian**: melograno; **Spanish**: Granada; **Hindi**: anar, anardana.

Introduction

History

The dried seed with the pulp is used as a spice. Pomegranate has been mentioned in the *Papyrus of Ebers*. The Pomegranate was familiar to the Hebrews in Biblical times and was certainly known in the gardens of Babylon. It is believed to be the apple in the Garden of Eden. It is still used by Jews in certain ceremonies, and has been used in architecture from ancient times. A picture of the fruit appeared in the decoration on the pillars of King Solomon's Temple, and was embroidered on the hem of the High Priest's ephod. In classical mythology, Persephone was forced to spend one-third of each year in Hades underworld kingdom because she had eaten pomegranate seeds while living with Hades. Because of its role in the Greek legend of Persephone, the pomegranate came to symbolize fertility, death, and eternity and was an emblem of the Eleusinian mysteries. In Christian art, the pomegranate is a symbol of hope. In Babylonia, the pomegranate was an agent of resurrection, while the Persians believed that the seeds of pomegranate conferred invincibility on the battlefield. In China, the pomegranate fruit symbolized longevity. Legend in Turkey has it that a bride could know the number of children she will have by the number of seeds that would spill out of a pomegranate when she dropped it on the floor.

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Producing Regions

It is believed to have originated in Western Asia and it now grows widely in the Mediterranean countries, China, Japan, India, and other tropical and subtropical countries.

Botanical Description

Pomegranate is a spiny, deciduous shrub, or small tree up to 5 m (15 ft) high, with small opposite leaves clustered at the branch tips, attractive, large orange-red flowers, a characteristic large fleshy fruit crowned with a persistent calyx and numerous seeds, each with a bright red, fleshy, edible layer. The flowers are terminal or axillary and solitary. The calyx is coriaceous and persistent, prolonged above the ovary and the distal and campanulate in shape. The seeds are angular with coriaceous testa. The dried seed is used as a spice and the dried root in traditional medicine. The fruit is about the size of an apple and is smooth-skinned and golden to red in color.

Parts Used

Seed (spice and medicinal), root (medicinal).

Flavor and Aroma

Pomegranate has a very astringent aroma. It has a very sweet-sour taste, astringent.

Active Constituents

The fruit rind contains gallo/elagitannins—mainly punicalin and punicalagin at very high concentrations (up to 28%). Several piperidine alkaloids are present in the roots, bark, leaves, and young fruit but not in the rind. The major active alkaloids are pelletierine (=isopelletierine) and *N*-methylisopelletierine. Also present is a homotropane alkaloid, pseudopelletierine. The fruit contains nicotinic acid, pectin, protein, riboflavin, thiamine, vitamin C, delphinidin diglycoside, aspartic, citric, ellagic, gallic and malic acids, glutamine and isoquercetin. The seeds contain asiatic and maslinic acids, pelargonidin-3, 5-diglucoside, sitosterol, and β-D-glucoside.

Oestrone with oestrogenic activity was reported from the seeds (Harborne and Baxter 1993). The seed coat had cyaniding-3-glucoside and 3,5-diglucoside, delphinidin-3-glucoside and 3,5-diglucoside (Rastogi and Mehrotra 1995). The leaves were reported to contain betulic acid, granatins A and B, and punicatolin (Chatterjee and Pakrashi 1994). The fruit of pomegranate consists of 80% juice and 20% seeds. The fresh juice contains 85% water, 10% total sugars, 1.5% pectin, ascorbic acid, and polyphenolic flavonoids. The soluble polyphenol content varies within the limits of 0.2–1.0%, depending on variety and includes mainly anthocyanins, catechins, ellagic tannins, and gallic and ellagic acids (Aviram et al. 2000). The acetone extract of the fruit contained anthocyanins, ellagitannins, and hydrolysable tannins (Afaq et al. 2005).

Preparation and Consumption

The seed dried with the pulp is used as a spice in many dishes. The fruit is used for dessert, and in the East, the juice is included in cold drinks. Crushed pomegranate seeds are sprinkled on hummus, the famous Middle Eastern dip. Pomegranate seeds are used as a souring agent instead of lemon juice, in Indian cooking.

Medicinal Uses and Functional Properties

Pomegranate seeds are used in gargles, is also believed to ease fevers and help in countering diarrhea. It is very widely used in Indian medicine. Root bark is traditionally used as a vermifuge to treat intestinal parasites, mainly tapeworm (Chopra 1982). It is considered astringent and anthelmintic. The dried fruit rind or the fruit pulp is a common remedy for upset stomachs and especially to treat diarrhea. Fruits are used to produce grenadine, a cordial, and the rind to tan leather. The pulp and seeds are stomachic (Chopra 1982). The flower buds are powdered and used in dysentery and diarrhea (Singh et al. 2000). The seeds are demulcent. Pomegranate fruit extract possesses strong anti-inflammatory (Afaq et al. 2005), anti-proliferative (Malik et al. 2005; Khan et al. 2007), and anti-tumorigenic properties (Afaq et al. 2005; Khan et al. 2007) and photochemopreventive potential (Afaq et al. 2010). The leaves are made into a paste and applied on eyes for conjunctivitis, while the leaf juice is given in dysentery (Chatterjee and Pakrashi 1994). Acetone extract of pomegranate fruit was found to inhibit conventional as well as novel biomarkers of 12-*O*-tetradecanoylphorbol-13-acetate (TPA)-induced tumor promotion, and hence it may possess chemopreventive activity in a wide range of tumor models (Afaq et al. 2005). A pomegranate extract (PE) from rind containing 90% ellagic acid was found to be an effective whitening agent for the skin. The authors (Yoshimura et al. 2005) suggest that the skin-whitening effect of PE was probably due to inhibition of the proliferation of melanocytes and melanin synthesis by tyrosinase in melanocytes.

A polysaccharide fraction from pomegranate showed inhibition of tyrosinase by 43%, suggesting its efficacy as a possible skin whitener (Rout and Banerjee 2007). Whole fruit extract of pomegranate has been found to have cardioprotective effects against Dox-induced cardiotoxicity in rats (Hassanpour et al. 2011). Faria et al. (2007b) reported that the prevention of procarcinogen activation through CYP activity/expression inhibition could be involved in pomegranate juice's effect on tumor initiation, promotion, and progression. The high content of ellagitannins was reported to be responsible for the antioxidant and antimutagenic activities of pomegranate peel extract (Zahin et al. 2010). Pomegranate exerts antiproliferative, anti-invasive, and antimetastatic effects, induces apoptosis through modulation of Bcl-2 proteins, increases p21 and p27, and downregulates cyclin-cdk network. In addition, pomegranate inhibits the activation of inflammatory pathways including, but not limited to, the NF-κB pathway. Anti-cancer effects with the most impressive data have been demonstrated so far in prostate cancer (Faria and Calhau 2011).

The well-established health beneficial value of pomegranate juice has lead to increased demand for pomegranate products and to the expansion of pomegranate orchards worldwide. In vitro and in vivo studies have demonstrated its anti-atherosclerotic capacity, chemoprevention, and chemotherapy of prostate cancer, and antiproliferative, apoptotic, and antioxidant activity among others.

Antioxidant Properties

Pomegranate juice (PJ) is a polyphenol-rich fruit juice with high antioxidant capacity and also the different pomegranate extracts have antioxidative properties (Schubert et al. 1999, 2002; Aviram 2000; Singh et al. 2002; Noda et al. 2002; Chidambara Murthy et al. 2002; Schubert et al. 2002; de Nigris et al. 2003; Aviram et al. 2004; Wang et al. 2004, 2006; Kelawala and Ananthanarayan 2004; Ajaikumar et al. 2005; Azadzoi et al. 2005; Kaur et al. 2006; Rosenblat et al. 2006a, b; Ricci et al. 2006; Lansky and Newman 2007; Sestili et al. 2007; Guo et al. 2007; Katz et al. 2007; Heber et al. 2007; Sezer et al. 2007; Tzulker et al. 2007; Toklu et al. 2007; Seeram et al. 2008; Türk et al. 2008; Saruwatari et al. 2008; Orak 2009; Basu and Penugonda 2009; Elfalleh et al. 2009; Schwartz et al. 2009; Borges et al. 2010; Rababah et al. 2010; Calín-Sánchez et al. 2011; Cayır et al. 2011; Choi et al. 2011; Fazeli et al. 2011; Stowe 2011; Johanningsmeier and Harris 2011; Mena et al. 2011; El Kar et al. 2011; Niwano et al. 2011; Faria and Calhau 2011; Pan et al. 2012; Zhang et al. 2011; Kelishadi et al. 2011; Joseph et al. 2012). The in vitro antioxidant activity of pomegranate has been attributed to the high polyphenolic content, specifically punicalagins, punicalins, gallagic acid, and ellagic acid. These polyphenolic compounds are metabolized during digestion to ellagic acid and urolithins, and this could suggest that the bioactive compounds that provide in vivo antioxidant activity may not be the same as those present in the whole food. Anthocyanins and the unique fatty acid profile of the seed oil may also play a role in pomegranate's health effects. The antioxidant capacity of pomegranate juice has been reported to be three times higher

than that of red wine and green tea (Gil et al. 2000) and higher than other juices (Rosenblat and Aviram 2006; Seeram et al. 2008). Several studies have confirmed its antioxidant and anti-inflammatory properties (Lansky and Newman 2007; Jurenka 2008). Pomegranate fruit peel extract (PPE) has been found to show important antioxidant and apoptotic effects (Dikmen et al. 2011). Pomegranate juice may increase serum antioxidant capacity, decrease plasma lipids and lipid peroxidation, diminish oxidized-LDL uptake by macrophages, reduce intima media thickness, decrease atherosclerotic lesion areas, enhance biological actions of nitric oxide, lessen inflammation, decrease angiotensin converting enzyme activity, and lower systolic blood pressure (Lansky and Newman 2007; Jurenka 2008; Basu and Penugonda 2009). In humans, PJ consumption decreased LDL susceptibility to aggregation and retention and increased the activity of serum paraoxonase (an HDL-associated esterase that can protect against lipid peroxidation) by 20%. In atherosclerotic apolipoprotein E-deficient (E(0)) mice, oxidation of LDL by peritoneal macrophages was reduced by up to 90% after pomegranate juice consumption and this effect was associated with reduced cellular lipid peroxidation and superoxide release. The uptake of oxidized LDL and native LDL by mouse peritoneal macrophages obtained after pomegranate juice administration was reduced by 20%. The pomegranate juice supplementation of E(0) mice also reduced the size of their atherosclerotic lesions by 44% and also the number of foam cells compared with control E(0) mice supplemented with water (Aviram 2000). The antioxidant activity of commercial pomegranate juices (18–20 TEAC) was three times higher than those of red wine and green tea (6–8 TEAC). Also, the activity was higher in commercial juices extracted from whole pomegranates than in experimental juices (12–14 TEAC) obtained from the arils only (Gil et al. 2000). Kaplan et al. (2001) concluded that PJ supplementation to E(0) mice possessed very impressive antiatherogenic properties, which could be related to its potent antioxidative activity and beneficial effect on macrophage cholesterol flux, which results in decreased macrophage cholesterol accumulation. They also related the presence of a tannin fraction in pomegranate juice with potent antioxidative characteristics. Pomegranate juice consumption by hypertensive patients resulted in 36% decrement in their serum angiotensin converting enzyme (ACE) activity and a 5% reduction in their systolic blood pressure. This protection by PJ against cardiovascular diseases could be related to its inhibitory effect on oxidative stress and on serum ACE activity (Aviram and Dornfeld 2001). The methanol extracts of pomegranate peels and seeds showed strong antioxidant activities using different methods (Singh et al. 2002). The antioxidative and antiatherogenic effects of pomegranate polyphenols were demonstrated in vitro, as well as in vivo in humans and in atherosclerotic apolipoprotein E-deficient mice (Aviram et al. 2002). They suggest that the dietary supplementation of PJ to atherosclerotic mice significantly inhibited the development of atherosclerotic lesions because it protected LDL oxidation. Aviram et al. (2004) also suggest that PJ consumption by patients with carotid artery stenosis (CAS) decreases carotid intima–media thickness (IMT) and systolic blood pressure and that these could be related to the potential antioxidant characteristics of PJ polyphenols. The gastroprotective effect of the methanolic extract of fruit rind was found to be through

antioxidative mechanism (Ajaikumar et al. 2005). The polyphenolic antioxidants in the PJ can contribute to the reduction of oxidative stress and atherogenesis. The authors reported that the proatherogenic effects induced by perturbed shear stress can be reversed by chronic administration of PJ and pomegranate fruit extract (de Nigris et al. 2005; de Nigris et al. 2007). The PJ, punicalagin, ellagic acid (EA), and standardized total pomegranate tannin (TPT) extract were evaluated for their in vitro antiproliferative, apoptotic, and antioxidant activities. The authors found superior bioactivity of PJ compared to its purified polyphenols, and this illustrates the multifactorial effects and chemical synergy of the action of multiple compounds compared to single purified active ingredients (Seeram et al. 2005). The consumption of PJ by diabetic patients did not worsen the diabetic parameters, but it rather resulted in anti-oxidative effects on serum and macrophages, which could then contribute to attenuation of atherosclerosis development in these patients (Rosenblat et al. 2006a, b). Rozenberg et al. (2006) reported that PJ sugar fraction, unlike the white grape juice (WGJ) sugar fraction, decreased the macrophage oxidative state under both normal and diabetic conditions, suggesting the presence of unique complex sugars and/or phenolic sugars in PJ. Ignarro et al. (2006) reported that PJ was a potent inhibitor of superoxide anion-mediated disappearance of NO, and it was much more potent than Concord grape juice, blueberry juice, red wine, ascorbic acid, and DL-alpha-tocopherol. Their results indicated that PJ possesses potent antioxidant activity that results in marked protection of NO against oxidative destruction, thereby resulting in augmentation of the biological actions of NO. The anti-oxidative characteristics of the unique phenolics punicalagin and gallic acid of PJ could be related because of their stimulatory effect on macrophage PON2 expression, a phenomenon associated with activation of the transcription factors PAPR gamma and AP-1 (Shiner et al. 2007). Faria et al. (2007a) studied the effect of prolonged PJ ingestion on general oxidation status. They used mice that ingested PJ (or water in control group) for 4 weeks, after which damage to lipids, proteins, and DNA were evaluated as oxidative cell biomarkers. Protection against protein and DNA oxidation was found in PJ group. They also found a significant decrease in GSH and GSSG, without change in GSH/GSSG ratio and also all enzymatic activities (GPx, GST, GR, SOD, and catalase) studied were found to be decreased by PJ treatment. The GST and GS transcription were also decreased in this group as shown by RT-PCR results. Their results provided a protective effect of PJ against systemic oxidative stress in mice. Daily intake of PJ and pomegranate by-product as dietary supplements was found to augment the human immune system's antioxidant, antimalarial, and antimicrobial capacities (Reddy et al. 2007). Seeram et al. (2008) compared PJ's antioxidant activity to those of other widely available polyphenol-rich beverage products using a comprehensive variety of antioxidant tests. Antioxidant potency, ability to inhibit LDL oxidation and total polyphenol content were consistent in classifying the antioxidant capacity of the polyphenol-rich beverages in the following order: PJ > red wine > Concord grape juice > blueberry juice > black cherry juice, acai juice, cranberry juice > orange juice, iced tea beverages, apple juice. There is also consistent clinical evidence of antioxidant potency for the most potent beverages including PJ and red wine. Guo et al. (2008) compared the antioxidant capacity, activity

of antioxidant enzymes, and other tests in the mononuclear blood cells of elderly people who consumed either PJ or apple juice. Their results showed that daily consumption of pomegranate juice was potentially better than apple juice in improving antioxidant function in the elderly. PJ was shown to have inhibitory effects on renal tubular cell injury and oxidative stress caused by oxalate crystals by reducing ROS, iNOS, p38-MAPK, and NF-κB expression (Ilbey et al. 2009). Mohan et al. (2010) reported that PJ had hypertensive action in angiotensin II (Ang II) diabetic model. Their results also showed that PJ could prevent the development of high blood pressure induced by Ang II in diabetic rats probably by combating the oxidative stress induced by diabetes and Ang II and by inhibiting ACE activity. Supplementation of PJ provided a protective effect against isoproterenol (IP)-induced cardiac necrosis (CN) in rats (Jadeja et al. 2010). A strong correlation between antioxidant capacity and proanthocyanin contents was found in PJ of 9 Tunisian ecotypes, suggesting proanthocyanins as the principal contributor in the antioxidant capacity of pomegranate (El Kar et al. 2011). Pomegranate flower supplementation was shown to decrease oxidative stress and ameliorate impairment in learning and memory performances in diabetic rats (Cambay et al. 2011). Pomegranate constituents afford chemoprevention of hepatocarcinogenesis possibly through potent antioxidant activity achieved by upregulation of several housekeeping genes under the control of Nrf2 without toxicity (Bishayee et al. 2011).

Regulatory Status

GRAS 182.20.

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Chapter 47
Poppy

Botanical Name: *Papaver somniferum* L.
Synonyms: Opium poppy.
Family: Papaveraceae.
Common Names: **French**: pavot somnifere; **German**: Mohn; **Italian**: papavero; **Spanish**: ababa; **Hindi**: post dana.

Introduction

History

The genus name *Papaver* is Classical Latin for the poppy plant and lives today in several Romance languages, e.g., French *pavot* and Portuguese *papoila*. The species name *somniferum* (Latin *somnus* "sleep" and *ferre* "bring") refers to the narcotic properties of opium, as does Spanish *adormidera* (from Latin *dormire* "to sleep"), also an Arabic name of poppy, *abu al-num*, "father of sleep." The opium poppy, from which the culinary poppy seeds come, is among the oldest cultivated plants. The Romans and Greeks used poppy seeds in their food and medicines; Homer referred it in his writings. The Egyptians loved the poppy seeds as a condiment, while the ancient Greeks grew the plant specifically for the poppy seeds which among the other various uses, were mixed into cakes with honey and consumed by the Olympic athletes to provide an immediate burst of energy. In Roman times, poppy seeds decorated mushroom-shaped breads, a practice which continues even today. Poppy seed has none of the narcotic qualities of the opium drug. But the plant has been cultivated for centuries in the near East and Orient for its narcotic properties. The story of the Opium Wars in the nineteenth century is an inglorious chapter in British history. In the nineteenth century, an addictive tincture of opium was a universal cure-all, widely practiced by doctors—its abuse "celebrated" by Quincey, Coleridge and Baudelaire, among others. In the Ebers Papyrus, the Egyptians described poppy as a sedative. Egyptians, later produced an edible oil from the poppy seeds, and mixed the oil with

D.J. Charles, *Antioxidant Properties of Spices, Herbs and Other Sources*,
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honey to make the flavorful bread. Mohammed's missionaries in the seventh century introduced poppy seeds into India. The poem "Some Corner of a Foreign Field" by Rupert Brooke immortalized the poppy fields of Flanders.

Producing Regions

It is believed to have originated somewhere in the western Mediterranean region of Europe from where it spread through the Balkan peninsula to Asia Minor as early as the tertiary period. It is produced in the USA, Australia, the Netherlands, Romania, Poland, Germany, Great Britain, Canada, India, Iran, and Turkey. The better quality seeds come from the Dutch variety.

Botanical Description

Poppy plant is an erect, annual herb up to 150 cm (4 ft) high, with glabrous stem with thick waxy coating. The leaves are numerous, alternate, and spread horizontally. The pink or purple flowers are few and solitary on a long peduncle. The fruit is a capsule varying in shape and color. Poppy seeds are tiny, kidney shaped, and slate blue in color. Poppy seeds are devoid of narcotics.

Parts Used

Seeds (uniform slate blue) are used whole and ground, or as a paste, and nutty oil.

Flavor and Aroma

Poppy has a nutty, sweet aroma. It has a nut-like, sweet-spicy flavor, and slightly smoky aroma. The flavor is sweet-spicy and lingering.

Active Constituents

Seeds have moisture 4.3–5.2%, protein 24%, fiber 5–6%, calcium, phosphorous, iron, thiamine, riboflavin, nicotinic acid, iodine and lecithin, 40–50% fatty oil (60% linoleic acid, 30% oleic acid, 3% linolenic acid). Sitosterol is the major constituent in the unsaponified matter of the seed. The others are campesterol,

Table 47.1 Nutrient composition and ORAC values of poppy seed

Nutrient	Units	Value per 100 g
Water	g	5.95
Energy	kcal	525
Protein	g	17.99
Total lipid (fat)	g	41.56
Carbohydrate, by difference	g	28.13
Fiber, total dietary	g	19.5
Sugars, total	g	2.99
Calcium, Ca	mg	1,438
Vitamin C, total ascorbic acid	mg	1.0
Vitamin B-6	mg	0.247
Vitamin B-12	mcg	0.00
Vitamin A, RAE	mcg_RAE	0
Vitamin A, IU	IU	0
Vitamin D	IU	0
Vitamin E (alpha-tocopherol)	mg	1.77
Fatty acids, total saturated	g	4.517
Fatty acids, total monounsaturated	g	5.982
Fatty acids, total polyunsaturated	g	28.569
H-ORAC		406
L-ORAC		75
Total-ORAC		481
TP		20

Source: USDA National Nutrient Database for Standard Reference, Release 24 (2011)

avenasterol, cholestanol, and stigmasterol (Banerji et al. 1999). The nutritional constituents and ORAC values of poppy seed are given in Table 47.1.

Preparation and Consumption

Poppy seeds have high nutritive value and are used as a food and a source of edible oil. They are used in breads, curries, sweets, and confectioneries. Widely used in Jewish cooking and in Central Europe in cakes, pastries, sprinkled on breads, buns, pretzels, and biscuits; included in sweet stuffings, e.g., Jewish Hamantaschen, strudels; added to salads or noodles (in the USA); in India, white seeds ground for flavoring and thickening curries. The paste is used in desserts and sauces in Turkey. Germans and Turks use seeds to make bread, while the ancient Indians mixed the seeds with sugarcane juice for confectionery.

In Europe and the USA, the seeds are sprinkled on breads, bagels, buns, cakes, and cookies.

Medicinal Uses and Functional Properties

Seeds are used in painkillers, cough mixtures and syrups, and as an expectorant. An infusion of the seeds can provide relief to toothache and earache.

The pharmacological activity of *Papaver somniferum* (opium poppy) includes the interaction of alkaloid opioids with endogenous opiate receptors in the brain (Perry et al. 1999). It has been suggested that poppy seeds, which are all widely used in cooking, may prove to be a valuable anticarcinogenic agent (Aruna and Sivaramakrishnan 1992).

Adhami et al. (2003) showed the involvement of mitochondrial pathway and Bcl-2 family proteins during sanguinarine-mediated apoptosis of immortalized keratinocytes, suggesting sanguinarine as a potential drug for the management of hyperproliferative skin disorders, including skin cancer. Noscapine, an alkaloid from *Papaver somniferum*, is widely used as an antitussive and is being clinically studied because of its anti-angiogenesis properties. Noscapine, a phthalideisoquinoline alkaloid, has long been used as a cough suppressant in humans and in experimental animals. Moreover, unlike other opioids, noscapine lacks sedative, euphoric, and respiratory depressant properties and is free from serious toxic effects in doses up to 100 times the antitussive dose. Recently, it has been shown that noscapine interacts with α-tubulin resulting in apoptosis in cancerous cells both in vitro and in vivo. Moreover, it has also been shown to reduce neoangiogenesis resulting in reduced cell turnover. As such, its role in tumor and tumor-like conditions is being investigated (Lasagna et al. 1961; Empey et al. 1979; Chau et al. 1983; Wade 1997; Ye et al. 1998; Landen et al. 2002; Zhou et al. 2002, 2003; Barken et al. 2008; Mahmoudian and Rahimi-Moghaddam 2009).

Antioxidant Properties

Good antioxidant activity has been reported in poppy (Wu et al. 2004; Shan et al. 2005). There was good antioxidant activity reported for the corn poppy using different radical scavenging methods (El and Karakaya 2004). Schaffer et al. (2005) reported on the antioxidant properties of Mediterranean food plants extracts including poppy. The poppy suspension cultures responded to elicitor treatment with a transient increase in lipoxygenase (LOX) activity, followed by accumulation of sanguinarine (Holkova et al. 2010). Extracts of poppy flowers also exhibited dose-dependent free radical scavenging ability (Hasplova et al. 2011).

Regulatory Status

GRAS 182.10.

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Chapter 48
Rosemary

Botanical Name: *Rosmarinus officinalis* L.
Synonyms: *Rosmarinus coronarium*; compass plant.
Family: Lamiaceae (Labiatae).
Common Names: **French**: rosmarin; **German**: Rosmarein; **Italian**: rosmarino; **Spanish**: romero.

Introduction

History

The name "Rosemary" is derived from the Latin word "*rosmarinus*", meaning "sea dew". The ancient Greeks called it "*antos*", meaning "the flower of excellence" or "*libanotis*" for its smell of incense. It has been used since 500 BC. It was used to ward off evil spirits and nightmares by placing sprigs under the pillow, and the aroma could keep old age at bay. During the middle ages, rosemary leaves and twigs were burned to scare away evil spirits and disinfect the surroundings. In Hungary, ornaments made of rosemary were used as a symbol of love, intimacy, and fidelity for lovers. The Spaniards revere it as one of the bushes that provided shelter to Virgin Mary on her way to Egypt. Legend has it that Virgin Mary washed her sky-blue cloak and spread it over a rosemary bush to dry; the flowers henceforth became blue. The Sicilians believe that young fairies, taking the form of snakes, lie amongst the branches. It was also used in bridal wreaths with other herbs and flowers. It was thought that if rosemary thrived in one's house, the woman rules the house. In ancient Greece, rosemary was recognized for its alleged ability to strengthen the brain and memory. Greek students would braid rosemary into their hair to help them with their exams. Also known as the herb of remembrance, it was placed on the graves of English heroes. Dioscorides claimed that rosemary boiled in water and

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drunk before exercise would cure anyone with yellow jaundice. Tragus wrote of rosemary as a very desirable spice for Germans. Rosemary placed in closets among clothes protected them from moths and other vermin. Rosemary was a perfume in baths of ladies in France, Greece, and Turkey.

Producing Regions

Rosemary is native to the Mediterranean regions. It is now cultivated worldwide in Algeria, Spain, France, Portugal, Russia, China, Yugoslavia, Tunisia, Morocco, Italy, and USA. Major essential oil producing are Spain, Tunisia, Morocco, and France.

