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History, Global Distribution, and Nutritional Importance of Citrus Fruits

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Abstract: Although the mysteries of its history and origin remain unsolved, worldwide cultivation and high-demand production for citrus fruit (genus *Citrus* in family *Rutaceae*) make it stand high among fruit crops. Growth of the citrus industry, including rapid development of the processing technology of frozen concentrated orange juice after World War II, has greatly expanded with international trade and steadily increased consumption of citrus fruits and their products during the past several decades. Characterized by the distinct aroma and delicious taste, citrus fruits have been recognized as an important food and integrated as part of our daily diet, playing key roles in supplying energy and nutrients and in health promotion. With low protein and very little fat content, citrus fruits supply mainly carbohydrates, such as sucrose, glucose, and fructose. Fresh citrus fruits are also a good source of dietary fiber, which is associated with gastrointestinal disease prevention and lowered circulating cholesterol. In addition to vitamin C, which is the most abundant nutrient, the fruits are a source of B vitamins (thiamin, pyridoxine, niacin, riboflavin, pantothenic acid, and folate), and contribute phytochemicals such as carotenoids, flavonoids, and limonoids. These biological constituents are of vital importance in human health improvement due to their antioxidant properties, ability to be converted to vitamin A (for example, β-cryptoxanthin), and purported protection from various chronic diseases.

Introduction

Citrus, also known as *agrumes* (sour fruits) by the Romance loanword, is one of the world's major fruit crops with global availability and popularity contributing to human diets. Due to unclear numbers of natural species and wide areas for cultivation, the most well-known examples of citrus fruits with commercial importance are oranges, lemons, limes, grapefruit, and tangerines. Although citrus fruits are grown all over the world in more than 140 countries, most of the crop grows on either side of a belt around the equator covering tropical and subtropical areas of the world 35°N and 35°S latitudes with cultivation and production concentrated in major regions in the Northern Hemisphere (Ramana and others 1981; UNCTAD 2004; Figure 1). Annual global production of citrus fruit has witnessed strong and rapid growth in the last several decades, from approximately 30 million metric tons in the late 1960s (FAO 1967) to a total estimate of over 105 million metric tons between 2000 and 2004, with oranges contributing more than half of the worldwide citrus production (UNCTAD 2004). According to 2009 data from the Food and Agriculture Organization of the United Nations (FAO), China, Brazil, the U.S.A., India, Mexico, and Spain are the world's leading citrus fruit-producing countries, representing close to two-thirds of global production (FAO 2009; Table 1). In the United States, a total of 10.9 million metric tons of citrus production was reported for 2009 to 2010, with Florida constituting 65% as the leading state, California 31%, followed by Texas and Arizona (USDA 2010; Table 2).

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Although many citrus fruits, such as oranges, tangerines, and grapefruits can be eaten fresh, about a third of citrus fruit worldwide is utilized after processing, and orange juice production accounts for nearly 85% of total processed consumption (USDA 2006). Because the introduction of frozen concentrated orange juice after World War II, which preserves fresh flavor and full color, reduces transportation costs, and minimizes losses due to storage diseases, the U.S.A. has seen a significant increase in the use of citrus fruit (Florida Citrus Processors' Association 1978). California is the main producer for consumption as fresh citrus fruit, whereas citrus processing and orange juice production primarily occur in Florida (USDA 2010). Because of the preferred flavor, delightful taste, affordable economic reach, and consumer awareness of the increasingly recognized potential health properties, citrus fruits and products are very prevalent with widespread nutritional and economic impact in both developed and developing countries (Ting 1980).

The origin of citrus fruit is identified with a history full of controversy and interesting legends. Some researchers believe that citrus is native to the subtropical and tropical areas of Asia, originating in certain parts of Southeast Asia including China, India, and the Malay Archipelago (Bartholomew and Sinclair 1952; Sinclair 1961; Scora 1975; Ramana and others 1981; Gmitter and Hu 1990). According to old manuscripts found among ancient Chinese documents, the earliest reference to citrus was documented during the reign of Ta Yu (around 2205 to 2197 BC) when citrus fruits, particularly mandarins and pummelos, were considered highly prized tributes and were only available for the

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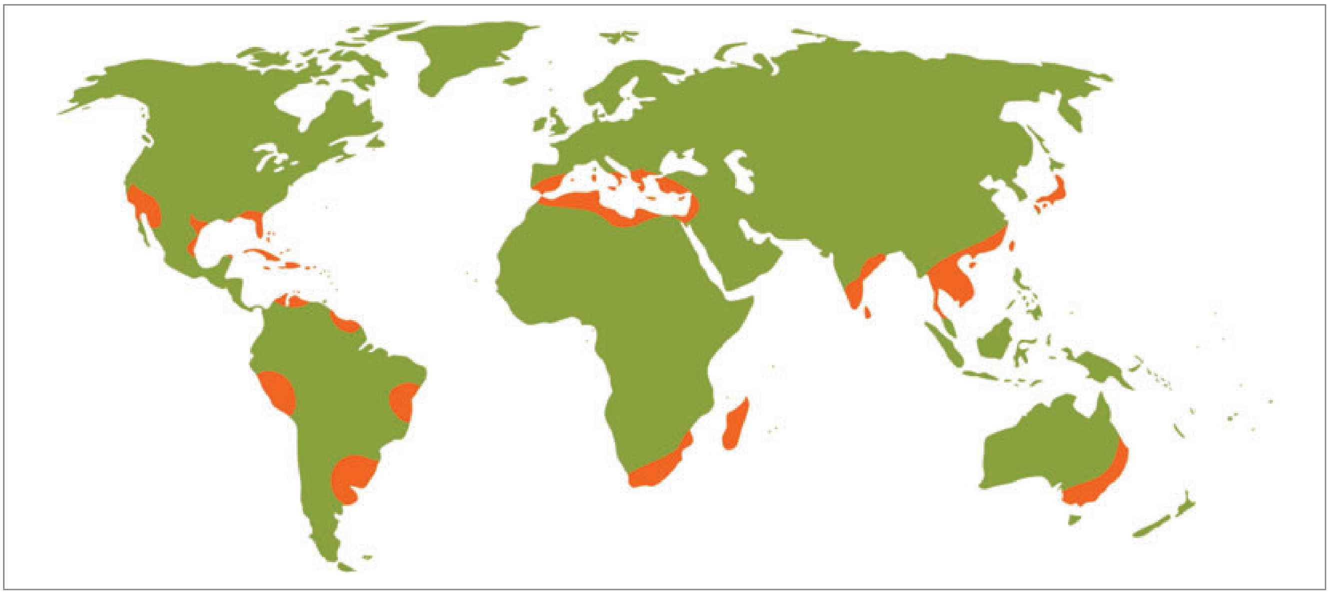

Figure 1–The world's major producing regions for citrus fruits (highlighted in orange). (Adapted according to FAO data from UNCTAD 2004).

Table 1–World's leading citrus fruit producers.

Country	Grapefruit	Lemons and limes	Oranges	Tangerines[a]	Other	Total
China	2768308	1014446	4864959	9746287	4694471	23088471
Brazil	66895	972437	17618500	1094430	NA[b]	19752262
U.S.A.	1182970	827350	8280780	401880	47170	10740150
India	193822	2571530	5201350	NA	161691	8128393
Mexico	395000	1987450	4193480	442108	106539	7124577
Spain	38700	551000	2617700	2026200	6500	5240100

Note: All values listed are tons.
[a] Includes tangerines, mandarins, and clementines.
[b] NA, not available.
Source: FAO 2009.

Table 2–Citrus production and utilization—individual states and the entire U.S.A.

	Production		
		Utilization	
State and season	Total (1000 tons)	Fresh (1000 tons)	Processed (1000 tons)
Arizona[a]			
2007 to 2008	90	62	28
2008 to 2009	133	54	79
2009 to 2010	97	51	46
California			
2007 to 2008	3312	2511	801
2008 to 2009	2954	2327	627
2009 to 2010	3410	2650	760
Florida			
2007 to 2008	9119	891	8228
2008 to 2009	8470	867	7603
2009 to 2010	7127	824	6303
Texas			
2007 to 2008	317	191	126
2008 to 2009	282	181	101
2009 to 2010	294	195	99
U.S.A.			
2007 to 2008	12838	3655	9183
2008 to 2009	11839	3429	8410
2009 to 2010	10928	3720	7208

Note: All values listed are 1000 tons.
[a] Oranges not included in the 2009 to 2010 season.
Source: USDA 2010.

imperial court (Webber 1967; Nagy and Attaway 1980). Lemon was originally grown in India and sweet oranges and mandarins are indigenous to China. Recent research suggests that, whereas some commercial species such as oranges, mandarins, and lemons originally came from Southeast Asia, the true origins of citrus fruit are Australia, New Caledonia (off eastern Australia), and New Guinea (Anitei 2007). The spread of citrus to other parts of the world was slow, including northern Africa and southern Europe. The first introduction of citrus to America was achieved by Spanish and Portuguese explorers, and orchards first appeared in Florida and California around 1655 and 1769, respectively. The commercial production, processing, and global trade of citrus have significantly increased since then, placing citrus as the most important fruit in the world (UNCTAD 2004; Ramana and others 1981).

Previous work reviewed the botanical classification and horticultural varieties of citrus in different ways (Tanaka 1954; Hodgson 1967; Swingle and Reece 1967). In addition to the traditional morphological identification, chemical characteristics of citrus fruits, such as enzymes, fatty acids, hydrocarbon profiles, flavonoid patterns, and carotenoid composition, were used to develop systems for studying citrus species (Yokoyama and White 1966; Iglesias and others 1974; Nordby and Nagy 1974, 1975; Dass and others 1977; Esen and Scora 1977). Because many named species of citrus are hybrids and the numerous varieties were derived from very few ancestral species based upon genetic evidence, the number of natural species remains unknown due to difficult systematics and complex taxonomy (Nicolosi and others 2000; De Araújo and others 2003). Some researchers believe that there may

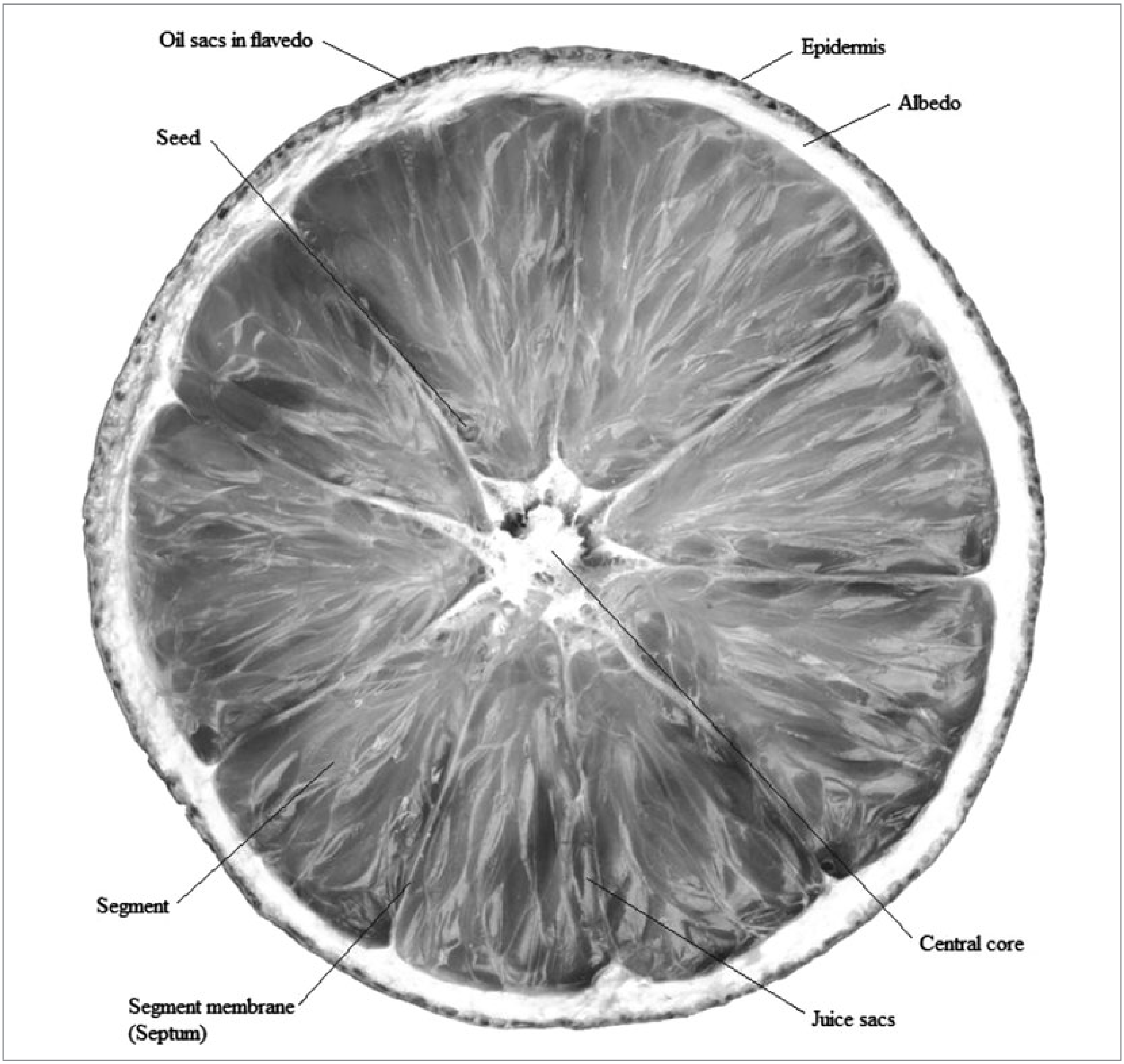

Figure 2–A schematic section of a typical citrus fruit illustrating different structures.

be only 25 true-breeding species of citrus (Anitei 2007). Citrus plants generally are evergreen shrubs or small trees, bearing flowers, which yield a strong scent. The fruits can have different forms (for example, round, oblong, or elongated) and various sizes from 3.8 to 14.5 cm in diameter (UNCTAD 2004; Ranganna and others 1983). Citrus fruits generally consist of an outer skin or rind made up of an epidermis (a leathery and waxy layer), the flavedo (a subepidermal layer that contains color and oil sacks producing aromatic oils), the albedo (a spongy layer below the flavedo, a source of flavanones), and vascular bundles (a network of thin threads along the flesh; Figure 2). The inner flesh has segments, usually aligned and situated around the soft central core of the fruit and wrapped by a thin segment membrane called the septum. Small and densely packed sacs containing juice and seeds in most varieties fill the segments, and the citric acid contained in the juice together with a complex mix of other acids, oils, and sugars, give the characteristic flavor (Albrigo and Carter 1977; Ranganna and others 1983). An increase in total sugar, decreases in acidity and ascorbic acid content, change of peel color, and increase in fruit size indicate advancement through maturation and ripening. Citrus fruits are ready to be consumed and processed upon harvesting with no further significant change in composition (Harding 1947; Bain 1958; Sinha and others 1962; Ramana and others 1981).

The established nutrient values of citrus fruits are beyond providing vitamin C (Nagy 1980). The fruits are abundant in macronutrients, such as simple sugars and dietary fiber, and are a source of many micronutrients including folate, thiamin, niacin, vitamin B_6, riboflavin, pantothenic acid, potassium, calcium, phosphorus, magnesium, and copper, which are essential for maintaining health and normal growth (Rouseff and Nagy 1994; Economos and Clay 1999). Citrus fruits are also low in energy density and free of sodium and cholesterol (Guthrie and others

Table 3–Nutritional characteristics for citrus fruits.