Botanical Description

Rosemary is a dense, aromatic, and evergreen perennial small shrub up to 2-m (6.6 ft) high. It has branched, sticky, and narrow leaves that are bright green above, with rolled-in margins and densely hairy below. The branches are rigid and the stem is square, woody, and brown. The flowers are small, pale purple or bluish, and appear in cymose inflorescence.

Parts Used

The parts used include fresh or dried leaves (grayish green), whole, chopped, crushed or ground, and essential oil. Essential oil is obtained by steam distillation of the fresh flowering tops. The oil is clear, colorless to pale yellow mobile liquid. Yield is 0.5–1.2%. Two oils are sold commercially—Rosemary (Spain) and Rosemary (Tunisia and Morocco). They differ in oil composition.

Flavor and Aroma

Rosemary has sweet and fresh, fragrant, slightly eucalyptus-like aroma and is slightly camphoraceous. Rosemary has a characteristic cooling, pine-woody aroma with camphoraceous, minty, balsamic undertones, and a fresh, bittersweet flavor. The taste is somewhat peppery, spicy, warming, and herbaceous, with bitter and camphoraceous aftertaste.

Table 48.1 Nutrient composition and ORAC values of rosemary dried

Nutrient	Units	Value per 100 g
Water	g	9.31
Energy	kcal	331
Protein	g	4.88
Total lipid (fat)	g	15.22
Carbohydrate, by difference	g	64.06
Fiber, total dietary	g	42.6
Calcium, Ca	mg	1,280
Vitamin C, total ascorbic acid	mg	61.2
Vitamin B-6	mg	1.740
Vitamin B-12	mcg	0.00
Vitamin A, RAE	mcg_RAE	156
Vitamin A, IU	IU	3,128
Vitamin D	IU	0
Fatty acids, total saturated	g	7.371
Fatty acids, total monounsaturated	g	3.014
Fatty acids, total polyunsaturated	g	2.339
H-ORAC	μmol TE/100 g	112,200
L-ORAC	μmol TE/100 g	53,080
Total-ORAC	μmol TE/100 g	165,280
TP	mg GAE/100 g	4,980

Source: USDA National Nutrient Database for Standard Reference, Release 24 (2011)

Active Constituents

The active constituents include essential oil up to 2.5%. Composition of different oils is as follows: Rosemary (Spain): 1,8-cineole (15–25%), camphor (13–18.5%), α-pinene (18–26%), camphene (8–12%), β-pinene, myrcene, limonene, bornyl acetate, borneol, and verbenone. Rosemary (Tunisia, Morocco): 1,8-cineole (38–55%), camphor (5–15%), α-pinene (9–14%), camphene (2.5–6%), β-pinene (4–9%), bornyl acetate, borneol, verbenone, linalool. Also present in leaves are phenolic acids (rosmarinic acid,), bitter diterpenes (carnosol, carnosic acid, rosmanol), triterpenes (oleanic and ursolic acid), triterpene alcohols (α-amyrin, β-amyrin, betulin), as well as several flavonoids and their glycosides (diosmetin, luteolin, genkwanin). The nutritional constituents and ORAC values of dried rosemary are given in Table 48.1.

Preparation and Consumption

It is a popular culinary flavoring for meat and meat products, baked foods, and Mediterranean recipes. Fresh or dried leaves can be used for special accent with cream soups made of leafy greens, poultry, stews, and sauces. Rosemary extract has

antioxidant properties in food products. It is in liqueurs like Benedictine. Rosemary leaves and flowering tops are used in lamb roast, mutton preparations, fish dishes, marinades, bouquet garni, with baked fish, rice, salads, occasionally with egg preparations, dumplings, apples, summer wine cups, and fruit cordials, and in vinegar and oil. Dried leaves and extractives are used to season fried chicken, salad croutons, baked products, confections, and nonalcoholic beverages and in perfumes and soaps.

Medicinal Uses and Functional Properties

Rosemary is a carminative and stomachic. It is used to treat stomach cramps and flatulence, and to stimulate appetite and the secretion of gastric juices. It is useful against headache and nervous complaints. It provides relief from muscle aches and joint pains. It is used for treating depression, migraine, and disorders of the liver and digestion. Ointment made from leaves is useful against neuralgia, rheumatism, eczema, and minor wounds. They are also used as hair rinses and mouthwashes.

Literature evidence from animal and cell culture studies has demonstrated the anticancer potential of rosemary extract, carnosol, carnosic acid, ursolic acid, and rosmarinic acid. The rosemary extract, phenolics and essential oil, stimulates blood circulation and has antibacterial, antifungal, antiviral, antimicrobial, antiparasitic, antiproliferative, spasmolytic, anti-inflammatory, and mild analgesic activity (Baratta et al. 1998; Hori 1998; Pintore et al. 2002; Oluwatuyi et al. 2004: Vitaglione et al. 2004; Amin and Hamza 2005; Moreno et al. 2006; Sharabani et al. 2006; Del Baño et al. 2006; Rau et al. 2006; Tsai et al. 2007, 2011b; Kennedy and Scholey; 2006; Costa et al. 2007; Yesil-Celiktas et al. 2010; Yi and Wetzstein 2010; Ait-Ouazzou et al. 2011; Jiang et al. 2011; Martinez-Velazquez et al. 2011; Toroglu 2011; Ventura-Martinez et al. 2011). Rosemary extract was found to have potent antiglycative bioactivity (Hsieh et al. 2007). Luteolin, a flavonoid found in rosemary, has been reported to induce apoptosis, inhibit angiogenesis, prevent carcinogenesis in animal models, reduce tumor growth in vivo, and sensitize tumor cells to the cytotoxic effects of some anticancer drugs, suggesting its cancer chemopreventive and chemotherapeutic potential (Lopez-Lazaro 2009). Carnosic acid, a major phenolic from rosemary, was shown to significantly inhibit collagen-, arachidonic acid-, U46619,- and thrombin-induced washed rabbit platelet aggregation in a concentration-dependent manner, suggesting its antiplatelet activity to be mediated by inhibition of cytosolic calcium mobilization (Lee et al. 2007). The ethanolic extract of rosemary was found to have differential anti-proliferative effects on human leukemia and breast carcinoma cells (Cheung and Tai 2007). Carnosic acid (CA) was found to decrease the viability of human promyelocytic leukemia cell line, HL-60, and induced G(1) arrest and apoptosis (Wang et al. 2008). Dieldrin-induced down-regulation of brain-derived neurotrophic factor production was found to be significantly attenuated by CA (Park et al. 2008). The essential oil of rosemary had good antibacterial activity on *E. coli*, *Salmonella typhi*, *S. enteritidis*, and *Shigella*

sonei, and significant antifungal activity on six fungi (Bozin et al. 2007). It was found to have antinociceptive effect in the PIFIR model (Martínez et al. 2009). Rosemary extracts prevented protein glycation and their total phenolics were highly correlated with FRAP values, and this suggests a strong antidiabetic potential for rosemary bioactive compounds (Dearlove et al. 2008). Rosmanol, a polyphenol from rosemary, downregulates inflammatory iNOS and COX-2 gene expression by inhibiting the activation of NF-kappaB and STAT3 by interfering with the activation of PI3K/Akt and MAPK signaling (Lai et al. 2009). Rosemary is one of the top ten botanical in antiaging creams (Cronin and Draelos 2010). Carnosol and carnosic acid were found to have strong antimicrobial activity against a variety of microorganisms responsible for initiating dental caries (Bernardes et al. 2010). Carnosic acid and rosmarinic acid from rosemary exhibited neurotrophic effects in PC12 cells through cell differentiation induction and cholinergic activities enhancement (El Omri et al. 2010).

Rosemary leaf extract limited weight gain, and improved cholesterol levels and glycaemia in mice on a high-fat diet (Ibarra et al. 2011). Rosemary extract and essential oil were shown both to be effective and to possess anti-colitic activity, and therefore reinforces the use of this plant as a remedy for inflammatory bowel diseases in traditional medicine (Minaiyan et al. 2011). Rosemary has also been found to be promising as a nutritional strategy for improving meat quality (Banon et al. 2012).

Antioxidant Properties

Rosemary has been shown to have strong antioxidant properties (Aruoma et al. 1996; Basaga et al. 1997; Saito et al. 2004; Rababah et al. 2004; Almela et al. 2006; D'Evoli et al., 2006; Wijeratne and Cuppett 2007; Atsumi and Tonosaki 2007; Aherne et al. 2007; Gladine et al. 2007; Bhale et al. 2007; Ho et al. 2008; Topal et al. 2008; Mirshekar et al. 2009; Gobert et al. 2009; Klancnik et al. 2009; Hasani-Ranjbar et al. 2009; Sasse et al. 2009; Zhang et al. 2009; Botsoglou et al. 2010; Furtado et al. 2010; Herrero et al. 2010; Ibarra et al. 2010; Kelsey et al. 2010; Kong et al. 2010; Kosaka et al. 2010; Luo et al. 2010; Malo et al. 2010, 2011; Menghini et al. 2010; Pennisi et al. 2010; Perez-Fons et al. 2010; Puangsombat and Smith 2010; Tamaki et al. 2010; Tian et al. 2010; Yang et al. 2010; Zaouali et al. 2010; Ahmed et al. 2011; Beretta et al. 2011; Bobilev et al. 2011; Cazzola et al. 2011; Colindres and Brewer 2011; Johnson 2011; Kim et al. 2011; Kuo et al. 2011; Lara et al. 2011; Mohamed et al. 2011; Pop 2011; Puangsombat et al. 2011; Zegura et al. 2011). Rosemary exhibits high antioxidant activity both in ground form and as an extract and as such has been applied to various foods, displaying good antioxidative effects (Che Man and Tan 1999; Fernandez-Lopez et al. 2003; Serdaroglu and Felekoglu 2005; Estevez et al. 2007; Cadun et al. 2008; Liu et al. 2009; Yesilbag et al. 2011). The phenolic diterpenes (carnosol, carnosic acid, rosmanol) and flavonoids have been reported as the major constituents contributing to the antioxidative

effects of rosemary (Chen et al. 1992; Richheimer et al. 1996; Tsai et al. 2011a). The plant extracts rich in polyphenols (including rosemary) in association with vit. E were able to reduce lipoperoxidation in lactating cows having a diet rich in n-3 polyunsaturated fatty acids (Gobert et al. 2009). Different extracts of rosemary have been shown to possess antioxidative activity, with the methanol extract being the best (Chang et al. 1977). An ethanolic extract of rosemary was shown to have substantial antioxidant activity (8.1 and 12.6 μM Trolox equivalents) at 1/10 and 1/5 dilutions (Cheung and Tai 2007). The essential oil of rosemary reduced DPPH radical formation and had strong inhibition of lipid peroxidation in both systems of induction (Bozin et al. 2007). Peng et al. (2007) found the supercritical CO_2 extract of rosemary to have nontoxic potent antitumor bioactivity. The major constituents in the extract were rosmarinic acid, carnosol, 12-methoxycarnosic acid, carnosic acid, and methyl carnosate. The total phenolic content was 155.8 mg/GAE/g and the DPPH scavenging was 81.86% at 0.01 mg mL^{-1}. The NO production was also greatly reduced by the extract. Carnosic acid (CA) from rosemary herb activated the Keap1/Nrf2 transcriptional pathway by binding to specific Keap1 cysteine residues, and thus protected the neurons from oxidative stress and excitotoxicity (Satoh et al. 2008). They further presented evidence that both neuronal and non-neuronal distribution of CA may prevent neuroprotective effect. They also showed that CA translocated into the brain, increased the level of reduced GA in vivo, and protected the brain against middle cerebral artery ischemia/reperfusion. Yu et al. (2008) in their studies found CA to effectively inhibit TNF-alpha-induced migration of HASMC as compared to the control group, and it inhibited MMP-9 activity and expression. Furthermore, CA suppressed the production of reactive oxygen species and the nuclear translocation of NF-kappaB p50 and p65 induced by TNF-alpha (Yu et al. 2008). An ethanolic extract of rosemary (200 mg kg^{-1}) was found to significantly lower the blood glucose level and increase serum insulin levels in diabetic rabbits. The extract also possessed the capability to inhibit lipid peroxidation and activate antioxidant enzymes during 1 week treatment of diabetic rats (Bakirel et al. 2008). These results suggest that the remarkable antidiabetogenic effect of rosemary extract is due to its very potent antioxidant properties. Poeckel et al. (2008) found CA and CS to inhibit the formation of proinflammatory leukotrienes in intact PMNL and purified recombinant 5-lipoxygenase, and attenuate the formation of reactive oxygen species and secretion of human leukocyte elastase. Herrero et al. (2010) used different extraction procedures for rosemary antioxidants and found that pressurized liquid extraction (PLE) using ethanol produced extracts with high antioxidant activity. Rosemary was effective against thermal oxidation of natural virgin olive oil followed by thyme and lemon (Ayadi et al. 2009). Posadas et al. (2009) found the SFE rosemary extract (containing 20% CA) to reduce oxidative stress in aged Wistar rats. Carnosic acid and carnosol from rosemary significantly increased the intracellular level of total GSH and this could be an important step in the inhibition of adipocyte differentiation in mouse 3T3-L1 cells (Takahashi et al. 2009). Oral pretreatment of carnosic acid for 5 days to DMBA-treated hamsters significantly protected the DMBA-induced clastogenesis as well as the biochemical abnormalities. Although the exact mechanism of anti-clastogenic effects of carnosic acid is

unclear, the antioxidant potential and effect on modulation of Phase I and II detoxification enzymes could play a possible role (Manoharan et al. 2010). Rosemary was found to control lipid oxidation in salmon jerky snacks (Kong et al. 2011). The total phenolics of rosemary extract obtained from the most effective extraction conditions showed a high inhibitory effect on lipid peroxidation (IC(50) 33.4 μg mL^{-1}). Both the supercritical carbon dioxide extract and carnosic acid markedly suppressed the LPS-induced production of nitric oxide (NO) and tumor necrosis factor-α (TNF-α), as well as the expression of inducible nitric oxide synthase (iNOS) and cyclooxygenase-2 (COX-2), phosphorylated inhibitor-kappaB (P-IκB), and nuclear factor-kappaB (NF-κB)/p65 in a dose-dependent manner. The five major compounds in the $SCCO_2$ extract were verbenone, cirsimaritin, salvigenin, carnosol, and CA (Kuo et al. 2011). Carnosol and carnosic acid, the two major anti-inflammatory compounds from rosemary, differentially regulate the expression of inflammation-associated genes, thus demonstrating the pharmacological basis for the anti-inflammatory properties (Mengoni et al. 2011). Rosemary extract oral supplementation was found to improve the serum PAI-1 activity and endothelial dysfunction in both young and healthy individuals (Sinkovic et al. 2011).

Regulatory Status

GRAS 182.10 and GRAS 182.20.

Standard

ISO 11164.

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Chapter 49
Saffron

Botanical Name:	*Crocus sativus* L.
Synonyms:	Saffron crocus, Alicante saffron, Autumn crocus, Spanish saffron, true saffron.
Family:	Iridaceae.
Common Names:	**French**: safran; **German**: safran; **Italian**: zafferano; **Spanish**: azafran; **Arabic**: zafaran; **Hindi**: kesar.

Introduction

History

While pepper is the king of spices, saffron is the queen. Saffron was known to the ancient Middle Eastern civilizations of Assyria and Babylon, because the name *krokos* predates Greek. Saffron derives its name from the Arab word "*zaafaran*" meaning yellow. Oils scented with cassia, cinnamon, and saffron were used to anoint the kings during the days of the Egyptian Pharaohs. In the palace of Minos on Crete, there is a painted fresco dated to about 1650 BC, while on the neighboring island of Santorini is another one dated to 1500 BC. Sargon, founder of Accadian Empire, was born at an unknown village, the City of Saffron, "Azupirano", near the river Euphrates in Babylon. "Krokos" was the Greek word for saffron and appears in the songs IX and XII of the Iliad by Homer. The Persians, Greeks, and Romans valued saffron and used it to color and spice foods, saffron water to perfume their baths, houses, temples, and as a narcotic. In Greek mythology, Krokos, the lover of nymph Esmilax, was transformed into the plant saffron by Hermes. It is mentioned in the Ain-i-Akbari of AD 1590, by Abdul Fazi. Iran has been a major producer of saffron since the Persian times, and exported it to the Yuen dynasty in China (AD 1280–1368), where it was called *sa-fa-lang*. The Arabs introduced it into Spain and

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Portugal, which became major producers in Europe and saffron got to be the Alicante or Valencia crocus. John Gerard, states: "For those at death's door and almost past breathing, saffron will bringeth forth breath again". According to Richard Hakluyt (1552–1616), traveler and historian, saffron was introduced into England in the fourteenth century, during the reign of King Edward III, by a pilgrim who hid the corms in his staff. Saffron was grown at Saffron Walden, Essex, by growers known as "crockers", and later in Cambridgeshire till the end of the eighteenth century. The spice traders were commonly called "saffron grocer". The household notes of Dame Alice de Bryene (AD 1418–1419) state "three quarters of a pound of saffron bought from Stourbridge Fair"; during this period, one pound of saffron was sold at the same price as a horse or a cow. Saffron was cultivated in Spain in the ninth century AD, and in France and Germany in the twelfth century. Persons convicted of adulteration of saffron during the fifteenth century were either burned or buried alive. It was cultivated in Spain, North Africa, Turkey, southern Russian republics, Iran, Kashmir, and China. Saffron was the source of the deep yellow dye, used by Greeks and Chinese to color robes of rulers, and to dye the hair of ladies at the court of Henry VIII. The Buddhist monks use it on their robes. Its production in Pennsylvania, USA, still continues. According to Song of Solomon (Chapter 4: 13–14), saffron was one of the proclaimed spices: "Thy plants are an orchard of pomegranates, with pleasant fruits; camphire with spikenard, spikenard and saffron; calamus and cinnamon, with all trees of frankincense; myrrh and aloes, with all the chief spices".

Producing Regions

Saffron's exact origin is unknown. It is believed to have originated in Asia Minor, and ultimately to China and Japan. Major producing countries include China, France, Spain, Turkey, Morocco, Greece, Iran, and India. The most prized saffron comes from Iran and Kashmir, India.

Botanical Description

Saffron is a small bulbous, perennial herb up to 30 cm (1 ft) high, with a large fleshy corm. The corms are generally 3–5 cm in diameter, producing basal gray-green leaves. The flowers are produced in fall and are funnel shaped. They are very fragrant, and the color is variable depending on the region; usually the throat is whitish, segments reddish-purple to dark lilac or blue, very rarely white. The flowers are hermaphrodite (have both male and female organs) and are pollinated by bees and butterflies. The seeds are small, dark brown, globose, and papillose. The bright red stigma color is due to crocin. Almost 100,000–200,000 flowers or 5 kg fresh stigmas and styles are required to produce 1 kg of dried saffron.

Parts Used

Dried flower stigmas (color brilliant red not yellow) are the parts used and it is sold as whole threads or ground.

Flavor and Aroma

Saffron has a strong, tenacious perfume. It has a warm floral bouquet and has a strong perfume, with a pungent bittersweet taste reminiscent of honey and bitter back notes. The orange and red varieties from India have stronger flavors.

Active Constituents

Active constituents of saffron include moisture 8.5–9.5%, starch 13%, fixed oil 8–13%, total ash 1.2%, essential oil 0.4–1.5%, 2% picrocrocin, crocin (Hadizadeh et al. 2010), carotenoids, flavonoids, and vitamins B_1 and B_2. Saffron is a rich source of vitamin B_2. Lauric acid, hexadecanoic acid, 4-hydroxydihydro-2(3H)-furanone, and stigmasterol are the common constituents of the perianth, stamen and corm (Zheng et al. 2011). Crocin, crocetin, picrocrocin, safranal, and stigmasterol are the important constituents. The other constituents reported are catechol, vanillin, salicylic acid, cinnamic acid, *p*-hydroxybenzoic acid, gentisic acid, syringic acid, *p*-coumaric acid, gallic acid, *t*-ferulic acid, and caffeic acid (Esmaeili et al. 2011). The nutritional constituents of saffron are given in Table 49.1.

Preparation and Consumption

Saffron is used mainly as a coloring agent and as a flavoring agent. It has a wide range of use in cream or cottage cheese, chicken and meat, rice, mayonnaise, and liquors. It is used as a domestic spice and is used in Spanish and French cooking. It is used to color a great range of food products including rice (festive Indian pilaus and risotto Milanese), cheese and fish dishes, especially bouillabaisse. It is a common ingredient in Mediterranean and Arabian foods. Saffron is added to nonalcoholic beverages, baked goods, ice creams, condiments, and meats and is an ingredient of vermouths and bitters. Vinegar flavored with saffron, garlic, and thyme gives a unique flavor to marinades and salads. In England, it is known for its use in Cornish saffron buns where it is paired with dried fruit in a yeast cake. It is an important ingredient in the fish-based dishes of Mediterranean, like the zarzuela de pescado from Spain and bouillabaisse from France. Special Christmas buns and breads with saffron have been traditional in Sweden. Saffron is also used as perfume and in cosmetics.

Table 49.1 Nutrient composition of saffron

Nutrient	Units	Value per 100 g
Water	g	11.90
Energy	kcal	310
Protein	g	11.43
Total lipid (fat)	g	5.85
Carbohydrate, by difference	g	65.37
Fiber, total dietary	g	3.9
Calcium, Ca	mg	111
Vitamin C, total ascorbic acid	mg	80.8
Vitamin B_6	mg	1.010
Vitamin B_{12}	mcg	0.00
Vitamin A, RAE	mcg_RAE	27
Vitamin A, IU	IU	530
Vitamin D	IU	0
Fatty acids, total saturated	g	1.586
Fatty acids, total monounsaturated	g	0.429
Fatty acids, total polyunsaturated	g	2.067

Source: USDA National Nutrient Database for Standard Reference, Release 24 (2011)

Medicinal Uses and Functional Properties

Saffron is considered anodyne, antidepressant, antispasmodic, antistress, appetizer, emmenagogue, expectorant, sedative, aphrodisiac, chemopreventive, diaphoretic, and immunomodulatory (Duke 1985; Sarris et al. 2011; Srivastava et al. 2010; Dwyer et al. 2011; Halataei et al. 2011; Hooshmandi et al. 2011; Ghazavi et al. 2009; Pitsikas et al. 2008; Kianbakht and Ghazavi 2011; Samarghandian et al. 2011). It is used to treat coughs, whooping cough, stomach gas, gastrointestinal colic, and insomnia, and in China for depression, shock, and to ease childbirth. Saffron has also been found to accelerate wound healing in burn injuries (Khorasani et al. 2008).

Crocin, an important compound from saffron, has been reported to be a promising cancer therapeutic agent (Escribano et al. 1996), protect retinal photoreceptors against light-induced cell death (Laabich et al. 2006), have antitussive activity (Hosseinzadeh and Ghenaati 2006), have potential haemorrhagic shock treatment (Yang et al. 2006), have hypolipidemic effect (Sheng et al. 2006), antidepressive activity (Wang et al. 2010), and enhancing effect on memory (Pitsikas et al. 2007). Crocin was found to have significant antitumor (Bakshi et al. 2009) and anti-inflammatory activities (Xu et al. 2009). Saffron extract and trans-crocetin were found to inhibit glutamatergic synaptic transmission in rat cortical brain slices (Berger et al. 2011). Hosseinzadeh et al. (2008a) found crocin and an aqueous extract of saffron to have aphrodisiac activity when tested on male rats. Saffron extract and crocin were reported to significantly inhibit the growth of colorectal cancer cell lines and have no effect on the normal cells, suggesting its beneficial role in the treatment of colorectal cancer (Aung et al. 2007). Mousavi et al. (2011)

reported that crocin and its liposomes could cause cell death in HeLa and MCF-7 cells, in which liposomal encapsulation improved cytotoxic effects. They could be also considered as a promising chemotherapeutic agent in cancer treatment.

Crocetin, a carotenoid compound from saffron, has been shown to inhibit tumor promotion (Wang et al. 1995), is hepatoprotective (Wang et al. 1991), has neuroprotective potential (Ahmad et al. 2005), exerts anti-inflammatory effects (Hosseinzadeh and Younesi 2002), and is beneficial in cardiac diseases (Shen et al. 2006). In a recent clinical study, crocetin showed attenuating effects on physical fatigue (Mizuma et al. 2009). The antioxidant potential of crocetin may contribute to these pharmacological actions. Crocetin has a protective effect on bladder toxicity induced by cyclophosphamide, improves cerebral oxygenation in hemorrhaged rats, and strongly acts in atherosclerosis and arthritis treatment (Giaccio 2004). Dhar et al. (2009) studied the role of crocetin in pancreatic cancer growth both in vitro and/or in vivo. Their results suggest that crocetin had a significant antitumorigenic effect in both in vivo and in vitro on pancreatic cancer. The methyl methanesulfonate (MMS)-induced DNA damage in multiple mice organs was decreased by pretreatment with aqueous extract of saffron (Hosseinzadeh et al. 2008b). Furthermore, crocin significantly decreased DNA damage in a dose-dependent manner. Das et al. (2010) studied the effect of aqueous saffron extract on chemically induced skin carcinogenesis in mice using a histopathological approach. They found a beneficial action of saffron in mice where saffron treatments were given both before and after induction of skin carcinogenesis. In a separate study, crocetin exhibited a good membrane stabilizing activity (Gadgoli and Shelke 2010). Crocin and safranal were found to have hypotensive properties (Imenshahidi et al. 2010). Crocetin is a potential anticancer agent, which may be used as a chemotherapeutic drug or as a chemosensitizer for vincristine (Zhong et al. 2011). Crocetin was shown to reduce the activation of hepatic apoptotic pathways and improve survival in experimental hemorrhagic shock (Yang et al. 2011). Crocetin inhibited MDA-MB-231 cell invasiveness via downregulation of MMP expression (Chryssanthi et al. 2011). Amin et al. (2011) showed that saffron exerted a significant chemopreventive effect against liver cancer by inhibition of cell proliferation and induction of apoptosis. They also reported some evidence that saffron protected rat liver from cancer by modulating oxidative damage and suppressing inflammatory response.

Antioxidant Properties

Saffron has been found to have strong antioxidant properties (Martínez-Tome et al. 2001; Assimopoulou et al. 2005; Saleem et al. 2006; Pellegrini et al. 2006; Papandreou et al. 2006; Keyhani and Keyhani 2006; Kanakis et al. 2007, 2009; Termentzi and Kokkalou 2008; Sengul et al. 2009; Hasani-Ranjbar et al. 2009; Ordoudi et al. 2009; Hosseinzadeh et al. 2009; Gallo et al. 2010; Goyal et al. 2010; Joukar et al. 2010; Karimi et al. 2010; Shukurova and Babaev 2010; Sharifi and Ebrahimzadeh 2010; Esmaeili et al. 2011; Zheng et al. 2011).