	Orange[a]	Grapefruit[b]	Tangerine[c]	Lemon[d]
Energy (kcal)	47	42	53	29
Carbohydrates (g)	11.75	10.66	13.34	9.32
Protein (g)	0.94	0.77	0.81	1.10
Total fat (g)	0.12	0.14	0.31	0.30
Cholesterol (g)	0	0	0	0
Dietary fiber (g)	2.40	1.60	1.80	2.80
Folate, total (μg)	30	13	16	11
Niacin (mg)	0.282	0.204	0.376	0.100
Pantothenic acid (mg)	0.250	0.262	0.216	0.190
Pyridoxine (mg)	0.060	0.053	0.078	0.080
Riboflavin (mg)	0.040	0.031	0.036	0.020
Thiamin (mg)	0.087	0.043	0.058	0.040
Vitamin C (mg)	53.20	31.20	26.70	53
Vitamin A (IU)	225	1150	681	22
Vitamin E (mg)	0.18	0.13	0.20	0.15
Vitamin K (μg)	0	0	0	0
Sodium (mg)	0	0	2	2
Potassium (mg)	181	135	166	138
Calcium (mg)	40	22	37	26
Copper (μg)	45	32	42	37
Iron (mg)	0.10	0.08	0.15	0.60
Magnesium (mg)	10	9	12	8
Manganese (mg)	0.025	0.022	0.039	0.030
Zinc (mg)	0.07	0.07	0.07	0.06
β-Carotene (μg)	71	686	155	3
α-Carotene (μg)	11	3	101	1
β-Cryptoxanthin (μg)	116	6	407	20
Xanthophylls[e] (μg)	129	5	138	11
Lycopene (μg)	0	1419	0	0

Note: All values are listed as per 100g fruit.
[a]Oranges, raw, all commercial varieties. Nutrient Databank nr. 09200.
[b]Grapefruit, raw, pink, and red, all areas. Nutrient Databank nr. 09112.
[c]Tangerines, raw (mandarin oranges). Nutrient Databank nr. 09218.
[d]Lemons, raw, without peel. Nutrient Databank nr. 09150.
[e]Xanthophylls represent combined lutein and zeaxanthin.
Source: USDA National Nutrient Database for Standard Reference, Release 24, 2011a.

1995; Whitney and others 2009; USDA Natl. Nutrient Database 2011a; Table 3). In addition, understanding the variety of naturally occurring phytochemicals, including limonoids, flavonoids, and carotenoids, is actively being researched. Recent epidemiological studies and other investigations have demonstrated that these bioactive compounds have a broad range of physiological effects and may contribute to the associations between citrus fruit consumption and prevention of chronic diseases (Steinmetz and Potter 1991; Silalahi 2002; Liu 2003; Yao and others 2004), such as cardiovascular disease (Clinton 1998; Ford and Giles 2000), cancer (Steinmetz and Potter 1996; Nishino 1997), neurological deficits (Youdim and others 2002), cataracts (Taylor and others 2002), age-related macular degeneration (Gale and others 2003; Zhou and others 2011), and osteoporosis (Yang and others 2008). For example, a reduced lung cancer risk was associated with an increase of 1 grapefruit or grapefruit juice serving/day, whereas no other associations were found for other fruits or vegetables (Feskanich and others 2000). In a pooled analysis of cohort studies, a significant inverse relationship between lung cancer risk and orange and tangerine fruit or orange and grapefruit juice consumption were found when comparing the lowest to highest quartiles of intake (Smith-Warner and others 2003). Some epidemiological studies report a 40% to 50% reduced risk of certain cancers with increased citrus consumption (Baghurst 2003). Previous findings also suggest possible cardioprotective effects of citrus fruits. In 1 study, dietary intake of fresh orange juice reduced lipoprotein oxidation (Harats and others 1998). In a separate trial, plasma folate increased and plasma homocysteine concentration decreased after 4 wk of high vegetable and citrus fruit consumption in healthy subjects (Brouwer and others 1999). Findings from a small clinical study in hypercholesterolemic subjects also indicated improved plasma lipid profiles as a result of daily orange juice consumption (750 mL) over a 4-wk period (Kurowska and others 2000). Several epidemiological studies have demonstrated possible protective benefits of citrus consumption against risk factors for cardiovascular diseases (Hertog and others 1993, 1997; Joshipura and others 2001; Knekt and others 2002). This review focuses on the nutritional value and economic importance of citrus consumption, as well as the health benefits related to prevention of micronutrient deficiencies and suggested protection against chronic diseases.

Table 4–Average sugar composition of citrus juices.

Fruit	Glucose	Fructose	Total reducing sugars[a]	Sucrose	Total sugars
Orange	2.03	2.48	4.51	4.81	9.32
Grapefruit	1.66	1.75	3.41	2.56	5.97
Tangerine	1.13	1.54	2.67	6.53	9.20
Lemon	1.40	1.35	2.75	0.41	3.16
Lime	NA[b]	NA	3.48	0	3.48

Note: All values listed are g/100 g.
[a]Total reducing sugars represent combined glucose and fructose.
[b]NA, not available.
Source: Ting and Attaway 1971.

Macronutrients

Citrus fruit composition varies significantly due to fluctuating effects from rootstock, fruit size, variety, maturity, storage, horticultural conditions, and climate, suggesting that nutrient and constituent analysis only provide within- and between-variety estimates, and general conclusions are difficult to form (Kefford and Chandler 1970). Different processing procedures with capabilities to adjust extraction and homogenization pressures affect juice composition (Betoret and others 2012), which is particularly important for fruits that contain flavonoids and have thick peels (Danziger and Mannheim 1967). Because protein and fat are low in citrus fruits, carbohydrate is the essential macronutrient supplying nutritional and caloric values (Watt and Merrill 1963; USDA Natl. Nutrient Database 2011a; Table 3).

Carbohydrates

Citrus fruits can be separated into those with soluble and others with insoluble constituents, based on 80% ethanol extraction (Sinclair and Jolliffe 1960). The soluble portion largely contains mono- and disaccharides, nonvolatile organic acids, amino acids, and other minor components, and the insoluble fraction primarily consists of cell structure polysaccharides, which establish the nature and profiling of citrus carbohydrates (Sinclair and Jolliffe 1960). Sucrose, glucose, and fructose, with a general ratio of 2:1:1, represent the major components of citrus fruit carbohydrates and hold the key to sweetness of the juice (Bartholomew and Sinclair 1943; Curl and Veldhuis 1948; McCready and others 1950; Ting and Attaway 1971). The ratios of sucrose to other reducing sugars tend to fluctuate with various stages of maturity and different varieties, and to decrease in the acidic environment with long-term storage (Ting and Attaway 1971; Chan and Kwok 1975; Kuraoka and others 1976; Daito and Sato 1985; Table 4). Depending on the specific fruit, total sugar content in the juice could range from lower than 1% in some limes to as high as 15% in some oranges (Ranganna and others 1983). In addition to the 3 major sugars, trace amounts of mannose, maltose, heptuloses, and galactose have been reported, and rhamnose, xylose, and trehalose have been identified in some Israel oranges, grapefruits, and lemons (Stepak and Lifshitz 1971; Ladaniya and Mahalle 2011). Citrus peels also contain substantial amounts of sucrose, glucose, and fructose, as

Table 5–Percentage distribution of polysaccharide fractions in citrus fruits.

	Pectic substance			Hemicellulose			Cellulose			Other		
Fruit	Peel[a]	Pulp[b]	Juice[b]	Peel[a]	Pulp[b]	Juice[b,c]	Peel[a]	Pulp[b]	Juice[b]	Peel[a]	Pulp[b]	Juice[b]
Oranges												
Hamlin	55.4	68.0	88.7	8.7	6.8	11.3	31.2	25.1	NA[d]	4.9	0.1	0
Pineapple	56.5	59.5	92.5	9.9	6.3	7.0	26.6	33.7	NA	7.0	0.6	0
Valencia	51.1	62.0	93.0	11.3	7.0	7.0	30.4	30.0	NA	7.2	1.0	0
Tangerine												
Dancy	NA	64.5	91.7	NA	8.6	8.3	NA	26.7	NA	NA	0.2	0
Grapefruit												
Duncan	NA	62.5	94.0	NA	6.6	6.0	NA	28.6	NA	NA	0.3	0
Marsh	52.4	63.0	92.6	11.7	6.7	7.4	30.8	29.0	NA	5.1	1.3	0

Note: Values listed are percentage distribution of various fractions in the alcohol-insoluble solids of citrus peel, pulp, and juice.
[a]Source: Ting and Deszyck 1961.
[b]Source: Ting 1970.
[c]Combined hemicelluloses and cellulose fractions in juice.
[d]NA, not available.

well as traces of other free sugars, such as xylose and rhamnose. Although the sugars soluble in ethanol generally increase with maturity and contribute 30% to 50% of the peel's dry weight, the sucrose content is considerably lower than that of the total reducing sugars (Ting and Deszyck 1961).

The insoluble solid portion in 80% ethanol yields polysaccharides upon further extractions (Sinclair and Jolliffe 1960). In citrus peel, pulp, juice, and membrane, 45% to 75% of the total solids are insoluble in ethanol and most solids are polysaccharides (Ting and Deszyck 1961; Ting 1970). The main fractions of citrus polysaccharides are pectic substances, hemicelluloses, cellulose, and lignin (Ting 1980; Table 5). Individual hydrolysis of the pectin, hemicelluloses, and cellulose revealed that certain monosaccharides, such as arabinose and galactose, were discovered in all fractions, whereas free xylose primarily existed in the hemicellulose fraction, and galacturonic acid and glucose dominated the pectin and cellulose fractions (Ting and Deszyck 1961; Rouse and others 1962, 1964). Previously reported results, based on the assumption that each hydrolyzed product is derived from a homogeneous polysaccharide, suggested that orange and grapefruit peels consist of 7% to 10% araban, 5% to 6% galactan, 2.5% xylan, 15% to 28% cellulose glucosan, and 23% polygalacturonic acids, accounting for approximately 53% to 70% of the ethanol-insoluble solids in the peel (Ting and Deszyck 1961).

Synthesis of starch has been documented in lemon fruit tissue by Kordan (Kordan 1965, 1974). Starch is abundant in the albedo and can also be found in the flavedo when fruits are still green (Shomer and Erner 1989). Starch can be found in all fruit components throughout the course of early citrus development as storage carbohydrate, which supplies energy for growth and respiration in immature fruits, and is completely degraded and fully metabolized during maturation (Webber and Batchelor 1943; Ranganna and others 1983; Lelièvre and others 1997; Holland and others 1999; Cajuste and others 2011).

Fiber

For citrus fruits, dietary fiber generally refers to the alcohol-insoluble compounds listed above, which is conventionally composed of cellulose, lignin, and pectin. In addition to the ability of dietary fiber to decrease transit time of food through the gastrointestinal tract and hence prevent digestive disorders (Truswell 1993; Hillemeier 1995), the methoxyl content of pectin is associated with a cholesterol-lowering benefit (Spiller and Amen 1974; McCready 1977; Ting 1980). Previous data on grapefruit showed changes in the composition and level of dietary fiber with maturity, suggesting that early harvest may result in a higher dietary fiber content (Larrauri and others 1997). In general, the polysaccharides of citrus fruits, particularly in the peel and pulp, are a source of dietary fiber (Church and Church 1970).

Table 6–Concentrations of organic acids in some varieties of citrus fruit juices.

Variety	Citric	Malic	Succinic
Orange			
Valencia	0.22 to 0.98	0.06 to 0.26	Trace to 0.54[a]
Navel	0.14 to 0.72	0.11 to 0.15	0.06 to 0.90
Pineapple	0.30 to 0.36	0.15 to 0.26	0.26 to 0.85
Hamlin	0.17 to 0.70	0.15 to 0.31	0.02 to 0.24
Parson Brown	0.40 to 0.50	0.21 to 0.27	0.27 to 1.48
Shamouti	0.88 to 2.37	0.075 to 0.182	NA[b]
Mandarin and tangerine	0.86 to 1.22	0.08 to 0.21	NA
Grapefruit			
Marsh	0.42 to 0.95[c]	0.03 to 0.23	0.06 to 0.86
Lemon			
Eureka	4.00 to 4.38	0.07 to 0.26	NA

Note: All values listed are g/100 mL citrus juice.
[a]Values as high as 1.27 and 1.59 have been reported in Valencia oranges grown in Texas and Arizona, respectively.
[b]NA, not available.
[c]Values as high as 1.41, 1.79, and 2.1 have been reported in Marsh grapefruit grown in Florida, California, and Arizona, respectively.
Source: Vandercook 1977a.

Organic acids

Citrus acidity not only impresses consumers as sourness, but also plays a key role in the criteria assessing the commercial acceptability of citrus fruits, and together with appropriate sugar levels, provides the delightful and typical taste. Carboxylic acids, particularly citric, malic, and succinic acids, comprise the content of organic acids (Vandercook 1977a; Table 6). The organic acids, in addition to the free form, also exist in the form of salts such as citrates and malates (Clements 1964). Although citric acid prevails in juices, malic, malonic, oxalic, and quinic acids are major organic acids in citrus peel (Sinclair and Eny 1947; Ting and Deszyck 1959; Clements 1964; Sasson and others 1976). During maturity, citrus acidity may demonstrate different fates depending on fruit species. As fruits ripen, the gradual decrease of citric acid leads to declined acidity whereas malic acid content remains relatively constant (Rasmussen 1963; Gepshtain and Lifshitz 1970). This trend has been documented in several orange and grapefruit varieties (Shaw and Wilson 1983). In lemons, however, acidity increases with maturity, resulting in a lower pH (Vandercook 1977a). Other acids, such as adipic, isocitric, lactic, aconitic, α-ketoglutaric, and benzoic acids, have also been recorded (Sasson and Monselise 1977). As acids enter the tricarboxylic acid cycle, mainly as malic and citric acids, these substrates are oxidized to yield ATP and

Table 7–Amino acid concentrations in some varieties of citrus fruits and juice products.

Amino acid	Grapefruit, white[a]	Grapefruit, pink and red[b]	Lime juice[c]	Oranges[d]	Orange juice[e]	Tangerines[f]
Tryptophan	7	8	2	9	2	2
Threonine	12	13	2	15	8	16
Isoleucine	7	8	2	25	8	17
Leucine	13	15	16	23	13	28
Lysine	17	19	16	47	9	32
Methionine	7	7	2	20	3	2
Cystine	7	8	2	10	5	2
Phenylalanine	41	13	11	31	9	18
Tyrosine	7	8	2	16	4	15
Valine	14	15	11	40	11	21
Arginine	78	87	15	65	47	68
Histidine	7	8	2	18	3	11
Alanine	22	24	24	50	15	28
Aspartic acid	123	138	114	114	75	129
Glutamic acid	176	197	67	94	33	61
Glycine	13	15	11	94	9	19
Proline	56	63	30	46	44	74
Serine	25	28	35	32	13	33
Hydroxyproline	NA[g]	NA	NA	NA	NA	NA

Note: All values listed are mg/100 g fresh weight, edible portion.
[a]Grapefruit, raw, white, all areas.
[b]Grapefruit, raw, pink and red, all areas.
[c]Lime juice, raw.
[d]Oranges, raw, all commercial varieties.
[e]Orange juice, raw.
[f]Tangerines, (mandarin oranges), raw.
[g]NA, data not available.
Source: USDA National Nutrient Database for Standard Reference, Release 24, 2011a.

produce new compounds. Many flavor and aromatic compounds are synthesized as metabolites during the utilization of organic acids (Kealey and Kinsella 1978).

Protein

Total nitrogen content is between 0.08% and 0.11% in oranges, 0.08% in grapefruit, and 0.06% in lemons (Clements and Leland 1962; Sawyer 1963; Vandercook 1977b). Free amino acids contribute the most to citrus nitrogen values, which account for about 70% of the nitrogenous constituents in all varieties (Zamorani and others 1973; Zamorani and Russo 1974; Russo and others 1975; Ranganna and others 1983). Therefore, citrus fruits are not considered a major protein source (Table 3).