Saffron dissolved in milk and fed to 20 human subjects decreased the lipoprotein oxidation susceptibility in both healthy individuals and patients of CAD (Verma and Bordia 1998). An aqueous extract of saffron was found to reduce lipid peroxidation and increase liver enzymatic (SOD, CAT, GST, GPx) and nonenzymatic antioxidants in animals pretreated with saffron compared to genotoxin alone treated animals (Premkumar et al. 2003). This chemopreventive effect of saffron is because of the modulation of lipid peroxidation, antioxidants, and detoxification systems. Ochiai et al. (2004) found crocin to inhibit the formation of peroxidized lipids, restore SOD activity, and maintain neurons morphology in PC-12 cells, and these antioxidant effects of crocin were more efficient than the alpha-tocopherol suggesting its role as a potent antioxidant to combat oxidative stress in neurons. Ochiai et al. (2007) showed crocin to have strong neuroprotective potency and promoted mRNA expression of gamma-glutamylcysteinyl synthase which has been shown to contribute to GSH synthesis as the rate-limiting enzyme. Assimopoulou et al. (2005) found a methanol extract of saffron, crocin, and safranal from saffron to have high radical scavenging activity. The aqueous extract of saffron was able to reduce lipid peroxidation and increase antioxidant power in ischemia–reperfusion injured rat kidneys. Crocin, in addition to reducing lipid peroxidation and elevating antioxidant power, also increased the thiol concentrations as compared to control group (Hosseinzadeh et al. 2005). Zheng et al. (2007) studied the effect of crocin on ischemia/reperfusion (I/R) injury in mice cerebral microvessels and found that pretreatment with crocin significantly inhibited the oxidizing reactions and modulated the ultrastructure of cortical microvascular endothelial cells (CMEC) in mice with 20 min of bilateral common carotenoid artery occlusion followed by 24 h of reperfusion in vivo. Safranal was found to efficiently increase the total sulfhydryl concentrations and antioxidant capacity and decline the MDA level in hippocampus in comparison to the ischemic group (Hosseinzadeh and Sadeghnia 2005). Saffron stigma extract was found to attenuate all the changes induced by ischemia in rats and this is most probably due to its strong antioxidant property (Saleem et al. 2006). The water:ethanol extract of saffron stigmas was found to inhibit Abeta fibrillogenesis and has strong antioxidant activity (Papandreou et al. 2006). Asdaq and Inamdar (2010) evaluated the hypolipidemic and antioxidant potential of saffron and crocin in hyperlipidemic rats. They found both saffron and crocin to be very effective in decreasing the elevated levels of TG, TC, ALP, AST, ALT, MDA, GSHPx, GSH, and GSSG in serum, while increasing the SOD, CAT, FRAP, and SH levels in liver tissue with a reduction in TBARS. The saffron was found better than crocin, suggesting the role of other constituents in saffron for the synergistic action of quenching free radicals and ameliorating the damages of hyperlipidemia. Goyal et al. (2010) studied the effect of crocin in isoproterenol (ISO)-induced cardiotoxicity in rats with reference to antioxidant, hemodynamic, histopathological, and ultrastructural parameters. Crocin was shown to significantly modulate hemodynamic and antioxidant derangements. The histopathological and ultrastructural examinations confirmed the preventive role of crocin on ISO-induced MI. These results suggest the modulation of oxidative stress by crocin in a way that maintains the redox status of the cell. Mousavi et al. (2010) in their studies found glucose to reduce the cell viability of

PC12 cells after 4 days, and glucose toxicity was consistent with ROS production which was reduced by saffron, crocin, and GSH treatments. Thus, saffron and crocin could be useful in diabetic neuropathy treatment. Saffron extract and crocin were shown to improve spatial cognitive abilities following chronic cerebral hypoperfusion and these effects may be related to the antioxidant effects of these compounds (Hosseinzadeh et al. 2012). Gallic acid and pyrogallol in the methanol extract of saffron were found to have strong antioxidant activity (Karimi et al. 2010). The stamen ether fraction displayed the strongest antifungal and cytotoxic activities, whereas both the saffron stamen and perianth ether fractions exhibited significant antioxidant activities. Thus, saffron stamen, perianth, and stigma possess significant antifungal, cytotoxic, and antioxidant activities (Zheng et al. 2011). Saffron and its active constituent crocin were found to prevent the impairment of learning and memory as well as the oxidative stress damage to the hippocampus induced by chronic stress (Ghadrdoost et al. 2011).

Crocetin, a carotenoid found in saffron, has been found to enhance the oxygen diffusivity through liquids such as plasma. Because of its antioxidant activity, it has an inhibitory effect on the intracellular nucleic acid and protein synthesis in malignant cells, as well on protein kinase C and prorooncogene in INNIH/3T3 cells (Giaccio 2004). The cardioprotective effects of crocetin are related to the modulation of endogenous antioxidant enzyme activities, and this is because crocetin was shown to markedly reduce lipid peroxidation and increase the activities of GSH-Px and SOD in cardiac hypertrophy (Shen and Qian 2006). Magesh et al. (2006) found crocetin treatment to bring the increased levels of LPO and marker enzymes in carcinogen administered animals back to normal. The changes associated with high fructose diet in male Wistar rats were effectively normalized in crocetin-treated rats, suggesting crocetin treatment as a preventive strategy of insulin resistance and related diseases (Xi et al. 2007a, b). Yang et al. (2008) found crocetin to inhibit platelet aggregation induced by ADP and collagen in a dose-dependent manner, and prolonged occlusive time in electrical stimulation-induced carotid arterial thrombosis. Both crocin and crocetin were found to provide neuroprotection by reducing the production of various neurotoxic molecules from activated microglia (Nam et al. 2010). Crocetin blocked inflammatory cascades by inhibiting reactive oxygen species production and preserving T-SOD activity to ameliorate the cardiac injury caused by hemorrhage/resuscitation (Yan et al. 2010). Papandreou et al. (2011) studied the effects of a daily, 7-day intraperitoneal administration of saffron on cognitive functions in both healthy adult (4 months old) and aged (20 months old), male Balb-c mice ($n = 8$/group) by passive avoidance test. Whole brain homogenates (minus cerebellum) were collected for examination of brain oxidative markers, caspase-3 and acetylcholinesterase (AChE) activity. Results showed that saffron-treated mice exhibited significant improvement in learning and memory, accompanied by reduced lipid peroxidation products, higher total brain antioxidant activity, and reduced caspase-3 activity in both age groups of mice. Furthermore, salt- and detergent-soluble AChE activity was significantly decreased only in adult mice. Thus, they showed, for the first time, that the significant cognitive enhancement conferred by saffron administration in mice is more closely related to the antioxidant reinforcement.

They compared the effect of saffron (1–250 μg mL^{-1}), crocetin, and safranal (1–125 μM) on H_2O_2-induced toxicity in human neuroblastoma SH-SY5Y cells. Both saffron and crocetin provided strong protection in rescuing cell viability (MTT assay), repressing ROS production (DCF assay) and decreasing caspase-3 activation. These data, together with earlier studies, suggest that crocetin is a unique and potent antioxidant, capable of mediating the in vivo effects of saffron. Crocetin was shown to exhibit protective effects against retinal damage in vitro and in vivo, suggesting that the mechanism may inhibit increases in caspase-3 and -9 activities after retinal damage (Yamauchi et al. 2011). Yoshino et al. (2011) demonstrated that crocetin exhibits antioxidant properties by scavenging ROS and that it may reduce oxidative stress induced by ROS generation in the isolated brain of stroke-prone spontaneously hypertensive rats. Moreover, crocetin might be able to prevent ROS-related brain diseases such as stroke.

Safranal, an active constituent of saffron because of its strong antioxidant and anti-apoptotic potential, could serve as an invaluable molecule in myocardial ischemia–reperfusion (IR) setting (Bharti et al. 2011).

Regulatory Status

GRAS 182.10 and GRAS 182.20.

Standard

ISO 3632-1 (Specification), ISO 3632-2 (Test methods).

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Chapter 50
Sage

Botanical Name: *Salvia officinalis* L.
Synonyms: Garden sage; English sage; True sage; Dalmatian sage.
Family: Lamiaceae (Labiatae).
Common Names: **French**: Sauge officinale; **German**: Salbei; **Italian**: Salvia officinale; **Spanish**: Salvia officinale.

Introduction

History

"The desire of sage is to render man immortal", instructs a late medieval treatise. "How can a man grow old who has sage in his garden?" is the substance of an ancient proverb much quoted in China and Persia and parts of Europe. It was so valued by the Chinese in the seventeenth century that Dutch merchants found the Chinese would trade three chests of China tea for one of sage leaves. The name *salvia*, from the Latin *salvere*, to be in good health, to cure, reflects its benevolent reputation. In French, the word "sage" means wise. To the Romans it was a sacred herb gathered with ceremony. The appointed person would make sacrifices of bread and wine, wear a white tunic, and approach with feet bare and well washed. Greeks called it *elifagus*, which became the Greek *sphakos* and later, *sawge* in Old English. To assure good health, the English toasted with, "He that would live for aye, Must eat Sage in May" as they drank an ale made of sage, betony, spikenard, squinnette, and fennel seed. The Chinese also valued sage (Shu-wei-ts'ao), eagerly trading their black tea for it. In the ninth century, Charlemagne had sage included among the herbs grown on the Imperial farms in Germany. The term "sage advice" most probably started in England where sage tea or sage with other brews was regularly used with a belief that sage made one strengthened and prudent. Gerard recommended sage be given to seniors to keep them vigorous. Sage was also known as *herba sacra*, meaning "sacred herb".

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Producing Regions

Sage is indigenous to the northeastern Mediterranean region and southern Europe. It is cultivated worldwide. Commercial cultivation is mainly in Eastern Europe, Asia, USA, and South Africa. Dalmatian sage oil is produced mainly in Yugoslavia. Smaller quantities distilled in France, Bulgaria, Germany, and Turkey.

Botanical Description

Sage is an evergreen shrub, perennial up to 80-cm (2 ft) high. It has long spindle-shaped root, woody stalk with straight branches, opposite silver oval wooly leaves, and large attractive violet flowers. The leaves are grayish-green to slightly silvery-green, shiny, covered with fine hairs, and oblong or spear shaped.

Parts Used

Silver-grayish leaves. Leaves (dried or fresh—whole, chopped, minced, finely ground, cut, or rubbed), essential oil, oleoresin. The essential oil is obtained by steam distillation of the partially dried leaves. The oil is clear, colorless to pale yellow mobile liquid. Yield 2–3.6%. Dalmatian oil is different from the Spanish sage oil which is obtained from *S. lavendulaefolia* Vahl and has a different oil composition.

Flavor and Aroma

The dried leaves are strongly aromatic, sweet, herbaceous, and spicy. It is strongly aromatic, sweet, characterized by a medicinal, lemony and bitter flavor. The taste is bitter, fragrant warm, and astringent.

Active Constituents

Essential oil, estrogen like substances, flavonoids, carotenoids, organic acids. The major constituents in essential oil are α-thujone (15–43%) β-thujone (3–9%), camphor (4–24%), 1,8-cineol (10%), camphene, α-pinene, β-pinene, limonene, α-humulene, β-caryophyllene, and borneol. The major phenolic compounds of sage are rosmarinic acid, caffeic acid, carnosol, and carnosic acid. The nutritional constituents and ORAC values of ground sage are given in Table 50.1

Table 50.1 Nutrient composition and ORAC values of sage ground

Nutrient	Units	Value per 100 g
Water	g	7.96
Energy	kcal	315
Protein	g	10.63
Total lipid (fat)	g	12.75
Carbohydrate, by difference	g	60.73
Fiber, total dietary	g	40.3
Sugars, total	g	1.71
Calcium, Ca	mg	1,652
Vitamin C, total ascorbic acid	mg	32.4
Vitamin B-6	mg	2.690
Vitamin B-12	mcg	0.00
Vitamin A, RAE	mcg_RAE	295
Vitamin A, IU	IU	5,900
Vitamin D	IU	0
Vitamin E (alpha-tocopherol)	mg	7.48
Fatty acids, total saturated	g	7.030
Fatty acids, total monounsaturated	g	1.870
Fatty acids, total polyunsaturated	g	1.760
H-ORAC	μmol TE/100 g	98,714
L-ORAC	μmol TE/100 g	21,214
Total-ORAC	μmol TE/100 g	119,929
TP	mg GAE/100 g	4,520

Source: USDA National Nutrient Database for Standard Reference, Release 24 (2011)

Preparation and Consumption

Sage is used in foods for seasoning and flavor. It is a popular spice in Italy, Greece, and other regions of Europe. Sage is mixed with onion for poultry seasoning. It is used with pork, duck, sausage, and fish. Wrap around tender liver and saute in butter; blend into cheeses. Make sage vinegar and sage butter. Young leaves are eaten fresh in salads and cooked in omelets, fritters, soups, yeast breads and rolls, marinades, sausages, meat pies, and poultry stuffing. They are also used in cooking with liver, beef, pork, veal, lamb, fish, poultry, duck, goose, artichokes, tomatoes, asparagus, carrots, squash, corn, potatoes, eggplant, beans, leeks, onions, Brussels sprouts, cabbage, lentils. Sage is used in seasonings for fried chicken, pork sausage products, meat balls, pickles, gums, and nonalcoholic beverages. The French use it in charcuterie, sausages, and stuffings, and the Germans in eel soups.

Medicinal Uses and Functional Properties

It aids digestion and is antiseptic, antifungal and contains estrogen. Helps combat diarrhea. A sage tea after a meal benefits digestion. Sage tea is a good nerve and blood tonic. Tea reduces sweating, soothes coughs and colds. It is used to treat irregular menstruation and menopause. It is gargled for laryngitis and tonsillitis.

The in vitro models have shown *Salvia* as possibly being antiangiogenic, antimutagenic, antidiabetic, and gastroprotective (Lima et al. 2006; Mayer et al. 2009; Patenkovic et al. 2009; Keshavarz et al. 2010). Animal experiments and in vitro studies have substantiated that sage extracts may significantly decrease the serum glucose in diabetic rats (Eidi et al. 2005) and positively affect the antioxidant status of the liver (Lima et al. 2005). Polyphenols such as carnosol, carnosic acid, rosmanol, apigenin, hispidulin, caffeic acid, and ursolic acid have been discussed as the active compounds for these pharmacological effects (Imanshahidi and Hosseinzadeh 2006). A statistically significant effect of symptomatic relief in patients with acute pharyngitis was detected (Hubbert et al. 2006). The efficacy of sage for the treatment of hot flushes during menopause has been proven by a multicenter, open clinical trial (Bommer et al. 2009, 2011). In addition, sage combined with *Echinacea* was found to be efficacious in the treatment of acute sore throats (Schapowal et al. 2009). A double-blind, randomized, and placebo-controlled trial also indicated that sage may improve the symptoms of Alzheimer's disease (Akhondzadeh et al. 2003). The hydroalcoholic extract of sage presents significant anti-inflammatory and also antinociceptive effects on chemical behavioral models of nociception that involves an opioid mechanism. In addition, carnosol and ursolic acid/oleanolic acid appear to contribute for the antinociceptive property of the extract, possibly through a modulatory influence on TRPA1-receptors (Rodrigues et al. 2012). *Salvia officinalis* L. (sage) leaves have PPAR γ agonistic, pancreatic lipase and lipid absorption inhibitory, antioxidant, lipid peroxidation inhibitory and antiinflammatory effects and thus sage may be effective and safe in the treatment of hyperlipidemia (Kianbakht et al. 2011). *Salvia fruticosa* (Greek sage) extract and rosmarinic acid were reported to modulate the trafficking of intestinal Na^+/glucose cotransporter-1 (SGLT1) to the enterocyte brush-border membrane and thus may contribute to the control of plasma glucose (Azevedo et al. 2011).

Several compounds like carnosol, carnosic acid, oleanolic acid, ursolic acid, uvaol, betulinic acid, and betulin were found to have antimicrobial activity against vancomycin-resistant enterococci and *S. pneumoniae* and MRSA (Horiuchi et al. 2007a, b). The essential oil of sage showed strong antibacterial activity against *E. coli*, *S. typhi*, *S. enteritidis*, and *Shigella sonnei* and antifungal activity against six fungi (Bozin et al. 2007; Sokovic et al. 2010). Sage has the same antioxidants like rosemary which includes carnosic acid, carnosol, rosmanol, rosmadial, and rosmarinic acid (Cuvelier et al. 1994, 1996; Schwartz and Ternes 1992; Miura et al. 2002; Masuda et al. 2002, 2005; Matsingou et al. 2003; Iuvone et al. 2006; Rau et al. 2006). Alcoholic extracts of sage were reported to show potent scolicidal effects (Yones et al. 2011).

Plants and their extracts that have produced promising clinical data in dementia patients, with respect to cognition, include saffron (*Crocus sativus*), ginseng (*Panax* species), sage (*Salvia* species), and lemon balm (*Melissa officinalis*), although more extensive and reliable clinical data are required (Howes and Perry 2011).

Antioxidant Properties

Sage has strong antioxidant activity, antimicrobial activity, anticancer activity, antiproliferative, antidiabetic properties, and anti-inflammatory properties (Wang et al. 1999; Shahidi 2000; Beddows et al. 2000; Bandoniene et al. 2001; Triantaphyllou et al. 2001; Karakaya et al. 2001; Dauksas et al. 2001; Choi et al. 2002; Dragland et al. 2003; Campanella et al. 2003; Radtke et al. 2003; Blomhoff 2004; Lima et al. 2005; Qiao et al. 2005; Jaswir et al. 2005; Kennedy and Scholey 2006; Apak et al. 2006; Aherne et al. 2007; Bozin et al. 2007; Dragan et al. 2007; Hayouni et al. 2008; Buyukbalci and El 2008; Dearlove et al. 2008; Ayadi et al. 2009; Brandstetter et al. 2009; Ryan et al. 2009; Xavier et al. 2009; Bulku et al. 2010; Ciesla and Waksmundzka-Hajnos 2010; Giao et al. 2010; Karpinska-Tymoszczyk 2010; Lamien-Meda et al. 2010; Yi and Wetzstein 2010; Janicsak et al. 2011; Johnson 2011; Miguel et al. 2011; Mohamed et al. 2011; Rababah et al. 2011; Walch et al. 2011). The strong antioxidant and protective effect of sage leaf could be used for the treatment and prevention of degenerative diseases associated with oxidative stress. Sage tea was effective in the improvement of lipid profile, antioxidant defenses, and lymphocyte Hsp70 protein expression in human volunteers. Sage may also inhibit pro-oxidant-induced lipid peroxidation in rat brain and liver homogenates (Oboh and Henle 2009; Sa et al. 2009).

Sage extracts were better antioxidant than BHT in rapeseed oil oxidation process (Bandoniene et al. 2001). Carnosic acid and carnosol from sage substantially inhibited pancreatic lipase activity, while carnosic acid significantly inhibited triglyceride elevation in olive oil-loaded mice and reduced the gain of body weight and accumulation of epididymal fat in high fat diet-fed mice (Ninomiya et al. 2004). Rosmarinic acid from sage showed significant cytoprotective effect in vitro from OTA- and AFB(1)-induced cell damage and dose dependently attenuated radical oxygen species production and DNA and protein synthesis inhibition induced by toxins (Renzulli et al. 2004). Sage extract along with Melissa, St. John's Wort, and Buckwheat extracts significantly reduced the level of irradiation-induced lipid peroxidation (Trommer and Neubert 2005). Iuvone et al. (2006) reported the neuroprotective effect of sage against Abeta-induced toxicity, which validates the traditional use of sage in the treatment of Alzheimer's disease. Sage has been shown to attenuate cognitive declines in sufferers from Alzheimer's disease and as such may well provide effective and well-tolerated treatments for dementia, either alone or in combination with conventional treatments (Kennedy and Scholey 2006). Sage increased the GSH content in Caco-2 cells and HeoG2 cells (Aherne et al. 2007; Lima et al. 2007) and afforded protection against H_2O_2-induced cytotoxicity in Caco-2 cells (Aherne et al. 2007). Carnosic acid, a phenolic compound found in sage and rosemary

was found to have anti-inflammatory properties and prevent migration of human aortic smooth muscle cells by suppressing matrix metalloproteinase-9 expression through down-regulation of NF-kappaB (Yu et al. 2008). Carnosic acid and carnosol were found to attenuate the formation of ROS and secretion of human leukocyte elastase, and inhibit the formation of pro-inflammatory leukotrienes in intact PMNL (Poeckel et al. 2008). Polysaccharides (crude and purified fractions) isolated from aerial parts of sage inhibited liposome lipid peroxidation (Capek et al. 2009). Sage grown under greenhouse conditions showed higher TPP and TEAC than those grown under normal field conditions (Yi and Wetzstein 2010). Sage showed the highest antioxidant activity (91%) among the common Mediterranean plants (Rababah et al. 2011). The aqueous extracts of rosemary and sage were the richest in phenolic compounds and showed the highest ability in binding iron and inhibiting DPPH, superoxide radicals and advanced glycation end-product production, lipid peroxidation, and the activity of α-glucosidase and α-amylase. Therefore, these spices may be preventive not only against cardiovascular diseases but also type 2 diabetes (Cazzola et al. 2011). Sage extract was shown to minimize lipid oxidation, improve color, and decrease off-odor production in irradiated ground beef (Mohamed et al. 2011). A few pharmacological activities of sage attributed to Alzheimer's disease (Howes et al. 2003; Obulesu and Rao 2011) have pointed towards the antioxidant activity (Hohmann et al. 1999), anti-inflammatory effects (Baricevic et al. 2001), and cholinesterase inhibition (Perry et al. 1996).

Regulatory Status

GRAS 182.10 and GRAS 182.20.

Standard

ISO 11165.

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Chapter 51
Savory

Botanical Name: *Satureja hortensis* L.
Synonyms: *Calamintha hortensis* Hort., summer savory.
Family: Lamiaceae (Labiatae).
Common Names: **French**: sarriette des jardin; **German**: bohnenkraut; **Italian**: santoreggia; **Spanish**: saborija.

Introduction

History

Savory has been used to enhance the flavor of food for over 2,000 years. The genus name *Satureja* is attributed to the Roman writer Pliny, and is derived from the word for "satyr," the half-man, half-goat creature that roamed the ancient mythological forests. Legend has it that the savories belonged to the satyrs. The Romans used it extensively in their cooking. The poet Virgil suggested growing savory near beehives, because of the great tasting honey it produced. The Romans introduced savory to England during Caesar's reign, and it quickly became popular as a medicine and also as a cooking herb. Because of its pungent, spicy taste, the Saxons named it savory. The Italians are probably the first to grow savory as a garden herb. Herbalist Nicholas Culpeper, in the seventeenth century, wrote that the savories were valuable for their "heating, drying and carminative (action), expelling wind from the stomach and bowels, and are good in asthma and other affections of the breast." He also said that "it is much commended for pregnant women to take inwardly and to smell often unto." William Shakespeare, in his *The Winter's Tale*, mentions savory along with lavender and marjoram. Banckes's *Herbal* states: "It is forbidden to use it much in meats since it stirreth him to use lechery." The herbalist John Parkinson, in the seventeenth century, wrote how savory was dried and powdered and mixed with bread

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crumbs “to breade their meate, be it fish or flesh, to give it a quicker relish.” American settler John Josselyn wrote about savory in his book *New England Rarities*, in 1672. Cresentius recommended savory “as a purgative, as a remedy in complaints of the liver and lungs, and as a bleach for a tanned complexion.” The Germans called savory the herb bean because it complemented green beans, dried beans and lentils so well.

Producing Regions

It is native to Europe. It is now cultivated in Spain, Germany, other parts of Europe, Canada, and USA. In India it is cultivated in Kashmir. Spain, Albania and Yugoslavia are the major producers. The Yugoslavian savory is considered premium grade. The savory used in USA is the summer savory. Summer savory is cultivated throughout the Mediterranean region and France. Winter savory (*Satureja montana* L.) grows wild in southern Europe.

Botanical Description

Summer savory is an annual herbaceous plant up to 30 cm (0.5 ft) high, with small erect stems. The branches are pink, and the leaves are elliptical, leathery, petiolate, and dark green. The stem is covered with short and decurved hairs. The flowers are fragrant, white, pink, or lilac, and appear in small spikes in the leaf axils. It has well-developed taproot. The other savory is the winter savory (*Satureja montana* L.).

Parts Used

The parts used include the fresh or dried leaves and tender stems. The bright green leaves are used as spice. The flowering tops are used for oil extraction. Savory leaves are used whole or crushed.

Flavor and Aroma

Leaves have a strongly aromatic, sweet, spicy ,and herbaceous aroma. The taste is strongly aromatic, sweet, peppery thyme. The herb has a thyme-like flavor.

Table 51.1 Nutrient composition and ORAC values of savory ground (*Satureja hortensis*)

Nutrient	Units	Value per 100 g
Water	g	9.00
Energy	kcal	272
Protein	g	6.73
Total lipid (fat)	g	5.91
Carbohydrate, by difference	g	68.73
Fiber, total dietary	g	45.7
Calcium, Ca	mg	2,132
Vitamin C, total ascorbic acid	mg	50.0
Vitamin B-6	mg	1.810
Vitamin B-12	mcg	0.00
Vitamin A, RAE	mcg_RAE	257
Vitamin A, IU	IU	5,130
Vitamin D	IU	0
Fatty acids, total saturated	g	3.260
Savory fresh		
H-ORAC	μmol TE/100 g	9,465
Total-ORAC	μmol TE/100 g	9,465
TP	mg GAE/100 g	227

Source: USDA National Nutrient Database for Standard Reference, Release 24 (2011)

Active Constituents

The leaves contain moisture 72%, protein 4%, fat 2%, sugar 5%, fiber 9%, ash 2%, minerals, and vitamins. Leaves also contain about 1% essential oil with carvacrol as the major component, and camphene, β-pinene, limonene, *p*-cymene, β-phellandrene, camphor and 1,8-cineole. The leaves also contain pentosans and labiatic acid, ursolic acid and beta-sitosterol. The nutritional constituents (ground) and ORAC (fresh) values of savory are given in Table 51.1.

Preparation and Consumption

Summer savory is popular in teas, herb butters, flavored vinegars, and with shell beans, lentils, chicken soups, creamy soup, beef soup, eggs, beans, peas, eggplant, asparagus, onions, cabbage, brussels sprouts, squash, garlic, liver, fish, and chutneys. It is one of the spices included in "fines herbes." It is used in commercial dry-soup mixes and gravy mixes. In the Mediterranean, savory is used for vegetables like beans, cabbage, lentils, potatoes, and mushrooms. The French use it as part of the bouquet garni blends. Savory is usually added at the end of cooking to preserve its flavor.

Medicinal Uses and Functional Properties

Tea can be used for diarrhea, stomach upsets, and sore throats. They are used as tonic, carminative, astringent, and expectorant in treating stomach and intestinal disorders. It is also used for insect bites.

Güllüce et al. (2003) found the essential oil of summer savory to have great potential for antimicrobial activities against all 23 bacteria and 15 fungi and yeast species tested. The antifungal activities of the essential oil, hydrosol, ground material, and extract of summer savory on mycelial growth of *Alternaria mali* Roberts and *Botrytis cinerea* Pers were studied by Boyraz and Ozcan (2006). They found all doses of the extract to inhibit 100% of the mycelial growth of both fungi, and exhibited a fungicidal effect (Boyraz and Ozcan 2006). The essential oil and methanol extract of summer savory showed strong antifungal activity against *Aspergillus flavus* based on the inhibition zone and minimal inhibitory concentration values (Dikbas et al. 2008). The essential oil was also found to be a potent inhibitor of aflatoxins B1 (AFB1) and G1 (AFG1) production by *Aspergillus parasiticus* (Razzaghi-Abyaneh et al. 2008). Carvacrol is a major component of the essential oil of summer savory, and it has diverse activities such as antimicrobial, antitumor, antimutagenic, antigenotoxic, analgesic, antispasmodic, anti-inflammatory, angiogenic, antiparasitic, antiplatelet, Ache inhibitory, antielastase, insecticidal, antihepatotoxic, and hepatoprotective activities (Baser 2008). The essential oil of summer savory inhibited the growth of periodontal bacteria in the concentration that is safe on keratinocytes (Gursoy et al. 2009).

Antioxidant Properties

The ground material, essential oil and both ethanol and acetone extracts of summer savory and winter savory possess strong antioxidant activity (Exarchou et al. 2002; Souri et al. 2004; Aristatile et al. 2009; Grosso et al. 2009; Burlakova et al. 2010; Gião et al. 2010; Kim et al. 2011). The major component of all ethanol extracts of sage was rosmarinic acid. The polar subfractions of the methanol extract of intact plant and methanol extract of callus cultures of savory reduced the stable free-radical DPPH to yellow-colored DPPH (Güllüce et al. 2003). The strongest effect was observed for the tissue culture extract, which could be compared with the synthetic antioxidant agent butylated hydroxytoluene (Güllüce et al. 2003). High hydrophilic antioxidant capacity and total phenolic content were found in summer savory and were highly correlated (Rodov et al. 2010).The essential oil and extracts of winter savory were shown to have strong potential for use as natural antioxidants and antimicrobials in the preservation of processed food (Cetojević-Simin et al. 2004; Serrano et al. 2011). The savory had good antioxidant activity and this was correlated with the phenolic and flavonoid compounds (Kim et al. 2011).

Regulatory Status

GRAS 182.10 and GRAS 182.20.

Standard

ISO 7928-1 (Winter savory), ISO 7928-2 (Summer savory).

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Chapter 52
Spearmint

Botanical Name:	*Mentha spicata* L.
Synonyms:	*Mentha viridis*; common spearmint; garden spearmint; green mint; lamb mint; pea mint; fish mint.
Family:	Lamiaceae (Labiatae).
Common Names:	**French**: Menthe crepue; **German**: Krauseminz; **Italian**: Menta crispa; **Spanish**: Menta crespa.

Introduction

History

Spearmint is believed to be the oldest of the mints. It is probably the mint mentioned in the Bible (Matthew 23: 23, Luke 11: 42). In Greek mythology, Minthe was a nymph beloved by Pluto, who transformed her into this scented herb after his jealous wife took drastic action. The Pharisees collected tithes in mint, dill and cumin. The Hebrews laid it on synagogue floors, and this idea was later practiced in Italian churches, where the herb is called Erba Santa Maria and Our Lady's mint in France. The Roman poet Ovid wrote of two peasants, Baucis and Philemon, who scoured their serving board with mint before feeding guests. Gerard wrote in 1597 "they strew it in rooms and places of recreation, pleasure and repose, where feasts and banquets are made". Japanese wore pomanders made of mint leaves. Throughout the ancient world, it was used to keep milk from curdling. The Romans used its aroma as an appetite stimulant, while in Greece it was used as an aphrodisiac. In the sixteenth century, it became *spere mynte*, to describe the spear-shaped flowers that distinguish it from many other mints.

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Producing Regions

Spearmint is thought to have originated in Europe. It is now cultivated throughout Asia, Europe, Middle East and the USA. Oil is produced mostly in the USA, England, France, Spain, Russia, India, China, and Germany.

Botanical Description

Spearmint is a perennial hardy branched plant with bright green, lance shaped, sharply toothed leaves, quickly spreading underground runners, and white flowers clustered in the form of spikes. Leaves are sessile, lanceolate, or ovate-lanceolate, smooth above and glandular below. The flowers are sharply pointed, long, and narrow. The plant is from 25 to 75 cm (10–30 in.) high.

Part Used

Parts used include leaves (fresh or dried) and essential oil. Dried leaf is sold as whole, as flakes, chopped, and fine or coarse. Fresh leaf is used raw, cooked, or pureed. The essential oil is obtained by steam distillation of the newly flowering tops, partially dried. The oil is a pale yellow to colorless mobile liquid. Yield is 0.7%.

Flavor and Aroma

Spearmint has a fresh, minty, weedy, aroma. Very aromatic, sweet, green, minty, cooling, slightly pungent with lemony and sweetish notes.

Active Constituents

The active constituents include essential oil, flavonoids (diosmin, diosmetin), phenolic acids and lignans. The major constituents in the essential oil are carvone (60%), limonene (20%), dihydrocarvone, β-bourbonene, β-caryophyllene, myrcene, and α-pinene. The nutritional constituents of dried spearmint leaf are given in Table 52.1.

Table 52.1 Nutrient composition of spearmint leaf dried

Nutrient	Units	Value per 100 g
Water	g	11.30
Energy	kcal	285
Protein	g	19.93
Total lipid (fat)	g	6.03
Carbohydrate, by difference	g	52.04
Fiber, total dietary	g	29.8
Calcium, Ca	mg	1,488
Vitamin C, total ascorbic acid	mg	0.0
Vitamin B-6	mg	2.579
Vitamin B-12	mcg	0.00
Vitamin A, RAE	mcg_RAE	529
Vitamin A, IU	IU	10,579
Vitamin D	IU	0
Fatty acids, total saturated	g	1.577
Fatty acids, total monounsaturated	g	0.210
Fatty acids, total polyunsaturated	g	3.257

Source: USDA National Nutrient Database for Standard Reference, Release 24 (2011)

Preparation and Consumption

Spearmint is used in teas, beverages, jellies, syrups, ice creams, confections, and lamb dishes. Mint is used in Afghanistani, Egyptian, Indian, and Mid-Eastern cuisines and spice blends such as chat masala, mint sauce, and green Thai curry. They garnish cold drinks and flavor candy (Facciola 1990). Middle easterners use chopped spearmint in yogurt dressings, salads, dips, grilled lamb, fish, and tea. Spearmint tea has been used in the treatment of fevers, headaches, digestive disorders, and various minor ailments. They are used in salads and cooked foods. Dried leaves are popular in Turkish and Iranian cooking. The essential oil is used for flavoring sweets, toothpastes, and chewing gums. In India, spearmint is ground with coconut, green chili, onion, and green mango to flavor chat masalas for chutneys and curries.

Medicinal Uses and Functional Properties

Spearmint leaf is used in much the same way as peppermint leaf to treat digestive complaints, but not for most of the other indications. The oil is used mainly for inhalation, to treat catarrh. It is incorporated in mouthwashes and toothpastes, as well as chewing gum.

Spearmint herb is anti-inflammatory, antispasmodic, carminative, diuretic, restorative, stimulant, and stomachic (Grieve 1984; Duke and Ayensu 1985; Pearson et al. 2010). Spearmint tea has been used to treat fever, headaches, digestive

disorders, and many other ailments (Foster and Duke 1990). The essential oil is used in folk remedies for cancer and macerated leaves to remedy tumors (Duke and Ayensu 1985).

The essential oil of spearmint exhibited antimicrobial properties against eight strains of both Gram-positive and Gram-negative bacteria (Sivropoulou et al. 1995), and *Staphylococcus aureus* and *E. coli* (Torres et al. 1996). The essential oil of spearmint showed strong antimicrobial, insecticidal, and antibacterial activities (Franzios et al. 1997; Hussain et al. 2010; Koliopoulos et al. 2010; Sokovic et al. 2010; Zu et al. 2010). Spearmint was also found to have nematicidal activity (Walker and Melin 1996). The essential oil and the constituent carvone exhibited remarkable fungicidal activities against four phytopathogenic fungi (Yegen et al. 1992). Adam et al. (1993) reported significant antifungal activity of the essential oil against human pathogens like *Malassezia furfur*, *Trichophyton rubrum* and *Trichosporon beigelii*. Thyme, rosemary, sage, spearmint, and peppermint extracts significantly inhibited SW-480 colon cancer cell growth, with sage extracts exhibiting the highest bioactivity. Some mixtures of different herbal extracts also showed combination effects on cancer cell growth. The inhibitory effects of peppermint + sage combinations at a 1:1 ratio were significantly higher than rosemary + sage combinations at 1:1 ratio, although peppermint extracts showed lower inhibition than rosemary extracts (Yi and Wetzstein 2011).

Antioxidant Properties

The ethanol extract of spearmint was found to be very active in retarding the autoxidation process for stabilization of sunflower oil (Marinova and Yanishlieva 1997). Caffeic acid, eriocitrin, luteolin, and rosmarinic acid from the aqueous extract of spearmint were identified as the dominant radical scavengers in different *Mentha* species, varieties, hybrids, and cultivars (Kosar et al. 2004). Spearmint extract was found to be an effective chemopreventive agent that possibly suppresses benzoyl peroxide (BPO) induced cutaneous oxidative stress, toxicity, and hyperproliferative effects in the skin of mice (Saleem et al. 2000). They found that the prophylactic treatment of mice with spearmint extract 1 h before the BPO treatment resulted in the diminution of BPO-mediated damage, and the susceptibility of cutaneous microsomal membrane to lipid peroxidation and hydrogen peroxide generation was significantly reduced. Water-soluble extracts of spearmint and other *Mentha* species showed significant antioxidative activities and the level of activity identified was strongly associated with the phenolic content (Dorman et al. 2003). Arumugam et al. (2006) studied the total antioxidant activity (TAA) and relative antioxidant activity (RAA) in hexane, chloroform, ethyl acetate, and water extracts of spearmint and compared it against standard antioxidants such as quercetin, β-carotene, L-ascorbic acid, and glutathione using ABTS*+ decolorization assay. The antioxidant activities of the different solvent fractions were closely related to the content of total phenolics present in them. The RAA of ethyl acetate fraction was 1:1 compared to

quercetin, but greater when compared to β-carotene, L-ascorbic acid, and glutathione. Choudhury et al. (2006) reported significant radical scavenging activity in diethyl ether extract of mint (40 μg L^{-1}). Similarly, a positive correlation between antioxidant activity and polyphenol content was found in water extract of spearmint, suggesting the antioxidant capacity to be due to their polyphenols (Kiselova et al. 2006; Hosseinimehr et al. 2007; Adam et al. 2009). Arumugam and Ramesh (2009) studied the antigenotoxic potential of an aqueous fraction of spearmint by measuring the frequency of micronucleated polychromatic erythrocytes in mice bone marrow, using 4-nitroquinoline-1-oxide (NQO) as the reference mutagen. They also quantified the level of lipid peroxidation (LPO) and antioxidant levels with liver tissue of the same mice to assess their antioxidant potential. Their conclusion from their results was that the aqueous fraction of spearmint mediates their antigenotoxic effects by the modulation of LPO and antioxidant enzymes. Greenhouse grown spearmint were shown to have higher TPP contents and antioxidant capacities, and also had selective inhibition of COX-2 activity suggesting it could be a very useful anti-inflammatory agent (Yi and Wetzstein 2010).

Ahmad et al. (2012) reported strong free radical scavenging (DPPH) potential in the methanolic extracts of spearmint. Spearmint infusions in water showed high antioxidant properties and this was found probably due to the high levels and synergy between phenolics, flavonoids, and ascorbic acid found in these samples (Guimaraes et al. 2011). The essential oil had antioxidant activity and exhibited strong sprout inhibition activity (Chauhan et al. 2011).

Regulatory Status

GRAS 182.10 and GRAS 182.20.

Standard

ISO 2256.

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Chapter 53
Tarragon

Botanical Name: *Artemisia dracunculus* L. "Sativa."
Synonyms: Estragon, French tarragon.
Family: Asteraceae or Compositae.
Common Names: **French**: estragon; **German**: estragon; **Italian**: estragone; **Spanish**: estragon.

Introduction

History

It was named *taragonica*, probably from the Arabic *tarkhun*. Two varieties are traded commercially: *A. dracunculus* cv. "sativa" or French tarragon and *A. dracunculus* or Russian tarragon. The French tarragon has the fine flavor that makes it superior. The species name, *dracunculus*, means "little dragon" in Latin, which changed to *herbe au dragon* in French and *dragoncello* in Italian. The modern name probably derives from a combination of its French and Arabic names. Some believe tarragon was named because of its supposed ability to cure the bites of venomous reptiles, while others believe the plant was so named because of its coiled, serpent-like roots. It is believed by historians that tarragon originated in Asia and was introduced to Spain in the mid-1100s by the invading Mongols. It has been mentioned by Avicenna in the thirteenth century and by Ibn-al-Baytar and Arabian herbalist, as a breath freshener that induces sleep, and a vegetable seasoning. French tarragon was brought to France in the fourteenth century, when St. Catherine visited Pope Clement VI, with herbs she had from her native Sienna. It still grows there today. The French began cultivating it for salad green, garnish for vegetables, and as flavoring agent in vinegar. They called it estragon. Since the sixteenth century tarragon became popular in Europe. The herbalist John Evelyn in the seventeenth century proclaimed that tarragon was beneficial for "head, heart and liver." Russia received French tarragon

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from Catherine the Great (1684–1724). French Queen Marie Antoinette (1755–1793), in preparation for her dinner, had the lady-in-waiting wear kid gloves while picking five perfect tarragon leaves every morning to marinate in five tea spoons of lemon juice. Tarragon is believed to have saved Great Britain's King George IV when he was Prince of Wales. His chef, the famous Marie Antoine Careme, put him on a diet with no other seasoning. The chef Careme was rewarded with a gold snuff box. According to Alexander Dumas, "there is no good vinegar without tarragon."

Producing Regions

It is believed to be native to western Asia and Europe (southern Russia). But now it is extensively cultivated throughout Europe (France, Germany and Italy, Yugoslavia), United States (California), Argentina, Mexico, Brazil, etc. France and California are the major producers.

Botanical Description

It is a green, nonhairy, perennial herb up to 1.2 m (3 ft) high, with narrow, pointed, smooth, shiny deep green leaves. It has a characteristic anise-like flavor. The leaves are linear, lanceolate, and smooth.

Parts Used

Leaves (green), aboveground herb, essential oil, and oleoresin. Fresh leaves are used whole, chopped, or minced. The dried leaves are used whole, crushed, or ground.

Flavor and Aroma

Tarragon has sweet, anise, or licorice-like aroma. Aromatic, sweet, licorice like with sharp, aromatic undertones. It is minty, earthy, and green.

Active Constituents

The herb contains an essential oil (0.25–1%), coumarins, flavonoids (rutin, quercetin), carotenoids, sterols, tannins, proteins, and phenolcarbonic acids. The active secondary metabolites are essential oils (0.15–3.1%), coumarins (>1%), flavonoids,

Table 53.1 Nutrient composition and ORAC values of tarragon dried

Nutrient	Units	Value per 100 g
Water	g	7.74
Energy	kcal	295
Protein	g	22.77
Total lipid (fat)	g	7.24
Carbohydrate, by difference	g	50.22
Fiber, total dietary	g	7.4
Calcium, Ca	mg	1,139
Vitamin C, total ascorbic acid	mg	50.0
Vitamin B-6	mg	2.410
Vitamin B-12	mcg	0.00
Vitamin A, RAE	mcg_RAE	210
Vitamin A, IU	IU	4,200
Vitamin D	IU	0
Fatty acids, total saturated	g	1.881
Fatty acids, total monounsaturated	g	0.474
Fatty acids, total polyunsaturated	g	3.698
Tarragon fresh		
H-ORAC	μmol TE/100 g	15,542
Total-ORAC	μmol TE/100 g	15,542
TP	mg GAE/100 g	643

Source: USDA National Nutrient Database for Standard Reference, Release 24 (2011)

and phenolcarbonic acids (Obolskiy et al. 2011). The major constituent in the essential oil is methyl chavicol (70–80%). The nutritional constituents (dried) and ORAC (fresh) values of tarragon are given in Table 53.1.

Preparation and Consumption

Tarragon is used primarily in flavoring vinegar, mustard, and pickles. It is used in alcoholic and nonalcoholic beverages, salads, pickles, fish, meat and meat products, chicken, frozen dairy desserts, and mayonnaise. It makes delicious herb butters and mustards. It is famous for how it flavors vinegar. It flavors the famous sauce Bearnaise (served with fish and lamb), *poulet a lestragon* (chicken in tarragon and cream sauce), and *chaudfroid* (whole chicken in chilled aspic sauce). It is the special ingredient in the world-famous Dijon mustard from France. It is also an important component of fines herbes and an optional ingredient in herbs de Provence of France. The oil is widely used in perfumes and colognes, alcoholic and nonalcoholic beverages, baked goods, vinegars, soup mixes, and salad dressings.

Medicinal Uses and Functional Properties

Traditionally, it has been used as a stomachic, diuretic, hypnotic, emmenagogue to treat toothache, improve digestion, and treating tumors. Tarragon has potential anti-inflammatory, hepatoprotective, and antihyperglycemic effects. *Artemisia* plants are important medicinal plants and have long been used in Chinese traditional medicines (TCM) to treat microbial infections, inflammatory diseases, diarrhea, gastric ulcer, malaria, hepatitis, cancer, and circulatory disorders (Tan et al. 1998a; Lee et al. 2003). Several phytochemical studies conducted on *Artemisia* plants have revealed the presence of coumarins, glycosides, sterols, polyacetylenes, monoterpenes, triterpenes, sesquiterpene lactones, flavonoids, polysaccharides, and essential oils (Tan et al. 1998a, b). Among flavonoid constituents, eupatilin, and jaceosidin got enormous attention due to their broad spectrum pharmacological activities including antiulcer, antiallergic, antidiabetic, antimutagenic, antiproliferative, anti-inflammatory, antioxidative, and anticancer activities (Yoon et al. 2011). The ethanol extract of tarragon (*Artemisia dracunculus*) was found to potently inhibit α-melanocyte-stimulating hormone (α-MSH) induced melanin production in B16 mouse melanoma cells. The two alkamide compounds, isobutyl (1) and piperidiyl (2) amides of undeca-2E,4E-dien-8,10-dynoic acid were good for melanin biosynthesis inhibition (Yamada et al. 2011). The antidiabetic compounds davidigenin, sakuranetin, 2′,4′-dihydroxy-4-methoxydihydrochalcone, 4,5-di-*O*-caffeoylquinic acid, 5-*O*-caffeoylquinic acid, and 6-demethoxycapillarisin were reported in tarragon. These results suggest a use of the extract of *A. dracunculus* for ameliorating diabetic complications (Logendra et al. 2006; Eisenman et al. 2011; Kheterpal et al. 2010; Wang et al. 2008, 2011). The ethanolic extract of tarragon was shown to significantly decrease blood glucose levels in both genetic and chemically induced murine models of diabetes. Moreover, the extract significantly decreased PEPCK mRNA expression in the streptozotocin (STZ)-induced diabetic rats. The extract also inhibited aldose reductase, an enzyme involved in many diabetic complications and the phenoxychromone and dihydrochalcone were identified as the specific polyphenolics responsible for most of the activity (Logendra et al. 2006; Ribnicky et al. 2006; Govorko et al. 2007). An ethanolic extract of tarragon was found to alleviate peripheral neuropathy in high fat diet-fed mice, a model of prediabetes and obesity developing oxidative stress and pro-inflammatory changes in the peripheral nervous system. It also blunted sciatic nerve and spinal cord 12/15-lipoxygenase activation and oxidative-nitrosative stress, without ameliorating hyperglycemia or reducing sciatic nerve sorbitol pathway intermediate accumulation. Thus, the extract could be a safe and nontoxic botanical extract for the treatment of diabetic peripheral neuropathy (Watcho et al. 2010, 2011).

Artemisinin, an important constituent in *Artemisia* species is currently the most effective means to treat and reduce the transmission rate of malaria. Artemisinin content was studied in various species of *Artemisia* including *A. dracunculus*. It has been recommended by WHO as a first-line treatment for uncomplicated malaria caused by *Plasmodium falciparum*. Artemisinin has also been demonstrated to be effective against other parasites including *Leishmania*, *Schistosoma*, *Toxoplasma,* and *Trypanosoma*, has antiviral and allelopathic activities and can be used in the

treatment of hepatitis B, and a range of cancer cell lines, including breast cancer, human leukemia, colon, and small-cell lung carcinomas. Moreover, it has also been shown to be especially effective in treating drug-resistant cancers (Efferth et al. 2001, 2002; Sadava et al. 2002; Mutabingwa 2005; Romero et al. 2005, 2006; Sen et al. 2007; Utzinger et al. 2007; Dunay et al. 2009; Li and Zhou 2010; Mannan et al. 2010; Nibret and Wink 2010).

Antioxidant Properties

The ethyl acetate and dichloromethane extracts of tarragon had high phenolic content and radical scavenging activities. The plant material after oil distillation exhibited higher phenolic content as well as antioxidant and radical scavenging activities than the nondistilled plant material (Parejo et al. 2002). The essential oil of tarragon exhibited potent antifungal activity at a wide spectrum on the growth of agricultural pathogenic fungi. It also showed antibacterial activities and some antioxidant and DPPH radical scavenging activities (Kordali et al. 2005). Methanolic extract of tarragon displayed a linear dose-dependent NO-suppressing effect and NO-scavenging ability. The inhibitory effect upon the iNOS protein level was almost equivalent to their suppressive effect upon NO production, thus suggesting that iNOS expression was the primary mechanism of action as regards it exerting NO-suppressing activity (Tsai et al. 2007). The essential oil of tarragon inhibited the growth of bacteria (*E. coli*, *S. aureus*, and *S. epidermidis*), yeasts (*C. albicans*, *Cryptococcus neoformans*), dermatophytes (*Trichophyton rubrum*, *Microsporum canis*, *M. gypseum*), *Fonsecaea pedrosoi*, and *Aspergillus niger*. The oils also showed antioxidant (β-carotene/linoleate model) and DPPH radical scavenging activities (Lopes-Lutz et al. 2008). Total phenolics in tarragon were found to be highly correlated with the FRAP values (Dearlove et al. 2008). The flavones eupatilin and jaceosidin found in the genus *Artemisia* have been shown to exhibit antiallergic, antitumor, anti-inflammatory, and antioxidant activities (Ji et al. 2010). Phenolic acids, flavones, flavanones, and flavonols present in the extracts of tarragon showed strong antioxidant activity, and the total phenol content correlated well with the antioxidant capacity measured by DPPH assay (Miron et al. 2011).

Regulatory Status

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Standard

ISO 7926

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Chapter 54
Thyme

Botanical Name:	*Thymus vulgaris* L.
Synonyms:	*T. aestivus*; *T. valentianus*; *T. webbianus*; *T. ilerdensis*; garden thyme; French thyme, common thyme.
Family:	Lamiaceae (Labiatae).
Common Names:	**French**: thym; **German**: Echter Thymian; **Italian**: timo; **Spanish**: tomillo.

Introduction

History

Thyme is very nearly the perfect useful herb. The Greek word *Thymos* means "courage or strength" and seems appropriate for the herb that is invigorating to the senses. Another possible word would be from the Greek term "to fumigate" as this herb was burned to chase stinging insects from the house. It was believed that a bed of thyme was a home to fairies. Thyme represented style and elegance to the early Greeks, chivalry in the Middle Ages, and the Republican spirit in France. It was in the early Middle Ages that Benedictine monks brought thyme to Central Europe and England. Thyme pillows were thought to relieve epilepsy and melancholy. From the fifteenth through the seventeenth centuries, thyme was used during the plague that swept Europe. During WW I, the essential oil was used as a battlefield antiseptic. Dioscorides (first century AD) mentions thyme as "Thymo," "Serpo," and "Zygis." The Egyptians used *tham*, "thyme" to embalm the dead. The Romans burned and spread thyme on the floor to keep venomous creatures away. They used thyme to flavor cheese. The famous wild thyme honey was made by the bees on Mt. Hymettus near Athens. St. Hildegard mentioned it as a treatment for leprosy and paralysis. Rudyard Kipling wrote of the "wind-bit thyme that smells like the perfume of the dawn in paradise."

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Producing Regions

Thyme is native to southern and southeastern Europe. It grows wild or cultivated in Spain, France, Italy, Yugoslavia, Greece, Central European countries, Turkey, Israel, Morocco, and North America. Distillation is undertaken mainly in Spain, France, Morocco, and Israel.

Botanical Description

A perennial, herbaceous shrub up to 45-cm (2 ft.) high with a woody root, much branched upright stem and spreading branches. It has small, evergreen, opposite, gray-green, oval, aromatic leaves, minutely downy, and gland-dotted. The flowers are pale purple, two-lipped with a hairy glandular calyx, borne with leaf-like bracts in loose whorls in axillary clusters.

Parts Used

Dried herb, dried leaves (grayish-green), essential oil, and oleoresin. Essential oil is obtained by steam and water distillation of the partially dried above ground plant parts. The oil is brownish-red, orange-red, grayish-brown mobile liquid. Yield 0.5–1.5%.

Flavor and Aroma

Warm and pungent, herbaceous, slightly floral aroma. Minty-green, hay-like, musty flavor.

Active Constituents

Essential oil, labiate tannins (up to 7%), several polymethoxyflavones, triterpenes (ursolic acid), and polysaccharides. The essential oil has thymol (30–75%), carvacrol, *p*-cymene, γ-terpinene, linalool, and 1,8-cineole. Several flavonoids and phenolic acids are present in thyme (apigenin, luteolin, diosmetin, naringenin, kaempferol, quercetin, hesperidin, caffeic acid, rosmarinic acid). The nutritional constituents and ORAC values of thyme are given in Table 54.1.