Using electrophoresis to isolate proteins on polyacrylamide gels, previous results by Clements indicated that bands produced from different portions of orange, grapefruit, and lemon shared similarity, suggesting that a number of proteins are common in citrus fruits (Clements 1966). These proteins, in spite of their relatively low content, are largely enzymes, which include transferases, hydrolases, lyases, ligases, and oxidoreductases in different parts of the fruits (Vandercook 1977b). Seeds of citrus fruits, however, have higher amounts of protein. Previous studies reported from 9.8% protein in lime seeds to 18.2% in whole seeds of citrus fruits on a dry weight basis (Ammerman and others 1963; Kunjukutty and others 1966).

Considerable attention has been given to qualitative and quantitative estimation of individual amino acids in different fruits and products. Based on previous data, the majority of citrus amino acids are considered nonessential (Block and Bolling 1944). With little seasonal variation observed in free amino acid concentration (Wallrauch 1980), nonessential amino acids such as alanine, arginine, asparagine, aspartic acid, glutamic acid, glycine, serine, and proline are found in several orange, lemon, and mandarin varieties, whereas indispensable amino acids, such as valine, phenylalanine, threonine, leucine, methionine, and lysine, are reported in certain oranges and grapefruits (Zamorani and others 1973; Giacomo and others 1974; Zamorani and Russo 1974; Benk 1975; Russo and others 1975; Wallrauch 1980; USDA Natl. Nutrient Database 2011a; Table 7). Interestingly, though proline reportedly dominates the free amino acids in juices of all citrus fruits, it has the lowest concentration in lime juice (Vandercook 1977b; Table 7). In addition, among the many important amino acids in citrus juices, arginine is the only semiessential amino acid (Imura and Okada 1998) that exists in relatively detectable amounts (Attaway and others 1972). Overall, free amino acids in citrus fruits likely make a small impact on human nutrition.

Lipids

Although citrus flesh is not a good source of lipids, they are primarily found in the seeds and rinds. As seed moisture declines and lipid content increases during fruit maturation, about 30% to 45% lipids are present in dried seeds of oranges and 29% to 37% in grapefruit seeds (Hendrickson and Kesterson 1963a; Kesterson and Braddock 1976). However, the bitterness of these seed oils, owing to the presence of limonoids, often make them unpopular and rarely used, and need to be removed by treatment with alkali for refinement. As illustrated in Table 8, a mixture of unsaturated fatty acids, such as oleic (C18:1), linoleic (C18:2), and linolenic (C18:3) acids, as well as saturated fatty acids such as palmitic (C16:0) and stearic (C18:0), characterize the citrus seed oils with different varieties sharing similar fatty acid composition (Braddock and Kesterson 1973; Nagy 1977; Table 8). Measured by iodine values, an association between refractive index and degree of unsaturation has been observed (Hendrickson and Kesterson 1963b, 1964). Linoleic acid is abundant in mandarin seeds, with the highest refractive indices and iodine numbers, but also in lemon and lime seed oils. Orange seed oils, on the other hand, demonstrate the lowest refractive indices and iodine numbers. In addition to the major unsaturated fatty acids, other acids previously reported in trace amounts are lauric (C12:0), myristic (C14:0), and palmitoleic (C16:1) acids (Sattar and others 1987).

Minor amounts of nonpolar and polar lipids exist in citrus juice and flesh (Swift and Veldhuis 1951). Although the lipid content stays relatively constant in some varieties, fluctuation has been observed during fruit maturation (Kadota and others 1982). Previous data showed that total lipids in citrus juice generally range from

Table 8–Composition ranges of major fatty acids in citrus seed oils.

Variety	Refractive index[a]	Iodine value[a]	Major fatty acids (%)[b]				
			Palmitic	Stearic	Oleic	Linoleic	Linolenic
Orange	1.4649 to 1.4712	86.1 to 101.7	26 to 31	3 to 5	24 to 28	35 to 37	2 to 4
Grapefruit	1.4698 to 1.4700	100.9 to 106.3	26 to 36	1 to 4	18 to 25	32 to 41	3 to 6
Mandarin	1.4693 to 1.4702	94.1 to 107.3	22 to 30	2 to 5	20 to 25	37 to 45	3 to 5
Lemon	1.4707 to 1.4742	107.3 to 109.2	18 to 24	2 to 4	26 to 34	31 to 38	6 to 12
Lime	1.4699 to 1.4701	101.6 to 106.2	24 to 29	3 to 5	20 to 22	37 to 40	6 to 11

Note: Values listed are percentage in citrus seed oils.
[a]Source: Braddock and Kesterson 1973.
[b]Source: Nagy 1977.

Table 9–Major fatty acids in citrus juices.

Fatty acid	Orange[a]	Grapefruit[b]	Lemon[c]	Lime[d]
Palmitic $C_{16:0}$	21.2 to 23.3	21.7 to 23.7	23.0 to 23.4	21.7 to 22.3
Palmitoleic $C_{16:1}$	4.0 to 4.6	3.1 to 4.3	0.7 to 0.9	5.4 to 5.6
Oleic $C_{18:1}$	24.1 to 26.7	23.4 to 24.4	9.3 to 9.5	14.8 to 15.0
Linoleic $C_{18:2}$	27.8 to 35.2	33.5 to 35.5	34.8 to 36.0	26.9 to 27.5
Linolenic $C_{18:3}$	7.9 to 13.6	8.2 to 9.4	18.8 to 19.0	13.8 to 14.4
Others	5.9 to 7.1	5.8 to 7.2	12.0 to 12.4	16.0 to 16.6

Note: All values listed are percentage.
[a]Range of values for early (Hamlin), mid (Pineapple), and late (mainly Valencia) oranges.
[b]Juice from Florida factories.
[c]Juice from California factories.
[d]4-fold concentrate diluted to juice from Florida factories.
Source: Nagy 1977.

84 to 101 mg/100 mL in orange, from 75 to 86 mg/100 mL in grapefruit, and from 58 to 78 mg/100 mL in lemon (Nagy 1977). Free fatty acids form an essential part of nonpolar lipids, with palmitic, oleic, linoleic, and linolenic acids as the major components (Nordby and Nagy 1969; Nagy 1977). The major fatty acid profiles in juice are identical in orange and grapefruit, whereas lemon and lime juices have a decreased level of oleic acid and elevated concentrations of linolenic acid (Table 9). Because of this, previous data by Nagy and others suggested that citrus fruit fatty acid composition could be used to distinguish species (Nagy and Nordby 1974). Lemons, for example, can be differentiated from other varieties by the higher $C_{16:0}/C_{16:1}$ ratio, and together with lime, they contain higher concentrations of branched-chain fatty acids than other species. The polar lipids consist of a nonionic group of sugar-containing lipids, which include glycosyl glycerides and sterol glucosides (Nordby and Nagy 1971). The ionic polar lipids are generally characterized by phospho-, sulfo-, amino, or carboxyl groups, with phospholipids being 50% of the total juice lipid content (Nagy 1977). This number increases in commercially processed citrus juice due to extraction, heating, and evaporation leading to physical disruption of membranes and tissues (Braddock 1972). According to previous findings by Vandercook and others, phospholipids can also distinguish a citrus juice from other beverages (Vandercook and others 1970).

Like most plants, the aerial surfaces of citrus fruits are covered with a multilayered cuticle, which is primarily composed of cutin, a lipid whose long-chain constituents are interlinked with ester bonds and cross-polymerized with compounds of high molecular weight and intermediate size, and also poorly soluble in most solvents (Baker and Procopiou 1975; Holloway 1982). In addition, a layer of waxy lipid, called epicuticular wax, exists on the outer surface of the cutin, and can easily be dissolved in organic solvents (Albrigo 1972; Baker and others 1975). The wax content of cuticle lipids in the fruit peel plays an important role in controlling moisture loss, protecting the fruits from insects and pests, and reducing physical damage such as chilling injury (Nordby and McDonald 1990, 1991).

Micronutrients and Phytochemicals

Fat-soluble vitamins

In citrus fruits, vitamin A is the only fat-soluble vitamin that exists in an adequate quantity in the form of provitamin A carotenoids, with the carotenes and β-cryptoxanthin as the major vitamin A precursors (Ting 1977). Although α- and β-carotene are a minor portion of carotenoids in some oranges, β-cryptoxanthin is the main vitamin A precursor in tangerines, mandarins, and oranges (Curl and Bailey 1954, 1957; Ting 1961; Stewart 1977). Using high-performance liquid chromatography (HPLC), separation of cryptoxanthin from other carotenoids in citrus juice suggests that only the β-isomer has provitamin A activity and the α-isomer is inactive, as determined by its structure (Stewart 1977). Total provitamin A carotenoids vary widely among different citrus fruits; mandarins, tangerines, and red and pink grapefruits are the major sources (USDA Carotenoid Database 1998; Holden and others 1999; Table 10). The concentrations are dramatically lower in oranges and almost undetectable in white grapefruits (Lime and others 1954; Ting and Deszyck 1958; Ting 1961; Stewart 1977; Holden and others 1999).

Citrus fruits are the most concentrated dietary source of β-cryptoxanthin among foods. The best dietary sources are papaya, tangerine, and orange (Arscott and others 2010), but it is also found in red chilies, peaches, pumpkins (Burri and others 2011), and guava (Maiani and others 2009). β-Cryptoxanthin bioavailability from these food sources is affected by the food matrix, processing, and storage state. Although conversion to retinol does not occur until digestion, the degradation of β-cryptoxanthin in its native form (before consumption) is caused by natural light and heat, which results in isomerization. Cooking and other thermal processing alters the food matrix, making carotenoids more bioavailable for digestion (Shardell and others 2011).

Information on dietary β-cryptoxanthin intake exists from various sources, but little in-depth analysis is available. Because the major source of β-cryptoxanthin is citrus fruits, intake correlates with the geographic regions where they are grown or available through shipment. In European countries, sources of dietary β-cryptoxanthin include orange juice, oranges, and tangerines

Table 10–Major dietary carotenoid contents of selected citrus fruits and juice products.

Fruit description	Carotenoid concentration, μg/100 g fresh weight, edible portion			
	α-Carotene	β-Carotene	β-Cryptoxanthin	Lutein + Zeaxanthin
Grapefruit, raw, white	8	14	NA[a]	NA
Grapefruit, raw, pink and red	5	603	12	13
Orange, blood, raw	ND[a]	120	69	NA
Orange, raw, commercial varieties	16	51	122	187
Orange juice, raw	2	4	15	36
Orange juice, raw, hybrid varieties	8	39	324	105
Orange juice, frozen concentrate, unsweetened, diluted	2	24	99	138
Tangerines, raw (mandarin oranges)	14	71	485	243
Tangerine juice, raw	9	21	115	166
Tangerine juice, frozen concentrate, sweetened, undiluted	NA	227	2767	NA

Note: All values listed are μg of carotenoid/100 g fresh weight (edible portion), presented in weighted means.
[a]NA, data not available. ND, values not detected or below the detection limit.
Source: Holden and others 1999.

(O'Neill and others 2001); whereas in certain other regions the dietary source is largely papaya because of availability. This was supported by a meta-analysis of the European Prospective Investigation of Cancer Incidence (EPIC)-Norfolk study where higher β-cryptoxanthin intake was associated with higher orange, orange juice, and satsuma intake (Pattison and others 2005). In a study of Costa Rican adolescents, plasma concentrations of β-cryptoxanthin increased significantly with increasing servings of fruit per day. This took into account that one of the most consumed fruits was papaya, a high source of β-cryptoxanthin (Irwig and others 2002). An observational study in Chinese women showed that fruit intake was significantly and positively associated with plasma concentrations of β-cryptoxanthin, as well as other provitamin A carotenoids (Frankenfeld and others 2011).

Compared with provitamin A carotenoids, citrus fruits house negligible amounts of vitamin E and vitamin K (Newhall and Ting 1965; USDA Natl. Nutrient Database 2011a, USDA and HHS 2011). Although previous findings of several sterols were documented, neither sterol compounds related to vitamin D nor plant-derived precursors of vitamin D have been found in citrus fruits (Swift 1952; Mazur and others 1958; Williams and others 1967). However, fortification of orange juice with vitamin D has lately received considerable attention as an effective approach to help ensure adequate vitamin D intake and increase calcium absorption in children and adults (Tangpricha and others 2003; Biancuzzo and others 2010).

Water-soluble vitamins

The high concentration of vitamin C (ascorbic acid) is probably the most significant contribution of citrus fruits to human health and nutrition. Previous findings suggested that daily intake of as little as 5 mg ascorbic acid is adequate to prevent vitamin C deficiency and scurvy symptoms in adults (Mapson 1967). The most recent intake recommendations provided by the U.S. Department of Agriculture and U.S. Department of Health and Human Services set 75 to 90 mg as the Recommended Dietary Allowance (RDA) for adults and even higher values for individuals who are cigarette smokers and women during pregnancy and lactation (USDA and HHS 2011). Although citrus fruits are not the single supplier of vitamin C, they are particularly rich and a popular dietary source among vegetables and fruits, providing average vitamin C concentration ranging from 23 to 83 mg/100 g fresh weight (West and others 1966; Lee and Kader 2000; Table 11). A medium-sized orange or grapefruit contains approximately 56 to 70 mg ascorbic acid, and an average 225-mL serving of orange juice typically contains 125 mg ascorbic acid (Whitney and others 2009). The edible portion contains about one-fourth of the total vitamin C content in the whole fruit. The peels (flavedo and albedo), although generally recognized as nonedible parts, contain a higher concentration than other components (Nagy 1980). A recent study suggested that total vitamin C concentration was more than 1.5 times higher in pulp of orange (*Citrus sinensis Osb.*) than that in pulp of Satsuma mandarin (*Citrus unshiu Marc.*) during fruit development and ripening (Yang and others 2011).

Table 11–Vitamin C contents of some citrus fruits.

Fruit variety	Vitamin C content, mg/100 g fresh weight		
	l-Ascorbic acid[a]	Dehydroascorbic acid[a]	Total[a]
Grapefruit (fresh)[b]	21.3	2.3	23.6
Lemon (fresh)[c]	50.4	23.9	74.3
Mandarins (Ellendale)[c]	34.0	3.7	37.7
Orange (California Navel)[b]	75.0	8.2	83.2
Orange (Florida)[b]	54.7	8.3	63.0
Orange (China)[d]	57.8	5.0	62.8
Satsuma mandarins (China)[d]	30.5	1.2	31.7

Note: All values listed are mg of vitamin C/100 g fresh weight.
[a]l-Ascorbic acid, primary bioactive form of vitamin C; dehydroascorbic acid, the oxidized form also with biological activity of vitamin C; total vitamin C concentration.
[b]Source: Vanderslice and others 1990.
[c]Source: Mitchell and others 1992.
[d]Source: Yang and others 2011. Values were based on molecular weights of 176.12 g/mol for ascorbic acid and 174.11 g/mol for dehydroascorbic acid, respectively.
Source: Lee and Kader 2000.

The variability of vitamin C content in fresh citrus fruits and their commercial products is greatly influenced by variety, maturity, climate, handling, processing, and storage conditions. Vitamin C in freshly extracted juice is quite stable during short storage periods and processing into the various juice products results in no serious loss of vitamin C potency if kept at refrigerator temperature for reasonable times (Moore and others 1945; Lopez and others 1967; Horton and Dickman 1977). Even in open containers such as glass and cans, loss of vitamin C is still minimal as long as the juice products are kept cold. However, considerable degradation of vitamin C results from storage of finished citrus products with atmospheric oxygen at high temperatures (Mudambi and Rajagopal 1977; Smoot and Nagy 1980).