Table 54.1 Nutrient composition and ORAC values of thyme dried

Nutrient	Units	Value per 100 g
Water	g	7.79
Energy	kcal	276
Protein	g	9.11
Total lipid (fat)	g	7.43
Carbohydrate, by difference	g	63.94
Fiber, total dietary	g	37.0
Sugars, total	g	1.71
Calcium, Ca	mg	1,890
Vitamin C, total ascorbic acid	mg	50.0
Vitamin B-6	mg	0.550
Vitamin B-12	mcg	0.00
Vitamin A, RAE	mcg_RAE	190
Vitamin A, IU	IU	3,800
Vitamin E (alpha-tocopherol)	mg	7.48
Vitamin D	IU	0
Fatty acids, total saturated	g	2.730
Fatty acids, total monounsaturated	g	0.470
Fatty acids, total polyunsaturated	g	1.190
H-ORAC	μmol TE/100 g	137,720
L-ORAC	μmol TE/100 g	19,660
Total-ORAC	μmol TE/100 g	157,380
TP	mg GAE/100 g	4,470

Source: USDA National Nutrient Database for Standard Reference, Release 24 (2011)

Preparation and Consumption

The Benedictine monks added it to their famous elixir. It is used in chowders, sauces, tomatoes, gumbos, pickled beets, stews, and stuffings. It ranks as one of the fine herbs of French cuisine. Leaves and sprigs are used in salads as garnishes, and most famously in clam chowder, bouquets garnis, and French, Creole, and Cajun cuisines. It works great with beef, veal, eggs, lamb, poultry, fish, sausages, herbed butters, herbed mayonnaise, flavored vinegars, and lentils. It works well with carrots, eggplant, tomatoes, onions, cucumbers, mushrooms, asparagus, broccoli, beans, potatoes, spinach, corn, rice, and peas. It is an important herb in European cooking, especially southern areas, for stuffings, vegetable soups, mutton stews, fish, meat, and game. In the Middle East, thyme is present in spice mixture, zahtar from Jordan and dukkah from Egypt.

Medicinal Uses and Functional Properties

It is used to treat coughs, colds, bronchitis, inflammation of the upper respiratory tract, and gastrointestinal disturbances. It is locally applied against mucosal inflammation of mouth and throat and treating minor wounds. Thyme and thyme oil

are antibiotic, antispasmodic, anti-inflammatory, and antitussive. The oil is used in baths in cases of bronchial catarrh and itching skin.

The thyme extract and essential oils have been shown to have strong antibacterial, antimicrobial, and antifungal activities, anti-inflammatory activity, spasmolytic activity, and other functions (Deans and Ritchie 1987; Tantaoui-Elaraki and Beraoud 1994; Nelson 1997; Smith-Palmer et al. 1998; Horvath et al. 2011; Tornuk et al. 2011). Thyme leaf extract greatly reduced the minimum inhibitory concentration of tetracycline against MRSA, and the effective compound in the extract was found to be baicalein (Fujita et al. 2005). Thyme essential oil had great antibacterial activity against 13 bacterial strains and six fungi, even on multiresistant strains of *Pseudomonas aeruginosa* and *E. coli* (Bozin et al. 2006). The oils also had strong antifungal activity (Bozin et al. 2006). Braga et al. (2006a) found thymol from thyme oil to inhibit elastase and this suggests that it has great anti-inflammatory activity and could control the inflammatory processes present in many infections. Thyme methanol extracts showed strong linear dose-dependent NO-suppressing effect without any effect on cell viability (Tsai et al. 2007). The essential oils of rosemary, sweet basil, fennel, and summer savory were found to have good potential for use as an alternative to synthetic fungicides for the preservation and storage of table grapes (Abdollahi et al. 2012).

Antioxidant Properties

Thyme and thyme oil have strong antioxidative properties (Zheng and Wang 2001; Miura et al. 2002; Dapkevicius et al. 2002; Lee and Shibamoto 2002; Dragland et al. 2003; Vigo et al. 2004; Grande et al. 2004; Agbor et al. 2005, 2007; Apak et al. 2006; Mello et al. 2006; Kivilompolo and Hyötyläinen 2007; Chizzola et al. 2008; Figueiredo et al. 2008; Wang et al. 2008; Undeğer et al. 2009; Ayadi et al. 2009; Altiok et al. 2010; Fratianni et al. 2010; Grosso et al. 2010; Hossain et al. 2010; Jia et al. 2010; Kratchanova et al. 2010; McDermott et al. 2010, 2011; Rababah et al. 2010; Wei and Shibamoto 2010; Aazza et al. 2011; El-Nekeety et al. 2011; Kim et al. 2011; Komes et al. 2011).

Of the several culinary and medicinal plant volatiles tested, thyme oil was found to be the most effective antioxidant (Deans et al. 1993). The biphenyl compounds in thyme are also strong antioxidants (Haraguchi et al. 1996). Thyme oil was found to be a better antioxidant than thymol alone, suggesting that other components of the thyme oil also contribute to the antioxidant activity (Youdim and Deans 1999a). Rats fed a diet supplemented with thyme oil maintained a higher activity of the various antioxidant parameters suggesting they retained a more favorable antioxidant capacity during their life span (Youdim and Deans 1999b). Significant declines in superoxide dismutase and glutathione peroxidase activities and the total antioxidant status in untreated rats with age were observed, while thyme oil and thymol-fed rats maintained a more significantly high antioxidant enzyme activities and total antioxidant status (Youdim and Deans 2000). Thyme extract was found to delay rancidity

and preserve alpha-tocopherol concentration in sunflower oil heated to 85–105°C (Beddows et al. 2000). Zheng and Wang (2001) determined the antioxidant capacities and total phenolic contents in extracts of 27 culinary herbs and 12 medicinal herbs. They found thyme to be the medicinal herb with high ORAC values. Oregano, sage, peppermint, thyme, lemon balm, clove, allspice, and cinnamon all were shown to have very high concentrations (>75 mmol/100 g) of antioxidants (Dragland et al. 2003). Thymus oil has been shown to serve as a protective agent to damaged tissues by burn by decreasing the NO level (Dursun et al. 2003). Both pulverized plants and extracts of thyme showed strong antioxidant activity and had good phenolic content (Proestos et al. 2005). Thymol an important constituent of thyme oil was found to be a potential antioxidant and anti-inflammatory agent in human cells (Braga et al. 2006b). Methanol extracts of thyme collected from the wild in Valsesia (Northwest Italy) were shown to have strong antioxidant activity (Vitalini et al. 2006). The essential oils and aqueous tea infusions of thyme, wild thyme, and oregano exhibited a dose-dependent protective effect on the copper-induced low-density lipoproteins oxidation. The protective effect of the oil was supposed to be due to the presence of carvacrol and thymol, while for the aqueous extract it was due to the presence of large amounts of polyphenols (Kulisić et al. 2007). Büyükbalci and El (2008) suggested that the phenolic compounds and antioxidant activities of herbs including thyme may be useful for meal planning in type 2 diabetes. Rana and Soni (2008) studied the protective role of thyme against *N*-nitrosodiethylamine (NDEA)-induced oxidative stress in albino rats. They found that supplementation of diet with thyme extract improved the antioxygenic potential and thus prevent the oxidative stress. Aqueous extract of thyme and ginger were found to have detoxifying and antioxidant effects (Shati and Elsaid 2009). Mice were administered alcohol or alcohol and aqueous thyme extracts for 2 weeks. In the alcohol group there was significant increase in nitric oxide and malondialdehyde levels in liver and brain and significant decrease in total antioxidant capacity and glutathione peroxidase activity. In addition, the enzymes L-gamma-glutamyl transpeptidase and butyryl cholinesterase showed significant increase in activities in the alcohol group. However, significant amelioration on these changes both in brain and liver were observed with the aqueous extracts of thyme. Brandstetter et al. (2009) found that gamma-irradiation at the doses tested had no effect on the antioxidant capacity of sage, thyme, and oregano in chloroform and methanol extracts as well as in their mixture. Thyme oil showed excellent antibacterial and antioxidative activity when used on chicken breast meat (Fratianni et al. 2010). Thyme oil at higher doses showed significant antioxidant activity and protective effect in aflatoxin-induced rats (El-Nekeety et al. 2011). Thyme oil also showed strong free radical scavenging and antibacterial activity (Asbaghian et al. 2011)

Regulatory Status

GRAS 182.10 and GRAS 182.20.

Standard

ISO 6754.

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Chapter 55
Turmeric

Botanical Name:	*Curcuma longa* L.
Synonyms:	*C. domestica* Vale.; *Amomum curcuma* Jacq.; *C. domestica* Loir., curcuma, Indian saffron, yellow root, yellow ginger.
Family:	Zingiberaceae (Ginger family).
Common Names:	**Burmese**: anwin; **Chinese**: yu-chin; **French**: curcuma; **German**: Gelbwurz; **Italian**: curcuma; **Japanese**: ukon; **Spanish**: curcuma; **Arabic**: kharkoum; **Hindi**: haldi; **Thai**: kamin.

Introduction

History

Turmeric has been used from antiquity as a dye and a condiment (Ridley 1912; Burkill 1966; Velayudhan et al. 1999). The common name comes from Latin, "*terra merita*" meaning "meritorious earth" referring to the color of ground turmeric which resembles a mineral pigment. The genus name is derived from the Arabic and Hebrew "*kurkum.*" The use of saffron dates back to the Assyrians of 600 BC. Turmeric was used around 1500 BC as mentioned in the Vedas, the sacred scriptures of the Hindus, and the early Sanskrit word "*haridra*" means yellow wood. Hindu brides were always painted with turmeric dye, and in many parts of India it is used as cosmetic. It is believed that turmeric spread from India to distant Asian countries. The Sumarians and Assyrians used turmeric for cooking, receiving it overland from India. Garcia da Orta noted in 1563 that it was growing abundantly "in Cananor and Calicut," and the Ain-i-Akbari had price quotes for turmeric in 1590. Turmeric was regularly used in Hindu rituals and was adopted later by Indonesians and Polynesians. In India and Southeast Asia, it is also used as a cosmetic, to color rice dishes for

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auspicious ceremonies such as weddings, and providing color and aroma to the curry powder (Govindarajan 1980). Turmeric was introduced to East Africa by sea during the eighth century and later reaching West Africa in the thirteenth century. It was brought to China through the sea traders in the seventh century. Marco Polo noted in 1280 that it grew at Koncha "as a vegetable which has all the properties of true saffron, as well as the smell and the color, and yet it is not really saffron." Europe came to know about turmeric when it came via the Silk Road from India, but was at first used as a dye, later to be known as the Indian saffron. Turmeric since early times has been an ingredient in medicines and Jamaica had its first encounter with turmeric through a Mr. Edwards in 1783, where it is naturalized now.

Producing Regions

It is native to Southeast Asia and is extensively cultivated in India—Allepey, Madras, and Bengal being the most valued turmeric, having the best color value and flavor. It is also cultivated in Pakistan, Cambodia, Thailand, China, Taiwan, Sri Lanka, Indonesia, Malaysia, Nepal, Japan, Philippines, Madagascar, Peru, and Caribbeans especially Jamaica and Haiti.

Botanical Description

Turmeric is a tropical annual or perennial, stout, erect herb with perennial root-stock, or rhizome related to the ginger family. The plant has climbing stalks reaching a height of 60–100 cm (1–3 ft). The erect straight leafy shoots grow up bearing six to ten alternate, distichous leaves surrounded by bladeless sheaths forming a short pseudostem. The leaves are dark green in color above, midrib green, and below very light green covered with pellucid dots. They appear to be acute at both ends and somewhat broad up to 1–2 m long. The inflorescence is a cylindrical, fleshy, central spike of 10–15 cm length, arising through the pseudostem. The flowers are yellow and occur in cincinni of two in axils of bracts. The upper bracts are white in color; the lower bracts are green. Reproduction occurs through the splitting of the rhizomes which are filiform, fleshy, and tough. Rhizomes have a brownish-yellow, somewhat scaly outer skin and a bright orange-yellow flesh, with white young tips, and a spicy smell when bruised. These rhizome branches are 2–5 cm long, finger shaped, cylindrical, compressed, straight, or bent with the thickness about 1.8 cm. The main rhizome is about 3 cm thick and 5 cm long. Fresh turmeric has a bright orange flesh, while the dried rhizome is lemon yellow to orange yellow in color.

Parts Used

Turmeric is used as dried rhizome powder or whole. It is also used like fresh ginger chopped, grated, or cut. The fresh leaves are also used as wrappers or are chopped and used in local dishes in Indonesia. Essential oil of turmeric is occasionally used in the perfume industry. Turmeric extracts are used as a dye for cotton, silk, leather, and wood. Turmeric oleoresin is used increasingly by the processed food industries.

Flavor and Aroma

Strong earthy aroma, spicy and acrid with gingery, slightly bitter, peppery notes. It has a warm, slightly pungent, bitter undertone, but very aromatic with a mild mustard-ginger flavor.

Active Constituents

The rhizome contains moisture 11–13%, food energy 390 (kcal), protein 6–9%, fat 5–10%, carbohydrate 60–70% mainly starch, fiber 2–7%, ash 3–7%, (K-2,000, Ca-0.2, Fe-47.5, Na-30, P-260), ascorbic acid, vitamin C, sugars (glucose, fructose, arabinose), curcuminoids, and essential oil 2–10%. The essential oil contains ar-turmerone (60%), curlone, ar-curcumene, zingiberene, α-phellandrene, and sabinene. The yellow color is due to curcumin. The Indian Allepey rhizomes have the highest curcumin content and are considered to be of superior quality. The nutritional constituents and ORAC values of ground turmeric are given in Table 55.1.

Preparation and Consumption

In Indian and Southeast Asian cooking, turmeric is a popular spice used in curry powders to flavor curries, vegetables and meat, fish, rice pullaos, and sweet dishes or desserts (Peter 1999; Govindarajan 1980). Turmeric is used in sauces, chicken, gravies, seasonings, cheese pickles, relishes, soups, beverages, and confections. In western countries it is usually used as a colorant for mustard condiments and sauces. It is also used in cheeses, pickles, sausages, deviled eggs, relishes, and spreads. It is used in Worcestershire sauce, relishes, and spreads. It blends well with cilantro, ginger, mustard seeds, lemongrass, dill, cumin, clove, and black pepper. Turmeric is extensively used in the Eastern and Middle East dishes as a condiment and culinary dye. In Moroccan cuisines, it is used to spice meat, particularly lamb, and vegetables. It is used in fish curries. Turmeric is the main ingredient in curry powders. It provides the color and background aroma to the curry powder.

Table 55.1 Nutrient composition and ORAC values of turmeric ground

Nutrient	Units	Value per 100 g
Water	g	11.36
Energy	kcal	354
Protein	g	7.83
Total lipid (fat)	g	9.88
Carbohydrate, by difference	g	64.93
Fiber, total dietary	g	21.1
Sugars, total	g	3.21
Calcium, Ca	mg	183
Vitamin C, total ascorbic acid	mg	25.9
Vitamin B-6	mg	1.800
Vitamin B-12	mcg	0.00
Vitamin A, RAE	mcg_RAE	0
Vitamin A, IU	IU	0
Vitamin D	IU	0
Vitamin E (alpha-tocopherol)	mg	3.10
Fatty acids, total saturated	g	3.120
Fatty acids, total monounsaturated	g	1.660
Fatty acids, total polyunsaturated	g	2.180
H-ORAC	μmol TE/100 g	44,776
L-ORAC	μmol TE/100 g	82,292
Total-ORAC	μmol TE/100 g	127,068
TP	mg GAE/100 g	2,754

Source: USDA National Nutrient Database for Standard Reference, Release 24 (2011)

Medicinal Uses and Functional Properties

In traditional medicinal systems like the Ayurvedic, Unani, and Siddha systems as well as Chinese medicine, turmeric has been used for treating liver problems, high cholesterol, and digestive problems. It is also used for healing bruises and sores, inhibit blood clotting, strengthen the gall bladder, and treat skin diseases.

Turmeric is considered anti-inflammatory, hypocholesteremic, choleretic, antimicrobial, antirheumatic, antibacterial, antiviral, cytotoxic, spasmolytic, hypersensitive, antidiabetic, and antihepatotoxic (Govindarajan 1980; Brennan and O'Neill 1998; Khanna 1999; Velayudhan et al. 1999; Wang et al. 2008). It is also considered to have anticancerous properties and is often used as an antioxidant in capsules, tablets, and flavoring in tea.

The yellow pigment in turmeric is known as curcuminoids and one of these is curcumin. The curcuminoids are comprised of curcumin, demethoxycurcumin, and bisdemethoxycurcumin. This active ingredient curcumin comprises 2–5% of turmeric and has been shown to have antioxidant properties similar to vit. C and E. Research has shown that hydrocortisones may be replaced by turmeric in reducing pain and stiffness in arthritis. Since curcumin produces bile flow easily, it breaks

down fats and toxins and can protect liver damage from alcohol. Turmeric also reduces stomach acid by protecting the lining of the stomach and the colon. It can prevent atherosclerosis as it seems to reduce LDL in the blood, therefore preventing clots. Research shows that turmeric can be valuable in preventing and treating cancer. If turmeric is applied to wounds it prevents bacterial infection like staphylococcus aureus and heals wounds faster.

Curcumin is well documented for its medicinal properties and has been shown to exhibit numerous activities. Animal studies have suggested that curcumin could be active against a wide range of human diseases, including diabetes, obesity, neurologic and psychiatric disorders, and cancer, as well as chronic illnesses affecting the eyes, lungs, liver, kidneys, and gastrointestinal and cardiovascular systems. It binds to a variety of proteins, inhibits the activity of various kinases, and regulates the expression of inflammatory enzymes, cytokines, adhesion molecules, and cell survival proteins. It downregulates cyclin D1, cyclin E, and MDM2 and upregulates p21, p27, and p53. Curcumin's inhibitory effect on the NF-κB pathway is crucial in providing its anti-inflammatory properties. It has also been shown to decrease the metabolism of arachidonic acid by downregulating the activity of lipoxygenase and COX-2, both at transcriptional level and via the posttranslational enzyme inhibition (Huang et al. 1991; Zhang et al. 1999; Rao 2007; Oh et al. 2011; Zhong et al. 2011). Curcumin has been reported to have antibacterial, anti-inflammatory, antioxidant, antiproliferative, pro-apoptotic, chemopreventive, chemotherapeutic, wound healing, antinociceptive, antiparasitic, and antimalarial properties. Several studies suggest that curcumin has great promise as an antiproliferative, anti-invasive, and antiangiogenic agent; as a mediator of chemoresistance and radioresistance; as a chemopreventive agent; and as a therapeutic agent in wound healing, diabetes, Alzheimer disease, Parkinson disease, cardiovascular disease, pulmonary disease, and arthritis. It has also been shown to have therapeutic role in diseases like familial adenomatous polyposis, inflammatory bowel disease, ulcerative colitis, colon cancer, pancreatic cancer, hypercholesteremia, atherosclerosis, pancreatitis, psoriasis, and chronic anterior uveitis (Goel et al. 2008; Curcuzza et al. 2008; Banderali et al. 2011; Irving et al. 2011; Kaur and Saraf 2011; Rajasekaran 2011; Seo et al. 2011; Yu et al. 2011a, b; Waghmare et al. 2011; Bao et al. 2012; Mythri and Bharath 2012).

The antioxidant effects of curcumin have been shown to attenuate adriamycin-induced cardiotoxicity and prevent diabetic cardiovascular complications. The antithrombotic, antiproliferative, and anti-inflammatory effects of curcumin and the effect of curcumin in decreasing serum cholesterol may protect against the pathological changes occurring with atherosclerosis. The p300-HAT inhibitory effects have been demonstrated to ameliorate the development of cardiac hypertrophy and heart failure in animal models. The inflammatory effects may have the possibility of preventing atrial arrhythmias and the possible effect for correcting the $Ca^{(2+)}$ homeostasis may play a role in the prevention of ventricular arrhythmias (Wongcharoen and Phrommintikul 2009). Curcuminoid treatment in diabetic rat brain brought to normal levels the increase in lipid peroxidation and nitrite levels with simultaneous decrease in endogenous antioxidant marker enzymes. Curcuminoid administration

also profoundly elevated the ATP level, which was reduced in the diabetic brain (Rastogi et al. 2008). Curcumin has been found to exhibit activities similar to the recently discovered tumor necrosis factor blockers, a vascular endothelial cell growth factor blocker, human epidermal growth factor receptor blockers, and a HER2 blocker (Aggarwal et al. 2007). It can bind to the major and minor grooves of DNA duplex and to RNA bases as well as to the back bone phosphate group (Nafisi et al. 2009). Aqueous extract of turmeric exhibited insulin releasing and mimicking actions within in vitro tissue culture conditions (Mohankumar and McFarlane 2011).

Curcumin treatment has been shown to completely reverse the metalloproteinase (MMP)-9 activity to almost control level after increasing gradually in endometriotic tissues and arrested endometriosis (Swarnakar and Paul 2009). Curcumin inserts deep into the membrane in a transbilayer orientation, anchored by hydrogen bonding to the phosphate groups of lipids in a manner analogous to cholesterol (Barry et al. 2009). Naidu and Thippeswamy (2002) found that curcumin effectively inhibited the initiation and propagation phases of low-density lipoproteins when compared with butylated hydroxyl anisole, capsaicin, and quercetin. Curcumin, capsaicin, and garlic when fed to rats, eating cholesterol-enriched diet, prevented both the increase in membrane cholesterol and increased fragility of the erythrocytes (Kempaiah and Srinivasan 2002). Turmeric extract was found to reduce oxidative stress and attenuate aortic fatty streak development in rabbits. It prevented early atherosclerotic lesions in abdominal and thoracic aorta and significantly increased the concentrations of coenzyme Q, retinol, and α-tocopherol in plasma (Quiles et al. 2002).

Ortiz-Ortiz et al. (2009) have shown that subtoxic concentrations of curcumin sensitize N27 mesencephalic cells to paraquat-mediated apoptosis. Curcumin was shown to induce apoptosis through the intrinsic pathway and caspase-3-dependent and -independent pathways in N18 cells (Lu et al. 2009). The findings by Kuo et al. (2011) revealed that mitochondria and AIF caspase-3-dependent pathways play a vital role in curcumin-induced G2/M phase arrest and apoptosis of NPC-TW 076 cells in vitro. Aromatic (ar)-turmerone, a component of turmeric essential oil, has an apoptotic effect on human lymphoma U937 cells, and this involves caspase-3 activation through the induction of Bax and p53, rather than Bcl-2 and p21 (Lee 2009). Curcumin has a great potential in colorectal cancer (Villegas et al. 2008) and other cancers (Shanmugam et al. 2011). Curcumin has been shown to induce apoptosis in human breast cancer cells (Choudhuri et al. 2002; Shao et al. 2002), human melanoma cells (Zheng et al. 2004), human myeloma cells (Han et al. 2002), human leukemia cell lines (Bharti et al. 2004), human neuroblastoma cells (Liontas and Yeger 2004), lung cancer cells (Radhakrishna et al. 2004), oral cancer cells (Elattar and Virji 2000), and prostate cancer cells (Deeb et al. 2004; Hour et al. 2002; Nakamura et al. 2002; Mukhopadhyay et al. 2001). Ohashi et al. (2003) demonstrated the ability of curcumin to inhibit intrahepatic metastases. Curcumin has been found to possess excellent anticancer activities via its effect on a variety of biological pathways involved in mutagenesis, oncogene expression, cell cycle regulation, apoptosis, tumorigenesis, and metastasis. Curcumin has shown antiproliferative effect in multiple cancers and is an inhibitor of the transcription factor NF-κB and

downstream gene products (including c-myc, Bcl-2, COX-2, NOS, Cyclin D1, TNF-α, interleukins, and MMP-9). It affects a variety of growth factor receptors and cell adhesion molecules involved in tumor growth, angiogenesis, and metastasis (Wilken et al. 2011).

Turmeric and curcumin were found to produce significant improvements in blood glucose, hemoglobin, and glycosylated hemoglobin than in plasma and liver thiobarbituric acid-reactive substances and glutathione. It also lowered the activity of sorbitol dehydrogenase (Giltay et al. 1998). Mahady et al. (2002) found that turmeric and curcumin inhibited the growth of 19 different strains of *Helicobacter pylori*, a group 1 carcinogen. The *Helicobacter pylori*-induced mitogenic response was completely blocked by curcumin (Foryst-Ludwig et al. 2004). Turmeric leaf oil exhibited significant inhibition of fungal growth and also the aflatoxin production (Sindhu et al. 2011).

Curcumin treatment was found to significantly reduce the histological injuries, the acinar cell vacuolization and neutrophil infiltration of the pancreatic tissue, the intrapancreatic activation of trypsin, the hyperamylasemia and hyperlipasemia, and the pancreatic activation of NF-κB, IκB degradation, activation of activator protein (AP)-1 and various inflammatory molecules such as IL-6, TNF-α, chemokine KC, iNOS, and acidic ribosomal phosphoprotein (ARP). It also stimulated pancreatic activation of caspase-3 (Gukovsky et al. 2003). Nanji et al. (2003) found that curcumin prevented alcohol-induced liver disease in rats by inhibiting the expression of NF-κB-dependent genes. Curcumin administration was found to prevent the reduction of cytochrome enzyme P450 expression induced in inflammatory conditions (Masubuchi et al. 2007). Ukil et al. (2003) reported a significant reduction in degree of histological tissue injury, neutrophil infiltration, and lipid peroxidation in the inflamed colon by curcumin pretreatment in trinitrobenzene-induced colitis, and also a decreased serine protease activity. In another study on induced colitis, curcumin treatment resulted in reduction in COX-2 and iNOS expression and this was attributed to the lowered activation of MAPKp38 (Camacho-Barquero et al. 2007). Curcumin was found to modulate proinflammatory cytokines expression, attenuate IL-1β TNBS-induced damage, and increase IL-10 expression (Jian et al. 2004). Billerey-Larmonier et al. (2008) postulated that the therapeutic value of curcumin in mouse model depends on the nature of the immune alteration during intestinal bowel disease. Lim et al. (2009) showed that curcumin acts as an uncoupler. They found curcumin at higher concentrations (50 μM) inhibited mitochondrial respiration which is a characteristic feature of inhibitory uncouplers. Curcumin was also shown to have a protective effect on LPS-induced experimental renal inflammation, and this effect might be attributed to its inhibitory effects on MCP-1 mRNA expression and DNA-binding activity of NF-κB (Zhong et al. 2011).