In addition to ascorbic acid, citrus fruits also provide vitamin B complex, in particular thiamin (vitamin B_1) and pyridoxal phosphate (vitamin B_6). According to a previous study comparing different parameters for nutrient density in nonfortified 100% fruit juices, citrus juices received higher rankings than other juices (Rampersaud 2007). Although the applied methods differed in approach as far as number or type of nutrients, the findings suggested that citrus juices, especially orange and pink grapefruit juices, were more nutrient-dense than other commonly consumed juices (Rampersaud 2007). The current thiamin RDA for adults

Table 12–Folate content of some commonly consumed citrus fruits and juice products.

Fruit description	Weight (g)	Common measure	Dietary folate equivalent (μg) per measure	Amount (μg)[a] per 100 g FW
Grapefruit, raw, white	118	$\frac{1}{2}$ grapefruit	12	10
Grapefruit juice, white, raw	247	1 cup	25	10
Grapefruit, raw, pink and red	123	$\frac{1}{2}$ grapefruit	16	13
Grapefruit juice, pink, raw	247	1 cup	25	10
Lemons, raw, without peel	58	1 lemon	6	11
Lemon juice, raw	47	juice of 1 lemon	9	20
Limes, raw	67	1 lime	5	8
Lime juice, raw	38	juice of 1 lime	4	10
Oranges, raw, all commercial varieties	131	1 orange	39	30
Orange juice, raw	248	1 cup	74	30
Tangerines, raw (mandarin oranges)	84	1 tangerine	13	16
Tangerine juice, raw	247	1 cup	11	5

Note:
[a]Values listed are μg of folate/100 g fresh weight, edible portion.
Source: USDA National Nutrient Database for Standard Reference, Release 24, 2011a.

is 1.0 to 1.2 mg/d and 1.4 mg/d for women in pregnancy and lactation (USDA and HHS 2011). Citrus fruits and products provide similar or higher thiamin amounts than some well-known foods such as milk supplying this nutrient (USDA Natl. Nutrient Database 2011a).

Vitamin B_6 plays an essential role as a coenzyme governing many reactions of amino acids and glycogen metabolism. The current RDA is set at 1.3 mg/d for adult males and females aged 19 to 50 y old, and 1.9 to 2.0 mg/d for pregnant and lactating women (USDA and HHS 2011). Apart from orange juice, other foods that are good sources of vitamin B_6 include meat, dairy, whole grains, vegetables, bananas, and nuts (Nelson and others 1977; McCormick 2006). Orange juice, for example, contains an average vitamin B_6 concentration of 40 μg/100 g fresh weight, suggesting that orange juice supplies this nutrient at a comparable level to that of milk, an average of 36 μg/100 g fresh weight (USDA Natl. Nutrient Database 2011a).

Folic acid, a pteroyl-glutamic acid, or folate as the naturally occurring form, is another water-soluble B vitamin which acts as an essential coenzyme involved in many important biological functions such as synthesis, repair, and methylation of DNA; cell division and growth; and metabolism of homocysteine (Kamen 1997; Fenech and others 1998). Deficiency of folate could result in megaloblastic anemia because humans need this vitamin to synthesize normal red blood cells (Zittoun 1993). Current dietary recommendations set 400 μg folate/d as the RDA for adults (1 μg food folate is also called a Dietary Folate Equivalent [DFE]), 600 μg DFE/d for pregnant women, and 500 μg DFE/d for lactating women (IOM 1998; USDA and HHS 2011). Although certain foods are high in folate, such as leafy green vegetables (for example, asparagus, spinach, and turnip greens), egg yolk, and legumes (that is, dried beans and peas), its dietary level is usually low in most foods (USDA Natl. Nutrient Database 2011a), and the requirement to enrich processed grains by adding folic acid has made foods such as breads, cereals, flours, and corn meal contributors to folic acid intake in the U.S. diet (Oakley and others 1996; Daly and others 1997; Crandall and others 1998; Malinow and others 1998). Citrus fruits and juice are natural sources of folate, and orange juice contains higher concentrations of folate than other commonly consumed fruit juices (Hill and others 1971; USDA Natl. Nutrient Database 2011a; Table 12).

Niacin, riboflavin, and pantothenic acid, 3 other water-soluble vitamins of the B complex, are all present in citrus fruits and juice products in minor amounts. The concentrations are low in the range of 2% to 4% of the current RDA per serving, with grapefruit juice having the lowest concentrations (Ting and others 1974; USDA and HHS 2011).

Flavonoids

In addition to being a source of carotenoids (for example, β-cryptoxanthin), citrus fruits are also a source of flavonoids (Holden and others 2005; USDA Flavonoid Database 2011b; Table 13). Flavonoids have a polyphenol structure and are responsible for the flavor in many fruits and vegetables (Ross and Kasum 2002) and may act as a defense mechanism against fungal attacks (Ortuño and others 2011). Flavonoids are considered to be plant secondary metabolites and have many possible health-promoting effects when consumed (Wang and others 2011). One of the most common classes of flavonoids found in citrus fruits are flavonones, in particular naringin, which imparts the bitter flavor to grapefruit (Ross and Kasum 2002). Naringin is hydrolyzed to naringenin by gut bacteria before absorption (Shulman and others 2011), which is a common precursor to many other classes of flavonoids (Wang and others 2011). Naringenin is thought to have several health-related benefits and biological effects, which include acting as an antioxidant, inhibiting microsomal triglyceride transfer protein and acetyl-coenzyme A acetyltransferase, and playing a role in regulating cytochrome P450 enzymes (Shulman and others 2011).

An emerging role of naringenin is its involvement in the prevention of bone loss and osteoporosis. A big contributor to bone loss is the activation of osteoclast cells, which occurs in response to the protein called receptor activator of nuclear factor-κB ligand (RANK-L) located on osteoblasts and macrophage colony-stimulating factor (Ang and others 2011). Osteoclast formation is a crucial mechanism in bone loss, as it reduces and withdraws the calcium from bones, contributing to bone loss and osteoporosis. This pathway is thought to be the target of flavonoid interaction in the prevention of bone loss. Naringenin inhibited RANK-L and macrophage colony-stimulating factor induced differentiation of cultured primary human osteoclast precursors in a dose-dependent manner, whereas an absence of naringenin resulted in almost complete differentiation (La and others 2009). Naringenin treatment also reduced the total number of osteoclast cells formed. This was supported again in 2011, when naringin, which is metabolized to narigenin, was administered to osteoclastic cells and inhibited the RANK-L-induced activation of nuclear factor-κB and phosphorylation of extracellular signal-regulated kinase, blocking osteoclast cell formation and bone resorption (Ang and others 2011). The inhibition of osteoclast cell formation is potentially an

Table 13–Flavonoid contents of selected citrus fruits and juice products.

Fruit description	Subclass	Flavonoid	Mean (mg/100 g fresh weight)
Grapefruit, raw, white	Flavanones	Hesperetin	0.64
		Naringenin	21.34
Grapefruit juice, white, raw	Flavanones	Eriodictyol	0.65
		Hesperetin	2.35
		Naringenin	18.23
	Flavonols	Kaempferol	ND[a]
		Myricetin	0.05
		Quercetin	0.40
Grapefruit juice, white, frozen concentrate, unsweetened, diluted	Flavanones	Naringenin	31.18
Grapefruit, raw, pink and red	Flavanones	Hesperetin	0.35
		Naringenin	32.64
	Flavones	Apigenin	ND
		Luteolin	0.60
	Flavonols	Kaempferol	0.01
		Myricetin	0.01
		Quercetin	0.33
Grapefruit juice, pink, raw	Flavanones	Eriodictyol	ND
		Hesperetin	0.78
		Naringenin	17.19
Lemons, raw, without peel	Flavanones	Eriodictyol	21.36
		Hesperetin	27.90
		Naringenin	0.55
	Flavones	Apigenin	ND
		Luteolin	1.90
	Flavonols	Kaempferol	0.03
		Myricetin	0.50
		Quercetin	1.14
Lemon juice, raw	Flavanones	Eriodictyol	4.88
		Hesperetin	14.47
		Naringenin	1.38
Limes, raw	Flavanones	Hesperetin	43.00
		Naringenin	3.40
	Flavonols	Quercetin	0.40
Lime juice, raw	Flavanones	Eriodictyol	2.19
		Hesperetin	8.97
		Naringenin	0.38
Oranges, raw, commercial varieties	Flavanones	Hesperetin	27.25
		Naringenin	15.32
	Flavonols	Kaempferol	0.13
		Myricetin	0.15
		Quercetin	0.45
Orange juice, raw	Flavanones	Eriodictyol	0.17
		Hesperetin	20.39
		Naringenin	3.27
Orange juice, frozen concentrate, unsweetened, diluted	Flavanones	Hesperetin	26.21
		Naringenin	3.27
Tangerines, raw (mandarin oranges)	Flavanones	Hesperetin	7.94
		Naringenin	10.02
Tangerine juice, raw	Flavanones	Hesperetin	9.56
		Naringenin	1.20
Tangerine juice, frozen concentrate, sweetened, diluted	Flavanones	Hesperetin	22.01
		Naringenin	3.61

Note: All values listed are mg Flavonoid/100 g fresh weight (edible portion), presented in weighted means.
[a]ND, values not detected or below the detection limit.
Source: USDA Database for the Flavonoid Content of Selected Foods, Release 3.0, 2011b.

effective method for reducing the amount of bone loss and the delay and/or prevention of osteoporosis.

A less abundant citric flavonone with properties similar to narigenin, hesperidin, may also provide several health benefits. In addition to dietary sources, such as sweet oranges, lemons, and green fruits, supplementary hesperidin is often administered to relieve swelling and fluid accumulation in the legs. Low hesperidin levels have been attributed to capillary leakiness, fatigue, and nighttime leg cramps (Garg and others 2001). More recent evidence has suggested that hesperidin could have potential protective effects against cardiovascular disease. A 2011 clinical trial found that consumption of orange juice or purified hesperidin drink for 4 wk significantly decreased diastolic blood pressure, as well as improving endothelium-dependent microvascular activity, important in vasodilation (Morand and others 2011). Hesperidin has anti-inflammatory properties through the inhibition of prostaglandins E_2 and F_2 and thromboxane A_2 (Manthey and others 2001). It also increased HDL cholesterol and lowered LDL cholesterol, triglycerides, and plasma lipids when administered to rats (Garcia and Castillo, 2008). Hesperidin's aglycone form, hesperetin, has antioxidant potential in rats when administered as a supplement rather than from the diet (Shagirtha and Pari 2011).

More research is needed on dietary hesperidin to gain a better understanding of the potential health benefits.

Minerals

Although sodium and potassium are the major cations of the cells, citrus fruits and products are low in sodium, with less than 2 mg/100 g fruit weight (USDA Natl. Nutrient Database 2011a). In contrast, citrus fruits are good sources of potassium, and according to previously documented data could constitute up to 40% of the total ash, with concentrations of 4 to 6 meq (156 to 235 mg) in 100 mL orange juice (Benk 1965). Calcium, magnesium, and phosphorus have relatively low amounts in citrus fruits (USDA Natl. Nutrient Database 2011a), contributing only 2% to 3% of the U.S. RDA per serving (USDA and HHS 2011). In the U.S.A., inadequate calcium intake is a common problem among children and adolescents who often do not drink milk or consume dairy products (Black and others 2002; Nicklas 2003). Adult dietary calcium intakes are also well below recommended values especially for the elderly (Morgan and others 1985; Looker and others 1993). Calcium-fortified citrus juices, such as those commercially available, are considered an economically viable option to help adolescents and the elderly meet adequate calcium intake (Martini and others 2002; Gao and others 2006). Although supplied as important plant nutrients during cultivation and growth, copper, zinc, iron, and manganese, which are essential in numerous enzymatic reactions and human bodily functions, are trace minerals found in all citrus fruits.

Other Important Components of Citrus Fruit

Citrus oils and volatile flavoring constituents

Stored ripe citrus fruits have a distinctive odor. The aroma-active volatile flavoring compounds contained in the peel oils characterize the aroma emanated by citrus fruits and are associated with their flavors. The release of volatile compounds increases with rising temperature, maturity, and ruptured peel and juice components (Ladaniya 2008). There are over 300 citrus volatiles and oils, and the chemical constituents include terpene hydrocarbons (such as monoterpenes and sesquiterpenes), esters, aldehydes, ketones, alcohols, and volatile organic acids (Perez-Cacho and Rouseff 2008). They are primarily found in the ductless oil sacs in the flavedo, as cold-pressed peel oil, and can be incorporated into the juice during extraction (Ranganna and others 1983; Perez-Cacho and Rouseff 2008; Rouseff and others 2009).

The largest fraction by weight, representing approximately 90% of all citrus oil compounds, is total monoterpene hydrocarbons (including d-limonene; Hunter and Brogden 1965a). Other hydrocarbons present in orange peel oils include the sesquiterpenes, such as valencene (Hunter and Brogden 1965a, b). Previous findings also suggested that the fruity aromas in citrus oils, which are specific to different varieties, contain oxygenated terpenes (Stanley 1962). Although representing a small portion of all citrus oils, esters, such as ethyl butyrate in orange essence, provide the characteristic aroma to citrus fruits (Wolford and others 1963; Ikeda and Spitler 1964; Shaw 1979). Terpene aldehydes and ketones are important flavoring constituents in lemons, oranges, and grapefruits (Stanley and others 1961; MacLeod Jr. and Buigues 1964; Hunter and Brogden 1965b). Other volatile flavoring constituents and citrus oils include alcoholic compounds, such as linalool and octanol, which are in trace amounts in lemon, lime, grapefruit, and tangerine (Attaway and others 1962; Hunter and Moshonas 1965; Hunter and Moshonas 1966). Volatile organic acids are present in trace amounts in natural orange essence (Attaway and others 1964).

In industrial practice, cold-pressed peel oils are prepared by mechanically pressing and rupturing the oil sacs in the flavedo, and then centrifuging the extracted peel oils from its aqueous emulsion portion for separation. For most citrus fruits, such as orange, grapefruit, mandarin, and lemon, cold-pressed peel oils prepared using this method are well-received by consumers because natural aroma compounds are present, yielding the pleasant odor of freshly squeezed juice (Rouseff and others 2009). Distilled lime oil is sometimes commercially preferred due to its distinct terpene character rather than the natural aroma (Ranganna and others 1983). The peel oils of limes, lemons, mandarins, oranges, and grapefruits exhibit toxic insecticidal properties, with lime as the most effective (Abbassy and others 1979). Furthermore, citrus peel oils are known for their antibacterial properties (Settanni and others 2012).

Essence oil is a byproduct recovered from the concentration process in the preparation of frozen fruit juice concentrate (Moshonas and Shaw 1979). During juice evaporation, water in the juice is vaporized, and the vapor contains aqueous components, oils, and aromas. After the vapor mixture of water and oil is removed, condensed, and separated by decantation, the oil recovered is called essence oil and contains most of the flavoring components present in juice (Ranganna and others 1983). The essence oil is characterized by a fresh-juice aroma and is used commercially as an important flavoring agent to add desirable bouquet to frozen concentrated juice (Shaw 1977; Moshonas and Shaw 1979).

Conclusions

With high demand and popular dietary preference, citrus fruit is widely consumed and has become an inseparable part of our diet. Recent developments in horticultural utilization and improved analytical technology have helped establish the analysis of citrus fruit chemical constituents. Characterized by their distinctive flavor, citrus fruits are a good source of carbohydrates, dietary fiber, many B vitamins, minerals, and biologically active phytochemicals such as carotenoids and flavonoids, which provide provitamin A activity and purported antioxidant benefits, respectively. Such nutrient density, the low-fat, low-sodium profiles, and associations between citrus fruit intake and prevention of chronic diseases make promotion of citrus consumption important in improved human health.

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