Derivatives of curcumin, like bis-DemethoxyCurcumin (bDMC) and diAcetyl-Curcumin (DAC), were found to be more stable in physiological medium (Basile et al. 2009). Both were found to impair correct spindle formation and induce a p53- and p21(CIP1/WAF1)-independent mitotic arrest, which is more stable and long lasting for bDMC. They demonstrated that bDMC induces rapid DNA double-strand breaks, moving for its possible development in anticancer clinical applications.

The in vitro and in vivo cancer-related activities of curcumin are linked to its known antioxidant and pro-oxidant properties (Lopez-Lazaro 2008). Curcumin treatment was found to overcome stromal protection of chronic lymphocytic leukemia (CLL B) cells on in vivo testing (Ghosh et al. 2009; Angelo and Kurzrock 2009). Mahattanadul et al. (2009) found that bDMC directly accelerated gastric ulcer healing with potency equal to curcumin, and the antiulcer effect could be due to its properties of decreasing gastric acid secretion and enhancing the mucosal defensive mechanism through suppression of iNOS-mediated inflammation.

Antioxidant Properties

Curcumin's strong antioxidant and anti-inflammatory properties make it a potential candidate for the prevention and/or treatment of cancer and other chronic diseases (Pandya et al. 2000; Lim et al. 2001; Ram et al. 2003; Egan et al. 2004; Cao et al. 2008; Bengmark et al. 2009; Gowda et al. 2009; Ishrat et al. 2009; Kim et al. 2009; Aggarwal and Sung 2009; Aggarwal and Harikumar 2009; Aggarwal et al. 2007; Biesalski 2007; Dai et al. 2009; Hatcher et al. 2008; Jurenka 2009; Pari et al. 2008; Shapiro et al. 2009; Yarru et al. 2009; Alex et al. 2010; Bao et al. 2010; Bhartiya et al. 2010; Biswas et al. 2010; Darvesh et al. 2010; El-Agamy 2010; Epstein et al. 2010; Harish et al. 2010; Lee et al. 2010; Madhusudhan et al. 2010; Menghini et al. 2010; Nagarajan et al. 2010; Nayak and Sashidhar 2010; Rungseesantivanon et al. 2010; Singh et al. 2010; Wei et al. 2010; Yen et al. 2010; Zhao et al. 2010; Al-Suhaimi et al. 2011; Basnet and Skalko-Basnet 2011; Cerny et al. 2011; Jin et al. 2011; Kamal et al. 2012; Karami et al. 2011; Khuwaja et al. 2011; Kuo et al. 2011; San Miguel et al. 2011; Yu et al. 2011a; Kam et al. 2012; Liao et al. 2012).

Curcumin has been found to inhibit lipid peroxidation using linoleate, a polyunsaturated fatty acid that is able to be oxidized and form fatty acid radical. It has been reported that curcumin acts as a chain-breaking antioxidant at the 3′ position, and thus resulting in an intramolecular Diels–Alder reaction and neutralization of lipid radicals (Masuda et al. 2001). In addition, it has been shown to scavenge various ROS produced by macrophages (superoxide anions, hydrogen peroxide, and nitrite radicals) both in vivo and in vitro using rat peritoneal macrophages as a model (Joe and Lokesh 1994; Joe et al. 2004). Curcumin also reduces the amount of ROS generated in response to oxidative stress by downregulating the iNOS activity in macrophages (Brouet and Ohshima 1995; Chan et al. 1998). Curcumin treatment reduced NO generation and protection of neural cells from oxidative stress, and thus could be useful in reducing the neuroinflammation associated with degenerative conditions like Alzheimers's disease (Jung et al. 2006; Ishrat et al. 2009; Ray and Lahiri 2009; He et al. 2010). The free radical scavenging activity of curcumin has also been shown to contribute to its anti-inflammatory properties by decreasing the amount of oxidative stress that can start the inflammatory reactions. Curcumin's antioxidant and free radical scavenging activity has an important role in the anticarcinogenic activity. Its inhibitory effect on carcinogenesis has been shown in various tumor models like oral cancer, intestinal tumors, and mammary carcinoma in animal

models (Krishnaswamy et al. 1998; Inano et al. 1999; Collett et al. 2001; Zhao et al. 2010: Karami et al. 2011)

Ishrat et al. (2009) studied the modulating impacts of curcumin against cognitive deficits and oxidative damage in intracerebroventricular-streptozotocin infused rats. Their study suggests that curcumin is effective in preventing cognitive deficits, and it could be beneficial for the treatment of sporadic dementia of Alzheimer's type (SDAT). Curcumin significantly reduced oxidative damage and amyloid pathology in an Alzheimer transgenic mouse (Lim et al. 2001). Frautschy et al. (2001) reported reductions in both Aβ deposits and memory deficits in Sprague–Dawley rats. Studies have shown significant preventive effects of curcumin against cataracts induced by naphthalene, galactose, and selenium (Pandya et al. 2000; Suryanarayana et al. 2003; Padmaja and Raju 2004). Ram et al. (2003) reported that curcumin attenuated allergen-induced hyperresponsiveness in sensitized guinea pigs. Curcumin has been reported to correct Cystic fibrosis defects (Egan et al. 2004). Shishodia et al. (2003) reported that curcumin downregulates cigarette smoke-induced NF-κB activation through inhibition of I Bα kinase in human lung cancer epithelial cells and which correlates with suppression of COX-2, MM-9, and cyclin D1.

Gowda et al. (2009) found that total curcuminoids ameliorated the adverse effects of aflatoxin B1 (AFB1) on serum chemistry in terms of total protein, albumin, and gamma-glutamyl transferase activity. They concluded that the addition of 222 mg g^{-1} total curcuminoids to the 1 mg kg^{-1} AFB1 diet fed to chicks demonstrated maximum antioxidant activity against AFB1. Sompamit et al. (2009) showed for the first time the potential role of curcumin in the prevention and treatment of vascular dysfunction in mice with endotoxemia elicited by lipopolysaccharide (LPS) in mice. Male ICR mice were treated with curcumin (50 or 100 mg kg^{-1}), administered intragastrically, either before or after intraperitoneal injection of LPS (10 mg kg^{-1}). Curcumin was found to modulate heart rate and restore arterial blood pressure in a dose-dependent manner in both protectively and therapeutically treated regimens. Furthermore, the vascular responsiveness of LPS-treated mice was improved by curcumin. A potent antioxidant protein β-turmerin purified from turmeric waste grits inhibited diene–triene and tetraene conjugation, effectively scavenged hydroxyl radicals when compared to BHA and α-tocopherol, and also inhibited the activation of PMNL mediated by fMLP (Smitha et al. 2009). They postulated that the mechanism of antioxidant action by β-turmerin could be by counteracting/quenching of reactive oxygen species (ROS). Pure curcuminoids I, II, and III had strong antioxidant activity as determined by the DPPH method (Naidu et al. 2009). Curcumin at 2.5 μg mL^{-1} significantly reduced acrylamide (AA)-induced ROS production, DNA fragments, micronuclei formation, and cytotoxicity in HepG2 cells. This protection is probably mediated by an antioxidant protective mechanism. Curcumin consumption may be a good way to prevent AA-mediated genotoxicity (Cao et al. 2008). Biochemical and histological findings demonstrated that turmeric extract had an ameliorative effect against doxorubicin (DOX)-induced cardiac toxicity and hepatotoxicity and blocked DOX-induced nephrosis (Mohamad et al. 2009). They also found that turmeric extract inhibited the DOX-induced increase in plasma cholesterol, lactate dehydrogenase, and creatine kinase activities that block the cardiac, hepatic, and renal toxicities induced by DOX, and acts as a free radical scavenger.

A polyherbal formulation including turmeric was found to significantly reduce levels of lipid peroxidation and increased activities of antioxidant enzymes (Patel et al. 2009). Dutta et al. (2009) found that curcumin imparted neuroprotection in vitro, probably by decreasing cellular ROS level, restoration of cellular membrane integrity, decreasing pro-apoptotic signaling molecules, and modulating cellular levels of stress-related proteins. They also demonstrated that curcumin, by inhibition of ubiquitin–proteasome system, caused reduction in infective viral particle production from previously infected neuroblastoma cells. Curcumin prevented lipid peroxidation and protein oxidation in endometriotic tissues (Swarnakar and Paul 2009). Tang et al. (2009) demonstrated curcumin's role in suppressing the stimulatory effect of leptin on HSC activation in vitro by reducing the phosphorylation level of Ob-R, stimulating peroxisome proliferator-activated receptor-gamma activity, and attenuating oxidative stress, leading to the suppression of Ob-R gene expression and interruption of leptin signaling. Curcumin affords substantial protection against oxidative damage caused by Fe-NTA, and these protective effects may be mediated via its antioxidant properties. These properties suggest that curcumin could be a great cancer chemopreventive agent (Iqbal et al. 2009). Curcumin inhibited 97.3% lipid peroxidation of linoleic acid emulsion. It also had effective DPPH* scavenging, ABTS*(+) scavenging, DMPD*(+) scavenging, superoxide anion radical scavenging, hydrogen peroxide scavenging, ferric ions ($Fe^{(3+)}$) reducing power, and ferrous ions ($Fe^{(2+)}$) chelating activities (Ak and Gulcin 2008). Data from different laboratories have demonstrated that curcumin, as well as some other polyphenols, strongly induces heme oxygenase 1 and Phase II detoxification enzymes in neurons and, by this activation, protects neurons against different modes of oxidative challenge. The potential role of curcumin as a preventive agent against brain aging and neurodegenerative disorders has been recently reinforced by epidemiological studies showing that in India, where this spice is widely used in the daily diet, there is a lower incidence of Alzheimer's disease than in the USA. These studies identify a novel class of compounds that could be used for therapeutic purposes as preventive agents against the acute neurodegenerative conditions that affect many in the world's increasingly aging population (Scapagnini et al. 2011). Curcumin may play a significant role in downregulating obesity as data suggest that it regulates lipid metabolism, which plays the central role in the development of obesity and further complications (Alappat and Awad 2010). Turmeric extract showed significant antiproliferative and antiradical activity against HepG2 cells (Menghini et al. 2010). Curcumin was found to be an inhibitor of vascular hyperpermeability following hemorrhagic shock, with its protective effects being mediated through its antioxidant properties (Tharakan et al. 2010). The hydrophilic extract of turmeric was shown to potently suppress the incidence of atherosclerosis via a strong antioxidant potential, prevention of apolipoprotein A-I glycation and LDL phagocytosis, and inhibition of CETP in zebrafish (Jin et al. 2011). Curcumin protected against A53T mutant α-synuclein-induced cell death via inhibition of oxidative stress and the mitochondrial cell death pathway, suggesting that curcumin may be a candidate for neuroprotective agent for A53T α-synuclein-linked Parkinsonism, and possibly for other genetic or sporadic forms of Parkinson's disease (Liu et al. 2011). It was

shown to dose dependently suppress the kindling in mice and at the same time reduced the increased levels of MDA and glutathione (Agarwal et al. 2011). Turmeric has been reported to improve vasorelaxation of the aorta in hypercholesterolemic rats by increasing antioxidant enzyme activities and likely suppressing apoptosis (Kam et al. 2012).

Regulatory Status

GRAS 182.10 and GRAS 182.20, 73.600 and 73.615.

Standard

ISO 5562 (Specification), ISO 5566 (Determination of coloring power).

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Chapter 56
Vanilla

Botanical Name:	*Vanilla planifolia* Jacks.
Synonyms:	*Vanilla fragrans* (Salisb.) Ames.; *V. viridiflora* Blume; *V. mexicana* (P. Miller); *Epidendrum vanilla* L.; Mexican vanilla; Bourbon vanilla; Madagascar vanilla.
Family:	Orchidaceae.
Common Names:	**French**: vanille; **German**: vanille; **Italian**: vaniglia; **Spanish**: vainilla; **Indonesian**: panili.

Introduction

History

Vanilla is the only fruit-bearing member of the orchid family. It is the greatest contribution of the Americas to the world of flavors. The genus name "*Vanilla*" is from the Spanish "*vaina*", meaning little pod. Vanilla beans rival saffron in intensity and cardamom in aromatic complexity. Bernal Diaz, a Spanish officer with Hernando Cortes, first recorded the use of vanilla when he saw the Aztec leader Montezuma drinking *chocolatl* (hence chocolate) prepared from pulverized cocoa seeds (*Theobroma cacao* L.) and ground vanilla beans. In the Aztec language, Nahuatl, vanilla is called tlilxochitl, and its seeds collected from wild plants were considered among the most important tributes paid to the Aztec leader. A Franciscan friar, Bernhardino de Saghun, writes in his published work (1829–1830) that the Aztecs used vanilla seeds (pods) in cocoa drinks and as a medicine, and sold them in their markets. It is most highly unlikely that the Aztecs knew how to cure the beans, so they probably only dried them or used fresh. The Spaniards in the second half of the sixteenth century produced the commercially available chocolate flavored with vanilla. The Spaniards used the bean, which they called "*vaynilla*" (little sheath, referring to the fruit appearance) as a flavoring

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for chocolate. Dr. Francisco Hernandez, the celebrated physician to Emperor Philip II, described and illustrated many orchids under the collective name *Tzautlis*, including vanilla (*Rerum Medicarum Novae Hispaniae Thesaurus*, 1651 in Rome). He translated the Aztec name for vanilla, *tlilxochitl*, as black flower, but noted that it referred to the pod and not the flower. He also pointed out that the Aztecs used the "seeds" as a tonic, for headaches, and as an antidote to bites of poisonous insects. Vanilla cultivation in Mexico was traditionally done by the Totonec Indians on small plants. Charles Moren of Liege was able to produce vanilla beans by hand pollination in around 1836. Currently it is confined to central Veracruz and northern Puebla. Vanilla plants were brought to England prior to 1733, but was apparently lost and then reintroduced at the beginning of the nineteenth century by Marquis of Blandford. Charles Gerville had vanilla plants at Paddington in 1807, and supplied cuttings to the botanic gardens in Paris and Antwerp. It was Madame du Barry's favorite aromatic in her relationship with King Louis XV of France. Hugh Morgan, an apothecary to Queen Elizabeth I, suggested vanilla as a flavoring; the Flemish botanist described it in his *Exoticorum Libri Decem* of 1605. The English navigator William Dampier found vanilla growing in the Bay of Campeche, southern Mexico in 1676, and in 1681 at Bocotoro in Costa Rica. The Indonesian plantings originated from the two plants sent in 1819 from Antwerp to Buitenzorg, Java. West and central Java and South Sumatra and Sulawesi are the major producers of Indonesian vanilla. The cuttings reached Mauritius in 1827, and the Malagasy Republic around 1840. Vanilla cultivation in Madagascar is concentrated along the northeast coast around Antalaha, Andapa, Sambava, and Vohemar. Seychelles received cuttings around 1866, and is now a cash crop on the islands of Praslin and La Digue. The cultivation in Comoro Islands, Reunion started in 1893, and it is now a leading producer of vanilla. Major production is on Grande Comoro with minor contributions from Anjouan, Moheli, and Mayotte. Vanilla was cultivated as early as 1839 on the West Indian island of Martinique, and probably about the same time on Guadeloupe. Tahiti received vanilla from Manila, Philippines in 1848, and is an important local industry. Uganda was supplied with vanilla plants in the 1920s, but is apparently only in the botanic gardens at Entebbe. Papua New Guinea is also now producing vanilla commercially. The Bourbon vanilla from Reunion is the most valued quality. Thomas Jefferson first encountered the bean during a trip to France. Upon returning to America in 1789, he missed its warm, enticing flavor; so he wrote to William Short, an American diplomat in Paris, and asked him to send 50 pods of vanilla for use in his kitchen. Between Jefferson's enthusiasm for the bean and the inevitable diffusion of food products from Europe to the USA, vanilla fast became a popular staple in American kitchens.

Producing Regions

Vanilla is native to Central America from southeastern Mexico through Guatemala to Panama. The major producers of vanilla beans and products are the bourbon vanilla from Madagascar, Reunion, and Comoro. The others are Indonesia, Tahiti, Mexico, Papua New Guinea, and India. The United States is the leading importer and consumer.

Botanical Description

Vanilla is a fleshy, herbaceous perennial vine, climbing trees or other supports to 10–15 m (45 ft) by adventitious roots. The long, succulent, cylindrical, monopodial stems are simple or branched and brittle. The leaves are large, fleshy, flat, subsessile, carried on short, thick petioles, and canalized above. The inflorescence is short and borne towards the end of the branches with 20 or more flowers. They are simple and rarely branched. The large, fragrant, pale greenish-yellow waxy flowers are about 10 cm in diameter with oblanceolate sepals and petals, and last 1 day. Vanilla normally flowers only once a year over a period of about 2 months. The flowers are hand pollinated. Hand pollination is essential for cultivated vanilla. Mr. Edmond Albius of Reunion in 1841 developed the hand pollination technique which is still in use. The fruit or pod, incorrectly, but commercially, known as vanilla bean is aromatic on drying and is about 20 cm long. The pod is pendulous, narrowly cylindrical, faintly three-angled, and variable. When ripe, it contains a mass of minute, round, black seeds. The vanilla beans are cured (processing to turn the green pods to dark brown pods takes 5–6 months). During curing, the glucoside (glucovanillin) is hydrolyzed by the enzyme β-glucosidase to yield the vanillin.

Parts Used

The parts used include vanilla beans, vanilla powder (vanilla sugar), vanilla extract, vanilla oleoresin, and vanilla absolute. High-quality beans are long, fleshy, supple, very dark brown to black, somewhat oily in appearance, strongly aromatic, and free from scars.

From Arctander (1960).

Bourbon vanilla (Madagascar, Reunion, and Comoro) has a very strong rich, sweet, tobacco-like aroma, somewhat woody and animal, possesses a very deep balsamic, sweet-spicy body note, but vanillin scent is lacking. Very moist beans have a stronger vanillin character.

Mexican vanilla is somewhat sharper and more pungent aroma than the Bourbon beans.

Java vanilla has very heavy/woody flavor.

Tahitian vanilla (*Vanilla tahitensis*) has almost perfumery sweet and not tobacco-like aroma, neither very deep woody nor distinctly animal.

Guadeloupe vanilla has a peculiar anisic-like floral sweet, heliotropine/isosafrole type, more perfumy aroma.

Flavor and Aroma

Highly aromatic, smooth, sweet, spicy, and fragrant. Rich, very full, powerful, sweet, creamy, chocolate like, and aromatic.

Active Constituents

Mature fresh pods contain moisture 20%, protein 3–5%, fat 11%, sugar 7–9%, fiber 15–20%, ash 5–10%, vanillin 1.5–3%, soft resin 2%, coumarin, ethyl vanillin, and an odorless vanillic acid. Vanillin is the major flavor component and is usually between 1.5 and 3.5%. Other major constituents are *p*-hydroxybenzoic acid, *p*-hydroxybenzaldehyde, vanillic acid, *p*-hydroxybenzyl alcohol, and vanillyl alcohol. Vanilla contains resins, gums, amino acids, and other organic acids (Purseglove et al. 1981). The biosynthetic pathway for vanillin is 4-coumaric acid → → ferulic acid → → vanillin → glucovanillin in mature vanilla pods (Negishi et al. 2009). The molecules, 5-(4-hydroxybenzyl)vanillin, 4-(4-hydroxybenzyl)-2-methoxyphenol, 4-hydroxy-3-(4-hydroxy-3-methoxybenzyl)-5-methoxybenzaldehyde, (1-*O*-vanilloyl)-(6-*O*-feruloyl)-beta-D-glucopyranoside, americanin A, and 4′,6′-dihydroxy-3′,5-dimethoxy-[1,1′-biphenyl]-3-carboxaldehyde, were found in cured beans (Schwarz and Hofmann 2009). The nutritional constituents (vanilla extract) and ORAC (dried beans) values of vanilla are given in Table 56.1.

Preparation and Consumption

Vanilla, vanilla extract, and vanilla oleoresin are widely used as flavor ingredients in most food products, including alcoholic and nonalcoholic beverages, frozen dairy desserts, candy, baked goods, gelatins, and puddings. Vanilla's mellow fragrance enhances the flavor of a variety of sweet dishes, like puddings, creams, custards, souffles, and ice creams. Some classic examples include creme caramel, creme brulee, peach Melba, and apple Charlotte. Liqueurs like Creme de Cacao and Galliano have vanilla flavor. Vanilla is the principal note of a lot of quality perfumes like "Amouge", "Jicky", and "Habanita". Vanilla beans or extracts are used in bakery products, chocolate, liqueurs, and dairy products.

Medicinal Uses and Functional Properties

Vanilla has been considered an aphrodisiac. It was also believed to reduce fevers. It is mostly used as a pharmaceutical flavoring.

Vanillin has been reported to have antimetastatic and antiangiogenic effects (Lirdprapamongkol et al. 2010). Vanillin was shown to sensitize HeLa cells to TRAIL-induced apoptosis by inhibiting NF-kappaB activation (Lirdprapamongkol et al. 2010). Vanillin has also been shown to have in vitro antifungal activity against *Candida albicans* and *Cryptococcus neoformans*, with minimal inhibitory concentrations of 1,250 and 738 μg mL^{-1} for *C. albicans* and *C. neoformans*. The minimal fungicidal concentrations were 5,000 and 1,761 μg mL^{-1}, respectively (Boonchird

Table 56.1 Nutrient composition and ORAC values of vanilla extract

Nutrient	Units	Value per 100 g
Water	g	52.58
Energy	kcal	288
Protein	g	0.06
Total lipid (fat)	g	0.06
Carbohydrate, by difference	g	12.65
Fiber, total dietary	g	0.0
Sugars, total	g	12.65
Calcium, Ca	mg	11
Vitamin C, total ascorbic acid	mg	0.0
Vitamin B-6	mg	0.026
Vitamin B-12	mcg	0.00
Vitamin A, RAE	mcg_RAE	0
Vitamin A, IU	IU	0
Vitamin D	IU	0
Vitamin E (alpha-tocopherol)	mg	0
Fatty acids, total saturated	g	0.010
Fatty acids, total monounsaturated	g	0.010
Fatty acids, total polyunsaturated	g	0,004
Vanilla beans dried		
H-ORAC	μmol TE/100 g	29,300
L-ORAC	μmol TE/100 g	93,100
Total-ORAC	μmol TE/100 g	122,400

Source: USDA National Nutrient Database for Standard Reference, Release 24 (2011)

and Flegel 1982). The minimum inhibitory concentration values of 21, 20, and 13 mM vanillin were found against three yeasts associated with food spoilage, *Saccharomyces cerevisiae*, *Zugosaccharomyces bailii*, and *Zygosaccharomyces rouxii* (Fitzgerald et al. 2003). Vanillin at concentrations of 20 and 10 mM achieved complete inhibition of both *Saccharomyces cerevisiae* and *Candida parapsilosis* inoculated at a level of 10^4 CFU mL^{-1} in the apple juice and peach-flavored soft drink over a 8-week storage at 25 °C (Fitzgerald et al. 2004b). Vanillin and vanillic acid had strong antimicrobial effects against *Listeria innocua*, *L. grayi*, and *L. seeligeri* and could be useful in the control of *Listeria* spp. in food products (Delaquis et al. 2005). Minimal inhibitory concentrations of 15, 75, and 35 mmol L^{-1} were established for *E. coli*, *Lactobacillus plantarum*, and *Listeria innocua* (Fitzgerald et al. 2004a). Vanillin at 2 mg mL^{-1} exhibited 90% mortality against mosquito (*Culex pipiens*) larvae (Sun et al. 2001).

Vanillin's antimutagenic effects have been shown in mice and bacteria (Imanishi et al. 1990; Ohta et al. 1988). Vanillin offers protection against X-ray and UV radiation-induced chromosomal change in V79 Chinese hamster lung cells (Keshava et al. 1998). Cytolytic and cytostatic effects shown by vanillin were found by Ho et al. (2009) and this could be a useful colorectal cancer preventive agent.

Antioxidant Properties

Vanillin is also found to be a good antioxidant. It offers significantly good protection against protein oxidation and lipid peroxidation induced by photosensitization in rat liver mitochondria (Kamat et al. 2000). Vanilla was shown to exhibit strong antioxidant activity by the peroxidase-based assay (Murcia et al. 2004). Extract of vanilla beans in ethyl alcohol (60%) had strong antioxidant activity using β-carotene-linoleate and DPPH in in vitro model systems, suggesting their potential as antioxidants for food preservation and in health supplements as nutraceuticals (Shyamala et al. 2007). The extract showed 26% and 43% of antioxidant activity by beta-carotene-linoleate and DPPH methods, respectively, in comparison to the corresponding values of 93% and 92% for BHA (Shyamala et al. 2007).

Regulatory Status

GRAS 182.10 and GRAS182.20, and 169.3.

Standard

ISO 3493 (Vocabulary), ISO 5565-1 (Specification), ISO 5565-2 (Test methods).

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Index

A
Abd El-Twab, T.M., 238
Abdalla, F.H., 312
Abdel-Wahhab, M.A., 419
Abdel-Zaher, A.O., 420
Abolhasani, F.A., 143, 163, 269, 291
ABTS cation radical scavenging capacity assay, 16–17
Adam, K., 540
Adhami, V.M., 550
Adisakwattana, S., 235
Aguilera, P., 313
Ahmad, N., 541
Ajowan
  active constituents, 142
  antioxidant properties, 143–144
  botanical description, 142
  cultivated in, 141–142
  flavor and aroma, 142
  history, 141
  medicinal uses and functional properties, 143
  parts usage, 142
  preparation and consumption, 142–143
Akinboro, A., 432
Al-Fayez, M., 441
Alkaloids
  curry leaf, 274, 276
  pepper black, 461
Allicin, 307, 309, 313–315
Allium cepa L. *See* Onion
Allium sativum L. *See* Garlic
Allium schoenoprasum L. *See* Chives
Allspice
  active constituents, 147
  antioxidant properties, 148–149
  botanical description, 146
  cultivated in, 146
  flavor and aroma, 146
  history, 145
  ISO standard, 149
  medicinal uses and functional properties, 148
  parts usage, 146
  preparation and consumption, 147
  regulatory status, 149
Allyl isothiocyanate
  horseradish, 349, 350
  mustard, 404, 405
Almajano, M.P., 96
Alpha-hederin, 416
Alvarez-Parrilla, E., 195
Aly, S.E., 419
Amensour, M., 412
Amin, A., 513
Amin, K.A., 238
Analgesic activity
  anise star, 167
  nigella, 420
  savory, 534
Anesthetic activity, 248
Anethole
  anise, 161
  anise star, 166–167
  fennel, 289
Anethum graveolens L. *See* Dill
Angelica
  active constituents, 152–153
  antioxidant properties, 154–155
  botanical description, 152
  cultivated in, 152
  flavor and aroma, 152
  history, 151–152

D.J. Charles, *Antioxidant Properties of Spices, Herbs and Other Sources*,
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Angelica (*cont.*)
medicinal uses and functional properties, 153–154
parts usage, 152
preparation and consumption, 153
regulatory status, 155
Angelica archangelica L. *See* Angelica
Angel's herb. *See* Angelica
Anise
active constituents, 161
antioxidant properties, 162–163
botanical description, 160
cultivated in, 160
flavor and aroma, 160
history, 159–160
ISO standards, 163
medicinal uses and functional properties, 162
parts usage, 160
preparation and consumption, 161–162
regulatory status, 163
Anise star
active constituents, 166
antioxidant properties, 167–168
botanical description, 166
cultivated in, 165
flavor and aroma, 166
history, 165
ISO standards, 168
medicinal uses and functional properties, 167
parts usage, 166
preparation and consumption, 166–167
regulatory status, 168
Anter, J., 95
Anthelmintic activity
fenugreek, 298
giner, 338
nigella, 417
pomegranate, 479
Anthocyanins
myrtle, 410
onion, 437
pomegranate, 479, 480, 483
Anthraquinones, 233
Anthriscus cerefolium L. *See* Chervil
Antibacterial activity
allspice, 148
anise star, 167
basil, 176
bay leaf, 184
caraway, 202, 203
cinnamon, 234–236
coriander, 259
cumin, 268
curry leaf, 275
dill, 285
geranium, 331
ginger, 338
juniper, 359
lavender, 363, 365, 366
lemon balm, 373
lemongrass, 379
nutmeg, 430, 431
onion, 438
oregano, 452, 453
pepper black, 463
tarragon, 549
thyme, 556, 557
tumeric, 566, 567
vanilla, 585
Anticancer activity
clove, 249
geranium, 331
mustard, 405, 406
nutmeg, 431
onion, 438, 441
oregano, 454
tarragon, 548
Anticarcinogenic effect
capsicum, 194
caraway, 202
celery seed, 217
poppy, 492
Antidepressant properties
lavender, 363, 365
saffron, 512
Antidiabetic activity
cumin, 268, 269
curry leaf, 275
garlic, 309
Antidiabetic effects
asafoetida, 171
marjoram sweet, 396, 397
onion, 438, 441
sage, 524, 525
Antifungal activity
allspice, 148
anise star, 167
asafoetida, 171
basil, 176
bay leaf, 184
clove, 248
coriander, 259
cumin, 268
curry leaf, 275
fennel, 290
garlic, 309

geranium, 331
ginger, 338
lemongrass, 379
rosemary, 498, 499
tarragon, 449
thyme, 556
vanilla, 584
Antihemolytic activity, 172
Anti-HIV, 355
Anti-inflammatory activity
capsicum, 194
cinnamon, 234, 236, 237
clove, 248–249
coriander, 260
fennel, 290, 291
giner, 338–340
ginger, 339
juniper, 359
lemongrass, 379, 380
licorice, 387, 389
myrtle, 411
nutmeg, 430, 431
nigella, 417, 418
onion, 439
oregano, 452
pepper black, 463
peppermint, 531
pomegranate, 479, 481
rosemary, 498, 501
sage, 524–526
savory, 534
spearmint, 539, 541
tarragon, 548, 549
thyme, 556, 557
tumeric, 566, 567, 570
Anti-lipoperoxidation, 224
Antimicrobial activity
ajowan, 143
anise, 162
basil, 176
bay leaf, 184
chives, 227, 228
cinnamon, 234–236
clove, 248
coriander, 259
cumin, 268, 269
dill, 285
fennel, 290
fenugreek, 298
garlic, 309
geranium, 331
giner, 338
horseradish, 350
hyssop, 355
juniper, 359
lavender, 365
lemon balm, 373
marjoram sweet, 396
myrtle, 411
nutmeg, 430
nigella, 417, 420
onion, 438, 442
oregano, 453
pepper black, 463
peppermint, 530
rosemary, 498, 499
sage, 524, 525
savory, 534
spearmint, 540
thyme, 556
tumeric, 566
vanilla, 585
Antimutagenic activity
pomegranate, 480
savory, 534
Antineoplastic activity, 275
Antioxidants
abiotic stresses, 21
ABTS cation radical scavenging capacity assay, 16–17
activity, 9
ajowan, 143–144
allspice, 148–149
angelica, 154–155
anise, 162–163
anise star, 167–168
asafoetida, 171–172
basil, 176–177
bay leaf, 184–185
capacity, 9
capsicum, 194–195
caraway, 203–204
cardamom, 210–211
celery seed, 216–217
cellular antioxidant activity assay, 25
chervil, 224
chives, 238
cinnamon, 237–238
clove, 249
copper (II) chelating capacity assay, 23
coriander, 260
crocin bleaching assay, 12
cumin, 268–269
cupric ion reducing antioxidant capacity assay, 18–19
curry leaf, 276
defense system, 22
definition, 9

Antioxidants (*cont.*)
dill, 285
DMPD$^{\bullet+}$ scavenging assay, 17–18
DPPH radical scavenging capacity assay, 12–14
electron transport chain (ETC), 21
enzymes, 20
catalase, 57
glutathione peroxidase, 57–58
superoxide dismutase, 56–57
factors, 11
fennel, 290–291
fenugreek, 298–299
ferric reducing antioxidant power assay, 18
ferric thiocyanate assay, 12
garlic
aged garlic extract, 310–311
allicin, 313
antiaging effects, 316
antiatherogenic effect, 310
anticancerous effect, 315
chemopreventive effects, 312
combination therapy, 317
hepatoprotective effects, 313
mechanisms, 309–310
OSC, 313–314
streptozotocin-induced, 310–311
Generally Recognized as Safe (GRAS) numbers, 22
geranium, 332
giner, 338–341
horseradish, 350–351
hydroxyl radical ($^{\bullet}$OH) scavenging capacity assay (HOSC)
hydrophilic antioxidants, 20–22
lipophilic antioxidants, 22
hyssop, 355, 356
iron (II) chelating capacity assay, 22
juniper, 359–360
lavender, 365, 366
lemon balm, 373, 374
lemongrass, 379, 380
licorice, 388, 389
lipid peroxidation inhibition assay, 23–24
low-density lipoprotein peroxidation inhibition assay, 24
marjoram sweet, 396, 397
mechanisms, 10
mustard, 406, 407
myrtle, 411, 412
nutmeg, 431–432
nigella, 417–420
nitric oxide radical (NO$^{\bullet}$) scavenging capacity assay, 24–25
onion
anti-resorbing properties, 439
apigenin, 441
chemopreventive effects, 440
erectile dysfunction, 442
methanolic extract, 440
protective effects, 442
quercetin, 439
spermiotoxicity, 441
oxidative stress, 19
oxygen radical absorbing capacity (ORAC) assay, 14–15
pepper black, 463–464
peppermint, 530–531
pomegranate, 480–483
poppy, 492
reactive oxygen species (ROS), 19–20
rosemary, 498–501
saffron, 513–517
sage, 524–526
savory, 534
spearmint, 540
superoxide anion radical ($O_2^{\bullet-}$) scavenging capacity (SOSA), 19–20
tarragon, 549
thyme, 556–557
total flavonoid content assay, 26
total phenolic content (TPC) assay, 25–26
total radical-trapping antioxidant parameter (TRAP) assay, 15–16
tumeric, 566, 567, 570–573
vanilla, 586
Antiparasitic activity
ginger, 338
licorice, 387
Antiproliferative activity
angelica, 153
bay leaf, 184
chives, 228
pomegranate, 479, 480, 482
sage, 525
Antirheumatic activity, 216
Antiseptic activity
clove, 248
cumin, 268
horseradish, 350
marjoram sweet, 396
myrtle, 409, 411
sage, 524
Antispasmodic activity
clove, 248
curry leaf, 275
saffron, 512
Antistress, 204

Antitermitic activity, 285
Antitumor activity
  chives, 227
  cinnamon, 234
  curry leaf, 275
  garlic, 310
  giner, 338
  lemon balm, 373
  licorice, 387
  pepper black, 463
  pomegranate, 479
  savory, 534
Antiulcer activity
  licorice, 387
  peppermint, 531
Antiulcerogenic activity, 184
Antiviral activity
  asafoetida, 171
  caraway, 203
  lemon balm, 373
  peppermint, 530
  rosemary, 498
  tumeric, 566
Apak, R., 18
Apigenin
  celery seed, 214, 217
  lemongrass, 378
  oregano, 451
  thyme, 554
Apiin, 222
Apium graveolens L. *See* Celery seed
Appetizer, 405
Aristatile, B., 454
Armoracia rusticana. *See* Horseradish
Arnao, M.B., 16
Artemisia dracunculus L. *See* Tarragon
Arulselvan, P., 276
Arumugam, P., 541
Asafoetida
  active constituents, 170–171
  antioxidant properties, 171–172
  botanical description, 170
  cultivated in, 169–170
  flavor and aroma, 170
  history, 169
  medicinal uses and functional properties, 171
  parts usage, 170
  preparation and consumption, 171
  regulatory status, 172
Ascorbic acid
  horseradish, 349
  oxygen scavenger, 56
  structures, 39, 45
Asdaq, S.M., 514
Ashraf, S.S., 419
Asnani,V.M., 340
Assimopoulou, A.N., 514
Augusti, K.T., 440
Avenasterol, 491
Aviram, M., 539
Azab, K.S., 238

B
Badary, O.A., 419
Baked goods, 331
Bakery products, 337
Baliga, M.S., 291
Ban, J.O., 316
Basil
  active constituents, 174–175
  antioxidant properties, 176–177
  botanical description, 174
  cultivated in, 174
  flavor and aroma, 174
  history, 173
  ISO standard, 177
  medicinal uses and functional properties, 175–176
  nutrient composition and ORAC values, 175
  parts used, 174
  preparation and consumption, 175
  regulatory status, 177
  uses, 173
Bay leaf
  active constituents, 183
  antioxidant activity, 184–185
  botanical description, 182
  cultivated in, 182
  flavor and aroma, 182
  history, 181–182
  ISO standard, 185
  medicinal uses and functional properties, 184
  nutrient composition, 183
  parts used, 182
  preparation and consumption, 183
  regulatory status, 185
Bayrak, O., 419
Beddows, C.G., 269
Belinky, P.V., 388
Ben Amor, N., 185
Benzie, I.F., 18
Bergapten, 161
Besharati-Seidani, A., 162
Betulin, 497

Bhadra, S., 167
Bhatnagar, D., 167
Billerey-Larmonier, C., 569
Bisdemethoxycurcumin, 566, 569
Blois, M.S., 12
Blomhoff, R., 148
Bors, W., 12
Botsoglou, N.A., 453, 454
Bouquet garni, 183
Brand-Williams, W., 13
Brassica juncea (L.). *See* Mustard
Buchbauer, G., 365

C
Caffeic acids
  celery seed, 214
  lemon balm, 373, 374
  lemongrass, 378, 380
  marjoram sweet, 394
  onion, 436
  oregano, 451
  peppermint, 528
  saffron, 511
  sage, 522, 524
  spearmint, 540
  thyme, 554
Campestrol, 490
Camphor
  rosemary, 496, 497
  sage, 522
  savory, 533
Campos, C., 19
Capsaicin, 192, 194
Capsaicinoids, 192, 194, 195
Capsanthin, 192, 194, 195
Capsicum
  active constituents, 192–193
  antioxidant properties, 194–195
  botanical description, 191
  cultivated in, 190
  flavor and aroma, 192
  history, 189–190
  ISO standard, 196
  medicinal uses and functional properties, 194
  parts used
    cayenne pepper, 192
    fruit, 191
    paprika pepper, 192
    red/chili pepper, 192
  preparation and consumption, 193
  regulatory status, 195
Capsicum annuum L. *See* Capsicum
Caraway
  active constituents, 201
  antioxidant properties, 203–204
  botanical description, 200
  cultivated in, 200
  flavor and aroma, 201
  history, 199–200
  ISO standard, 204
  medicinal uses and functional properties, 202–203
  parts used, 200
  preparation and consumption, 202
  regulatory status, 204
Cardamom
  active constituents, 209
  antioxidant properties, 210–211
  botanical description, 208
  cultivated in, 208
  flavor and aroma, 208
  history, 207–208
  ISO standard, 211
  medicinal uses and functional properties, 210
  parts used, 208
  preparation and consumption, 209–210
  regulatory status, 211
Carminative
  allspice, 148
  capsicum, 194
  caraway, 202
  cardamom, 210
  celery seed, 216
  clove, 248
  coriander, 259
  cumin, 268
  curry leaf, 275
  dill, 284
  fennel, 290
  garlic, 309
  hyssop, 355
  juniper, 359
  lavender, 363, 365
  pepper black, 463
  peppermint, 530
  spearmint, 539
Carnosic acid
  rosemary, 497–501
  sage, 522, 524–526
Carnosol
  rosemary, 497–501
  sage, 522, 524, 525
Carotenes
  chives, 226
  curry leaf, 274
  peppermint, 529

Carotenoids
antioxidant defense system, 53
capsicum, 192, 194
classification, 54
coriander, 257
extended electron delocalization, 54
oxidative stress, 55
saffron, 511, 513–515
sage, 522
tarragon, 546
Carum carvi L. *See* Caraway
Carvacrol
nigella, 416
oregano, 451–454
savory, 533, 534
thyme, 554, 557
Carvone
caraway, 202, 203
dill, 283
spearmint, 538, 540
β-Caryophyllene
curry leaf, 274
fenugreek, 297
pepper black, 461
Catechol
lemongrass, 378
saffron, 511
Celery seed
active constituents, 214–215
antioxidant properties, 216–217
botanical description, 214
cultivated in, 213–214
flavor and aroma, 214
history, 213
ISO standard, 217
medicinal uses and functional properties, 216
parts used, 214
preparation and consumption, 216
regulatory status, 217
Cellular antioxidant activity assay, 25
Cereals
antioxidant content, 82
buckwheat, 83
corn, 84
oats, 87–88
rice, 85–86
wheat, 86–87
Chandra, S., 420
Chang, Y.P., 339
Chemopreventive
mustard, 406
saffron, 512–514
Cheng, Z., 13, 15, 22
Chervil
active constituents, 222–223
antioxidant properties, 224
botanical description, 222
cultivated in, 222
flavor and aroma, 222
history, 221–222
medicinal uses and functional properties, 223–224
parts used, 222
preparation and consumption, 223
regulatory status, 224
Chirathaworn, C., 431
Chives
active constituents, 226–227
antioxidant properties, 228
botanical description, 226
cultivated in, 226
flavor and aroma, 226
history, 225
medicinal uses and functional properties, 227–228
methanolic extract, 228
parts used, 226
preparation and consumption, 227
regulatory status, 228
Chlorogenic acid
lemongrass, 378, 380
peppermint, 528
Chohan, M., 107
Cholestanol, 491
Choudhury, R.P., 541
1,8-Cineole
bay leaf, 183
cardamom, 209
lavender, 364
rosemary, 497
sage, 522
savory, 533
thyme, 554
Cinnamaldehyde, 233–235, 237, 238
Cinnamate, 237
Cinnamic acid, 511
Cinnamomum verum. *See* Cinnamon
Cinnamon
active constituents, 233
antioxidant properties, 237–238
botanical description, 232
cultivated in, 232
flavor and aroma, 232
history, 231–232
ISO standard, 238
medicinal uses and functional properties, 234–236

Cinnamon (*cont.*)
parts used, 232
preparation and consumption, 233–234
regulatory status, 238
Cinnamtannin B-1, 185
Citronellal, 373, 374
Citronellol, 330
Clove
active constituents, 247
antioxidant properties, 249
botanical description, 246
cultivated in, 246
flavor and aroma, 246
history, 245–246
ISO standard, 250
medicinal uses and functional properties, 248–249
parts used, 246
preparation and consumption, 247–248
regulatory status, 250
Coenzyme Q10. *See* Ubiquinone
Colorant, 565
Coloring agent, 511
Conforti, F., 185, 291
Copper(II) chelating capacity assay, 23
Coriander
active constituents, 257–259
antioxidant properties, 260
botanical description, 256
cultivated in, 256
flavor and aroma, 257
history, 255–256
ISO standard, 261
medicinal uses and functional properties, 259–260
parts used, 256
preparation and consumption, 259
regulatory status, 261
Coriandrum sativum L. *See* Coriander
Costa, C.A., 379
p-Coumaric acid
celery seed, 214
saffron, 511
Coumarins
anise, 161
asafoetida, 170–171
cinnamon, 233
geranium, 330
juniper, 359
lavender, 364
licorice, 386
oregano, 349
tarragon, 546, 548
Crocetin, 511–513, 515, 516
Crocin, 510–515
Crocin bleaching assay, 12
Crocus sativus L. *See* Saffron
Cubebin, 461
Cumin
active constituents, 267
antioxidant properties, 268–269
botanical description, 266
cultivated in, 266
flavor and aroma, 267
history, 265–266
ISO standard, 269
medicinal uses and functional properties, 268
parts used, 266
preparation and consumption, 268
regulatory status, 269
Cuminic aldehyde, 267
Cuminum cyminum L. *See* Cumin
Cupric ion reducing antioxidant capacity assay, 18–19
Curcuma longa L. *See* Turmeric
ar-Curcumene, 337
Curcumin, 565–272
Curcuminoids, 565–567, 571
Curlone, 565
Curry leaf
active constituents, 274
antioxidant properties, 276
botanical description, 274
cultivated in, 273
flavor and aroma, 274
history, 273
medicinal uses and functional properties, 275–276
parts used, 274
preparation and consumption, 274
Cymbopogon citratus. *See* Lemongrass
p-Cymene, 416
Cytoprotective effect, 153–154

D

Das, A., 315
Das Gupta, A., 312
Das, I., 513
De Beer, D., 13
Dearlove, R.P., 397
Deeptha, K., 203
Demethoxycurcumin, 566, 569
Demirkaya, E., 312
Devasena, T., 299
Dhake, A.S., 431
Dhar, A., 513

Diallyl disulfide (DADS)
chives, 226, 228
garlic, 310
Diallyl monosulfide, 226, 228
Diallyl sulfide, 309, 310, 314, 315
Diallyl tetrasulfide, 226, 228
Diallyl trisulfide (DATS)
chives, 226, 228
garlic, 310, 315
Diaphoretic properties, 396
Dietz, B.M., 155
Digestive purposes, 175
Dihydrocapsaicin, 192
Dihydroguaiaretic acid, 430
Dill
active constituents, 283
antioxidant properties, 285
botanical description, 282
cultivated in, 282
flavor and aroma, 283
history, 281–282
medicinal uses and functional properties, 284–285
parts used, 282
preparation and consumption, 284
regulatory status, 285
Dill pickle, 284
Dilsiz, N., 299
Diosgenin, 297, 298
Diosmetin
oregano, 451
rosemary, 497
spearmint, 538
thyme, 554
Diosmin
hyssop, 354, 356
spearmint, 538
Dithymoquinone, 416
Diuretic
chervil, 223
horseradish, 350
juniper, 359
spearmint, 539
DMPD$^{\bullet+}$ scavenging assay, 17–18
Dorman, H.J., 531
DPPH radical scavenging capacity assay, 12–14
Dragland, S., 105, 148, 355, 374
Dutta, K., 572

E
Ebru, U., 419
El-abhar, H.S., 340
El-Ashmawy, I.M., 396
El-Demerdash, F.M., 441
Elettaria cardamomum. *See* Cardamom
Elimicin, 378
Elisabetsky, E., 331
El-Khawas, K.H., 162, 269
Ellagic acid (EA)
myrtle, 410
pomegranate, 479, 480, 482
Ellagitannins, 479, 480
Elsaid, F.G., 340
El-Sharaky, A.S., 340
Emmenagogue, 512
Eriodictyol, 451
Essential oil
ajowan, 142–144
allspice, 146, 148–149
angelica, 152, 154
anise, 160, 162, 163
anise star, 166–167
asafoetida, 170
basil, 174, 176
bay leaf, 182–184
capsicum, 192, 193
caraway, 200, 201, 203, 204
cardamom, 208, 210
celery seed, 214, 216, 217
chervil, 222
chives, 226
cinnamon, 232, 233, 235–238
clove, 248, 249
coriander, 259
cumin, 268, 269
curry leaf, 274, 275
dill, 283–285
fennel, 289–291
fenugreek, 296, 297
garlic, 309
geranium, 330–332
ginger, 336–338, 340
horseradish, 350
hyssop, 354, 355
juniper, 358, 359
lavender, 363–366
lemon balm, 373, 374
lemongrass, 377–379
licorice, 386
marjoram sweet, 394, 396, 397
mustard, 404
myrtle, 409–412
nutmeg, 429–431
nigella, 416, 418–420
onion, 436–438
oregano, 450–454
pepper black, 461, 463, 464
peppermint, 528–531

Essential oil (*cont.*)
rosemary, 496–500
sage, 522, 524
savory, 533, 534
spearmint, 538–541
tarragon, 546, 548
thyme, 553, 554, 556, 557
tumeric, 565, 568
Estevez, M., 53
Estrogenic property, 290
Ethyl vanillin, 584
Eugenol
allspice, 147–149
basil, 174
cinnamon, 233
clove, 247–249
Ezz, H.S., 420

F
Farag, R.S., 162, 269
Faria, A., 540
Fennel
active constituents, 289, 290
antioxidant properties, 290–291
botanical description, 288
cultivated in, 288
flavor and aroma, 288
history, 287–288
ISO standard, 291
medicinal uses and functional properties, 290
parts used, 288
preparation and consumption, 289
regulatory status, 291
Fenugreek
active constituents, 297
antioxidant properties, 298–299
botanical description, 296
cultivated in, 296
flavor and aroma, 296
history, 295–296
ISO standard, 300
medicinal uses and functional properties, 298
parts used, 296
preparation and consumption, 297
regulatory status, 299
Ferreira, A., 185
Ferric reducing antioxidant power assay, 18
Ferric thiocyanate assay, 12
Ferula assa-foetida L. *See* Asafoetida
Ferulic acid
angelica, 153–154
asafoetida, 171
celery seed, 214
marjoram sweet, 394
saffron, 511
Flavonoid glycosides, 161
Flavonoids
allspice, 147
angelica, 153, 155
anise, 163
anise star, 166
asafoetida, 171–172
basil, 174
capsicum, 195
caraway, 201, 203
cardamom, 211
celery seed, 214, 217
cinnamon, 233
clove, 247
coriander, 260
cumin, 267, 269
dill, 283
fennel, 289, 291
fenugreek, 297
geranium, 330–332
hyssop, 354
juniper, 359
lavender, 364, 366
lemon balm, 373
lemongrass, 378
licorice, 386, 387
marjoram sweet, 396
myrtle, 410, 412
onion, 436, 438–440, 442
oregano, 451
peppermint, 528, 531
rosemary, 497–499
saffron, 511
sage, 522
savory, 534
spearmint, 538, 541
tarragon, 546, 548
thyme, 554
Flavonols, 461
Flavoring
ajowan, 142–143
allspice, 146–147
angelica, 151–153
anise, 160–162
anise star, 166–167
asafoetida, 170–171
bay leaf, 183
capsicum, 193
caraway, 201
cardamom, 210
celery seed, 214, 216
chervil, 223

chives, 226, 227
cinnamon, 232–234
clove, 247
coriander, 256, 259
cumin, 265, 266, 268
curry leaf, 273, 274
dill, 281
fennel, 289
fenugreek, 296
garlic, 307, 309
horseradish, 350
hyssop, 354
juniper, 358
lavender, 365
lemon balm, 373
lemongrass, 377, 379
licorice, 386, 387
marjoram sweet, 394
mustard, 403
myrtle, 409, 411
nutmeg, 429
nigella, 416
onion, 436
oregano, 449
pepper black, 462
peppermint, 527
pomegranate, 478
poppy, 490, 491
rosemary, 497
saffron, 511
sage, 522, 523
savory, 531–533
spearmint, 538, 539
tarragon, 545–547
thyme, 553–555
tumeric, 564–566
vanilla, 581–585
Foeniculum vulgare. *See* Fennel
Fogliano, V., 17
Food of the Gods. *See* Asafoetida
Franceschelli, S., 389
Frautschy, S.A., 571
Fruits and berries
antioxidant content, 66, 88
apple, 92–93
beverages, 68, 88
blueberries, 91–92
cherries, 90
citrus fruit, 93
color code groups, 68, 98
cranberry and blueberry, 89
grapes, 94–95
kiwifruit, 93–94
phenolics, 91
polyphenol-rich beverages, 89
strawberries, 90–91
Furocoumarins, 153

G
Gallic acid
myrtle, 411
pomegranate, 482
saffron, 511, 515
Galluzzo, P., 439
Gamal El-Din A.M., 419
Garlic
active constituents, 307–308
antioxidant properties
aged garlic extract, 310–311
allicin, 313
antiaging effects, 316
antiatherogenic effect, 310
anticancerous effect, 315
chemopreventive effects, 312
combination therapy, 317
hepatoprotective effects, 313
mechanisms, 309–310
OSC, 313–314
streptozotocin-induced, 310–311
botanical description, 306
cultivated in, 306
flavor and aroma, 307
history, 305–306
ISO standard, 317
medicinal uses and functional properties, 309
parts used, 306
preparation and consumption, 308
regulatory status, 317
Garnish
chervil, 223
chives, 227
Lemon balm, 373
thyme, 555
Gastroprotective effect, 210
Gentisic acid, 511
Georgiev, V.G., 101
Geranial
lemon balm, 373, 374
lemongrass, 378
Geraniol, 330
Geranium
active constituents, 330
antioxidant properties, 332
botanical description, 330
cultivated in, 330
flavor and aroma, 330

Geranium (*cont.*)
history, 329–330
ISO standard, 332
medicinal uses and functional properties, 331
parts used, 330
preparation and consumption, 331
regulatory status, 332
Ghiselli, A., 15
Ghosh, M., 407
Ginger
active constituents, 337
antioxidant properties, 339–341
botanical description, 336
cultivated in, 336
flavor and aroma, 336
functional properties, 338–339
history, 335–336
ISO standard, 341
medicinal uses, 338–339
parts used, 336
preparation and consumption, 337–338
regulatory status, 341
Gingerbread, 335, 337
Gingerols, 337–339
Glabridin 4'-*O*-methylglabridin, 388
Glucosinolates, 349, 350
Glycyrrhiza glabra L. *See* Licorice
Glycyrrhizin, 386
Gollapudi, S., 355
Gowda, N.K., 571
Goyal, S.N., 514
Guo, C., 540
Gupta, S.K., 299
Gurjenene, 274

H
Haleagrahara, N., 442
Halvorsen, B.L., 105
Ham, A., 184
Hamdy, N.M., 420
Hart, S., 331
Hassan, H.A., 312
Hayder, N., 412
Heinonen, M., 53
Heo, H.J., 396
Hepatoprotective activity, 299
Herbe royale, 173
Herbs and spices
active constituents, 73–75, 106
antioxidant activity and polyphenol content, 70, 105
antioxidant content, 71, 105
curcumin, 106
dietary agents, 108
medicines, 104
oregano, 107
parsley, 107–108
phenolic, flavonoid, and ORAC values in spices, 70, 105
phenolic, flavonoid, flavanol, and ORAC values in herbs, 71, 105
scavenging rate of herbs, 72, 106
total phenolic and flavonoid content of spices, 70, 105
total phenolic content and ORAC values, 69, 105
Hesperidin
peppermint, 528
thyme, 554
Hispaglabridin A, 388
Hispaglabridin B, 388
Ho, K., 585
Ho, S.C., 269
Horseradish
active constituents, 349
antioxidant properties, 350–351
botanical description, 348
cultivated in, 348
flavor and aroma, 348
history, 347–348
medicinal uses and functional properties, 350
nutrient composition, 349
parts used, 348
preparation and consumption, 349–350
regulatory status, 351
Horseradish peroxidase (HRP), 350
Hosono-Fukao, T., 315
Hosseinzadeh, H., 512
HRP. *See* Horseradish peroxidase
Huang, B., 236
Huang, C.C., 236
Huang, D., 15
Hubbard, G.B., 439, 441
Hung, H., 440
Huo, H.Z., 389
Hydroquinone, 378, 380
p-Hydroxybenzaldehyde, 584
p-Hydroxybenzoic acid, 584
Hydroxyl radical ($^{\bullet}$OH) scavenging capacity assay (HOSC), 20–22
hydrophilic antioxidants, 20–22
lipophilic antioxidants, 22
Hypoglycemic activity, 338
Hypolipidemic activity
bay leaf, 184
clove, 249

Hyssop
active constituents, 254
antioxidant properties, 355–356
botanical description, 354
cultivated in, 354
flavor and aroma, 354
history, 353
ISO standard, 356
medicinal uses and functional properties, 355
parts used, 354
preparation and consumption, 354–355
Hyssopus officinalis L. *See* Hyssop

I
Ignarro, L.J., 540
Illicium verum. *See* Anise star
Inamdar, M.N., 514
Insecticidal activity, 411
Iorizzi, M., 194
Iron (II) chelating capacity assay, 22
Ishrat, T., 571
Isoliquiritigenin, 387–389
Isomenthone
lemon balm, 374
peppermint, 529, 531
Isoorientin, 161
Isoorientin 2'-*O*-rhamnoside, 378
Isoquercetin
pepper black, 461
pomegranate, 478
Isoquercitrin, 201
Isorhamnetin 7-*O*-glucoside, 406
Isovitexin, 161
Iuvone, T., 525
Ivanova, D., 274
Izawa, H., 442

J
Jamal, A., 210
Jhanji, V., 388
Jia, Z., 94
Jowko, E., 97
Juglans sregia L., 77
Jung, H.W., 340
Juniper
active constituents, 358–359
antioxidant properties, 360
botanical description, 358
cultivated in, 358
flavor and aroma, 358
history, 357–358
ISO standard, 360
medicinal uses and functional properties, 359
parts used, 358
preparation and consumption, 359
regulatory status, 360
Juniperus communis L. *See* Juniper

K
Kaempferol
celery seed, 214, 217
fennel, 289
lemongrass, 378
thyme, 554
Kaempferol glycosides, 406
Kale, R.K., 143
Kaleem, M., 419
Kamaleeswari, M., 203
Kampa, M., 12
Kanter, M., 419
Kaplan, M., 539
Kaspar, K.L., 100
Katikova, O., 472
Kaviarasan, S., 299
Kesari, A.N., 275
Khan, N., 419
Kikuzaki, H., 149
Kim, D.H., 237
Kim, G.D., 195
Kim, I.S., 107
King of spices, 459
Koutelidakis, A.E., 332
Kovacheva, E., 366
Kumari, K., 440
Kuo, C.L., 568

L
Larvicidal activity
ajowan, 143
anise, 162
lemongrass, 379
Laurus nobilis. *See* Bay leaf
Lavandula angustifolia. *See* Lavender
Lavender
active constituents, 364
antioxidant properties, 366
botanical description, 364
cultivated in, 364
flavor and aroma, 364
history, 363–364

Lavender (*cont.*)
ISO standard, 366
medicinal uses and functional properties, 365
parts used, 364
preparation and consumption, 365
regulatory status, 366
Lee, E.K., 311
Lee, H.S., 311
Lee, J.H., 101
Lee, J.K., 101
Lee, J.S., 237
Lee, M.A., 407
Lee, Y.M., 311
Legumes
antioxidant content, 66, 80
peanut, 81
phenolics, 81
tannins, 82
Lei, X, 418
Lei, Y.P., 310
Lemon balm
active constituents, 373
antioxidant properties, 374
botanical description, 372
cultivated in, 372
flavor and aroma, 372
history, 371–372
medicinal uses and functional properties, 373–374
parts used, 372
preparation and consumption, 373
regulatory status, 374
Lemongrass
active constituents, 378
antioxidant properties, 379–380
botanical description, 378
cultivated in, 378
flavor and aroma, 378
history, 377
ISO standard, 381
medicinal uses and functional properties, 379
parts used, 378
preparation and consumption, 379
regulatory status, 380
Lewith, G.T., 365
Licoagroaurone, 387
Licoagrochalcones, 387
Licoagrodin, 387
Licorice
active constituents, 386
antioxidant properties, 388–389
botanical description, 386
cultivated in, 386
flavor and aroma, 386
history, 385
medicinal uses and functional properties, 387–388
parts used, 386
preparation and consumption, 386
Lignans
anise star, 166
juniper, 359
nutmeg, 431, 432
pepper black, 461
spearmint, 538
Lignins, 201
Lim, H.W., 569
Limonene
allspice, 153
caraway, 202, 203
cardamom, 209
celery seed, 214
juniper, 358
lavender, 364
myrtle, 410
pepper black, 462
rosemary, 497
sage, 522
savory, 533
spearmint, 538
Linalool
basil, 174
coriander, 260
geranium, 330, 331
lavender, 364, 365
lemongrass, 378
marjoram sweet, 394
oregano, 451
thyme, 554
Lines, T.C., 442
Linoleic acid, 166
Lipid peroxidation inhibition assay, 23–24
Lis-Balchin, M., 331
Liu, J.H., 154
Liu, S.P., 154
Low-density lipoprotein peroxidation inhibition assay, 24
Lu, Y., 172
Luteolin
celery seed, 214, 217
lemon balm, 373
oregano, 451
peppermint, 528
rosemary, 497, 498
thyme, 554
Luteolin-7-glucoside, 222

M
Mabrouk, G.M., 419
Macelignan, 431
Machilin, F., 431
Maeda, A., 432
Magesh, V., 515
Mahady, G.B., 569
Mahattanadul, S., 570
Makino, T., 176
Marjoram sweet
  active constituents, 394–395
  antioxidant properties, 396–397
  botanical description, 394
  cultivated in, 394
  flavor and aroma, 394
  history, 393
  ISO standard, 397
  medicinal uses and functional properties, 396
  parts used, 394
  preparation and consumption, 395
  regulatory status, 397
Martinez-Tome, M., 269
Mastrangelo, S., 442
Mateos, R.M., 194
Materska, M., 195
Mattila, P., 85
Medicinal effects, 492
Meera, R., 299
Meeting house seeds, 282
Melissa officinalis L. *See* Lemon balm
Menon, V.P., 299
Mentha × piperita L. *See* peppermint
Mentha spicata L. *See* Spearmint
Menthol, 528–530
Menthone, 374
Methyl chavicol
  basil, 174
  chervil, 223
Meyers, K.J., 439
Miller, N.J., 16
Miyazaki, H., 355
Mofleh, I.A., 163
Mohan, M., 541
Monga, J., 177
Moore, J., 15
Morita, T., 431
Mousa, A.S., 315
Mousa, S.A., 315
Mousavi, S.H., 512, 514
Murcia, M.A., 431
Murota, K., 442
Murraya koenigii Spreng. *See* Curry leaf
Mustard
  active constituents, 403–404
  antioxidant properties, 406–407
  botanical description, 403
  cultivated in, 402–403
  flavor and aroma, 403
  history, 401–402
  ISO standard, 407
  medicinal uses and functional properties, 405–406
  parts used, 403
  preparation and consumption, 404–405
  regulatory status, 407
Myrcene, 358
Myristica fragrans. *See* Nutmeg
Myristicin
  cinnamon, 236
  nutmeg, 429–431
Myrtenol, 410
Myrtenyl acetate, 410
Myrtle
  active constituents, 410
  antioxidant properties, 411–412
  botanical description, 410
  cultivated in, 410
  flavor and aroma, 410
  history, 409
  medicinal uses and functional properties, 411
  parts used, 410
  preparation and consumption, 410–411
  regulatory status, 412
Myrtus communis L. *See* Myrtle

N
Naidu, A.K., 568
Nair, S., 211
Nakatani, N., 24, 148, 396
Nalini, N., 203, 464
Nanji, A.A., 569
Narasimhan, B., 431
Naringenin, 554
Natural antioxidants
  ascorbic acid, 56
  carotenoids, 53–55
  coenzyme Q, 55
  enzymes, 56–58
  sources of
    cereals, 82–88
    fruits and berries, 66, 68, 88–95, 98
    herbs and spices, 69–75, 104–108
    legumes, 66, 80–82

Natural antioxidants (*cont.*)
nuts, 66, 76–78
oilseeds, 78–80
teas, 95–98
total antioxidant capacity of food in USA, 65, 75
vegetables, 66–68, 98–104
structures
alpha-, beta, gamma-and delta-tocopherols and tocotrienols, 39, 44
ascorbic acid and ascorbyl palmitate, 39, 45
beta-carotene, 39, 44
phenolic compounds, 39–44
spice chemicals, 39, 45–46
ubiquinone, 39, 44
tocopherols, 52–53
Nectandrin, B., 431
Nematicidal activity, 290
Neral
Lemon balm, 373, 374
lemongrass, 378
Neryl acetate, 297
Nickavar, B., 143, 163, 269, 291
Nigella
active constituents, 416
antioxidant properties, 418–420
botanical description, 416
cultivated in, 416
flavor and aroma, 416
history, 415
medicinal uses and functional properties, 417–418
parts used, 416
preparation and consumption, 417
regulatory status, 420
Nigella sativa L. *See* Nigella
Nigellicine, 416
Nigellidine, 416
Nigellimine-N-oxide, 416
Nishimura, H., 440
Nitric oxide radical (NO•) scavenging capacity assay, 24–25
Nitzsche, A., 366
Noscapine, 492
Nutmeg
active constituents, 429, 430
antioxidant properties, 431–432
botanical description, 428
cultivated in, 428
flavor and aroma, 429
history, 427–429
ISO standard, 432
medicinal uses and functional properties, 430–431
parts used, 429
preparation and consumption, 429
regulatory status, 432
Nuts
antioxidant content, 66, 76
bioactive constituents, 77
cashew, 77
hazelnut oil, 76
pecan, 77
walnuts, 77–78

O
Obioha, U.E., 311
Ochiai, T., 514
Ocimum basilicum L. *See* Basil
Ohashi, Y., 568
Oilseeds
canola, 80
cottonseed, 79
flaxseed, 79
soybeans, 79–80
sterols, 78
sunflower, 78–79
Ola-Mudathi, K.F., 441
Onion
active constituents, 436–437
antioxidant properties
anti-resorbing properties, 439
apigenin, 441
chemopreventive effects, 440
erectile dysfunction, 442
methanolic extract, 440
protective effects, 442
quercetin, 439
spermiotoxicity, 441
botanical description, 436
cultivated in, 436
flavor and aroma, 436
history, 435
ISO standard, 442
medicinal uses and functional properties, 438–439
parts used, 436
preparation and consumption, 437–438
regulatory status, 442
Ono, M., 442
Oregano
active constituents, 451
antioxidant properties, 453–454
botanical description, 450
cultivated in, 450
flavor and aroma, 450
history, 449–450
ISO standard, 454

medicinal uses and functional properties, 452–453
parts used, 450
preparation and consumption, 452
regulatory status, 454
Organosulfur compounds (OSC), 309, 313
Origanum majorana L. *See* Marjoram sweet
Origanum vulgare L. *See* Oregano
Ortiz-Ortiz, M.A., 568
Ovicidal activity, 162
Oxygen radical absorbing capacity (ORAC) assay, 14–15
Oya, T., 148

P
Padmakumari, K.P., 149
Pan, X., 95
Panch phoron, 297
Panda, S., 285
Pandey, S.K., 143
Papandreou, M.A., 515
Papaver somniferum L. *See* poppy
Paradols, 337, 338
Park, I.K., 350
Park, S., 440
Patel, R.S., 276
Patil, S.B., 143
Pelargonium graveolens L'Her. ex Aiton. *See* Geranium
Peng, C.H., 500
Pepper black
active constituents, 461–462
antioxidant properties, 463–464
botanical description, 460–461
cultivated in, 460
flavor and aroma, 461
history, 459–460
ISO standard, 464
medicinal uses and functional properties, 463
parts used, 461
preparation and consumption, 462
regulatory status, 464
Peppermint
active constituents, 528–529
antioxidant properties, 530–531
botanical description, 528
cultivated in, 528
flavor and aroma, 528
history, 527
ISO standard, 532
medicinal uses and functional properties, 529–530
parts used, 528
preparation and consumption, 529
regulatory status, 531
Perucka, I., 195
Peterson, D.W., 234
Petroselenic acid, 283
Phenolic acids
allspice, 147–148
angelica, 153
asafoetida, 171
capsicum, 195
caraway, 201, 203
cardamom, 211
celery seed, 214, 217
cinnamon, 237, 238
clove, 247
coriander, 257, 260
cumin, 267, 269
curry leaf, 274
dill, 284
fennel, 291
fenugreek, 298
ginger, 340
hyssop, 354
juniper, 360
lavender, 366
lemon balm, 374
lemongrass, 378
marjoram sweet, 394
myrtle, 410
onion, 436
oregano, 451, 453
rosemary, 497
sage, 522, 525, 526
savory, 534
spearmint, 538, 540, 541
tarragon, 549
thyme, 554, 557
Phenolic compounds
ajowan, 143–144
biological effects, 48
coumarins, 50
curcuminoids, 50–51
flavonoids, 48–50
groups, 47
hydroxycinnamic acids, 49–50
lignans, 51
mechanisms of action, 46
quinones, 51
resveratrol, 52
sources, 47
stilbenes, 51
structures, 39–44
tannins, 51

Phenylpropanoids, 166
Phthalides, 214
Picrocrocin, 511
Pimenta dioica (L.). *See* Allspice
Pimpinella anisum L. *See* Anise
α-Pinene
  angelica, 153
  bay leaf, 183
  curry leaf, 274
  juniper, 358
  myrtle, 410
  nutmeg, 429
  nigella, 416
  pepper black, 461
  spearmint, 538
β-Pinene
  cumin, 267
  curry leaf, 274
  fenugreek, 297
  hyssop, 354
  juniper, 358
  nutmeg, 429
  nigella, 416
  pepper black, 461
  savory, 533
Pinocamphone, 354
Pinto, P.C.A.G., 17
Piperine, 461, 463, 464
Piper nigrum L. *See* Pepper black
Plieth, C., 19
Poeckel, D., 500
Polyphenolics, 479–482
Pomegranate
  active constituents, 478–479
  antioxidant properties, 480–483
  botanical description, 478
  cultivated in, 478
  flavor and aroma, 478
  history, 477
  medicinal uses and functional properties, 479–480
  parts used, 478
  preparation and consumption, 479
  regulatory status, 483
Poppy
  antioxidant properties, 492
  botanical description, 490
  cultivated in, 490
  flavor and aroma, 490
  history, 489–490
  medicinal uses and functional properties, 492
  nutrient composition and ORAC values, 491
  parts used, 490
  preparation and consumption, 491
  regulatory status, 492
Posadas, S.J., 500
Prajapati, N.D., 216
Prasad, S., 314
Preet, A., 299
Preservative, 268
Prior, R.L., 10
Punica granatum L. *See* Pomegranate

Q
Qiang, L., 25
Quercetin
  lemongrass, 378
  onion, 437–442
  oregano, 451
  pepper black, 461
  tarragon, 546
  thyme, 554

R
Rabbani, S.I., 380
Radad, K., 419
Radish. *See* Horseradish
Rai, S.K., 313
Rajini, P.S., 99
Rajorhia, G.S., 276
Ram, A., 571
Ramesh, A., 541
Ramesh, T., 108
Ramos, A., 148
Rapeseed oil, 80
Rassi, C.M., 439
Relaxant effect, 162
Root of the holy ghost. *See* Angelica
Rosemary
  active constitents, 497
  antioxidant properties, 499–501
  botanical description, 496
  cultivated in, 496
  flavor and aroma, 496
  history, 495–496
  ISO standard, 501
  medicinal uses and functional properties, 498–499
  parts used, 496
  preparation and consumption, 497
  regulatory status, 501
Rosmanol, 497, 499
Rosmarinic acid
  basil, 174, 176
  hyssop, 354

lavender, 366
lemon balm, 373, 374
oregano, 451, 453
peppermint, 528, 529
rosemary, 497–500
sage, 522, 524, 525
spearmint, 540
thyme, 554
Rosmarinus offcinalis L. *see* Rosemary
Rozenberg, O., 540
Rutin
angelica, 161
onion, 439
peppermint, 528
tarragon, 546

S
Sabinene
bay leaf, 183
marjoram sweet, 394
nutmeg, 429
Saffron
active constituents, 511
antioxidant properties, 513–516
botanical description, 510
cultivated in, 510
flavor and aroma, 511
history, 509–510
ISO standard, 516
medicinal uses and functional properties, 512–513
parts used, 511
preparation and consumption, 511–512
regulatory status, 516
Safranal, 511, 513, 514, 516
Sage
active constituents, 522, 523
antioxidant properties, 525–526
botanical description, 522
cultivated in, 522
flavor and aroma, 522
history, 521
ISO standard, 526
medicinal uses and functional properties, 524–525
parts used, 522
preparation and consumption, 523
regulatory status, 526
Saito, K., 396
Salad dressing, 289
Saleh, L., 19
Salicylic acid, 511
Salvia officinalis L. *See* Sage
Samarth, R.M., 531
Sanchez-Moreno, C., 13
Sang, S., 339
Saponins
basil, 174
licorice, 386
onion, 437
Sarmentine, 461
Satureja hortensis L. *See* Savory
Savory
active constituents, 533
antioxidant properties, 534
botanical description, 532
cultivated in, 532
flavor and aroma, 532–533
history, 531–532
ISO standard, 535
medicinal uses and functional properties, 534
parts used, 532
preparation and consumption, 533
regulatory status, 535
Schaffer, S., 550
Scopoletin, 161
Seasonings
basil, 175
bay leaf, 183
capsicum, 192
caraway, 202
chervil, 223
chives, 227
coriander, 259
horseradish, 350
lemongrass, 379
marjoram sweet, 395
onion, 438
rosemary, 498
sage, 523
tarragon, 545, 546
tumeric, 565
Sedative effect
anise star, 167
lavender, 365
Seeram, N.P., 540
Seki, T., 315
Sengupta, A., 407
Shaarawy, S.M., 312
Shahidi, F., 79, 97
Shaik, I.H., 313
Shati, A.A., 340
Shetty, A.V., 387
Shishodia, S., 571
Shogaols, 337–339
Shyamala, M.P., 148

Sigurdsson, S., 153
Simonetti, P., 94
Sinapic acids
  marjoram sweet, 394
  onion, 436
Singh, B., 143
Singh, N., 99
Singh, S.V., 316
Singh, U.P., 269
Sinigrin, 348, 349
Sitosterol
  poppy, 490
  savory, 533
Sompamit, K., 571
Souri, E., 285
Spasmolytic activity
  coriander, 259
  fennel, 290
  horseradish, 350
  rosemary, 498
Spearmint
  antioxidant properties, 540–541
  botanical description, 538
  cultivated in, 538
  flavor and aroma, 538
  herb, 541
  history, 537–538
  ISO standard, 541
  medicinal uses and functional properties, 539–540
  parts used, 538
  preparation and consumption, 539
  regulatory status, 541
Speroni, E., 184
Spiridon, I., 366
Sporicidal activity, 210
Sreelatha, S., 260
Srihari, T., 454
Sriram, N., 315
Stajner, D., 228
Stan, S.D., 316
Stearic acid, 166
Sterols
  onion, 436
  oregano, 451
Stevanato, R., 26
Stigmasterol
  poppy, 491
  saffron, 511
Stimulant activity
  chervil, 223
  hyssop, 355
  marjoram sweet, 396
  mustard, 405
  nutmeg, 430
Strain, J.J., 18
Subramanian, S.P., 276
Sulfur compounds
  asafoetida, 170–171
  onion, 436
Sultana, S., 210
Sun, T., 195
Suru, S.M., 441
Syringic acid, 511
Syzygium aromaticum (L.). *See* Clove

T
Tachibana, Y., 276
Taha, R.A., 420
Taniguchi, M., 56
Tannins
  basil, 174
  celery seed, 214
  cinnamon, 233
  cumin, 267
  geranium, 330, 332
  hyssop, 354, 355
  juniper, 359
  lavender, 364
  lemon balm, 373
  licorice, 386
  myrtle, 410
  oregano, 451
  pomegranate, 479, 480
  tarragon, 546
  thyme, 554
Tarragon
  active constituents, 546–547
  antioxidant properties, 549
  botanical description, 546
  cultivated in, 546
  flavor and aroma, 546
  history, 545–544
  ISO standard, 549
  medicinal uses and functional properties, 548–549
  parts used, 546
  preparation and consumption, 547
  regulatory status, 549
Teas, 95–98
Terpenene
  cumin, 267
Terpinene, 394
Terpinen-4-ol, 394
α-Terpineol, 394

α-Terpinylacetate
bay leaf, 183
cardamom, 209
Thippeswam, N.B., 568
Thirunavukkarasu, V., 298
α-Thujone, 522
Thyme
active constituents, 554, 555
antioxidant properties, 556–557
botanical description, 554
cultivated in, 554
flavor and aroma, 554
history, 553–554
ISO standard, 557
medicinal uses and functional properties, 555–556
parts used, 554
preparation and consumption, 555
regulatory status, 557
Thymohydroquinone, 416
Thymol
ajowan, 142–143
nigella, 416
oregano, 451, 452, 454
thyme, 554, 556, 557
Thymoquinone, 416–420
Thymus vulgaris L. *See* Thyme
Tocopherols
coriander, 257
peppermint, 529, 530
Total flavonoid content assay, 26
Total phenolic content (TPC) assay, 25–26
Total radical-trapping antioxidant parameter (TRAP) assay, 15–16
Trachyspermum ammi (L.). *See* Ajowan
Tricholein, 461
Trigonella foenum-graecum L. *See* Fenugreek
Trigonelline, 297
Tubaro, F., 12
Turmeric
active constituents, 565, 566
antioxidant properties, 570–573
botanical description, 564
cultivated in, 564
flavor and aroma, 565
history, 563–564
ISO standard, 573
medicinal uses and functional properties
anticancerous properties, 566
bis-DemethoxyCurcumin (bDMC), 569
blockers, 568
caspase-3, 568
chronic lymphocytic leukemia, 570
Helicobacter pylori, 569
inhibitory effects, 567
intrahepatic metastases, 568
therapeutic role, 567
uncoupler, 569
parts used, 565
preparation and consumption, 565
regulatory status, 573
ar-Turmerone, 565

U
Ubiquinone
free radical-scavenging activity, 55
potential mediator, 55
structures, 39, 44
Ukil, A., 569
Umbelliferone
anise, 161
asafoetida, 171
caraway, 201
fennel, 289
Ursolic acid
rosemary, 497, 498
sage, 524
savory, 533
thyme, 554
Uz, E., 340

V
Vallverdu-Queralt, A., 103
Vanilla
active constituents, 584
antioxidant properties, 586
botanical description, 583
cultivated in, 582
flavor and aroma, 583
history, 581–582
ISO standard, 586
medicinal uses and functional properties, 584–585
parts used, 583
preparation and consumption, 584
regulatory status, 586
Vanilla planifolia. *See* Vanilla
Vanillic acid
marjoram sweet, 394
vanilla, 584, 585
Vanillin
nutrient composition and ORAC values, 584, 585
saffron, 511
vanilla, 583–586

Vegetables
antioxidant content, 66, 98
asparagus, 103–104
beetroot, 100–101
carrot, 99
color code groups, 68, 98
cruciferous vegetables, 102–103
eggplant, 104
green leafy, 101–102
potato, 99–100
spinach leaves, 102
tomatoes, 103
total phenol, flavonoid, flavanol, and ORAC values, 67, 98
Verma, R.J., 340
Vijayababu, M.R., 440
Vijayakumar, R.S., 464
Vinson, J.A., 95
Vitex, 297
Vitexin glucoside, 297
Vora, S.R., 108

W
Wang, B.H., 314
Wang, M., 17
Wang, S.Y., 106
Wayner, D.D., 15
Wei, Y., 19
Weil, M.J., 350
Wenzel, U., 440
Whittern, C., 79
Wu, T.T., 260
Wu, X., 65, 106
Wu, X.J., 441

X
Xiao, D., 316

Y
Yadav, A.S., 167
Yadegarinia, D., 530
Yamamoto, Y., 440
Yamasaki, T., 310
Yang, L., 515
Yang, W.J., 155
Yao, Y., 217
Yi, W., 87
Yin, Q.H, 452
Yokozawa, T., 406
Yoshino, F., 516
Yu, Y.M., 500
Yun, Y.S., 106

Z
Zeaxanthin, 226
Zhang, L., 19, 108
Zhang, R.F., 108
Zhang, Y., 91
Zhang, Y.K., 316
Zheng, W., 106
Zheng, Y.Q., 514
Zhong, Y., 97
Zhou, J., 25
Zhou, Y., 438
Zingerone, 337–340
Zingiberene, 337
Zingiberine, 565
Zingiber officinale Roscoe. *See* Ginger
Z-ligustilide, 154, 155