NUTS

1. Introduction

Nuts, as generally defined, are hard-shelled seeds enclosing a single edible oily kernel. Most of the common nuts fall within this classification. Many species, however, differ greatly in size, structure, shape, composition, and flavor. A more technical definition of a nut is a hard, one-seeded fruit developed from many carpels united to form a compound ovary, the woody pericarp of the shell remaining closed at maturity. Examples are the beechnut, butternut, chestnut, hickory nut, pecan, and walnut, which are all true nuts. The word nut, moreover, is applied indiscriminately to many seeds, fruits, and tubers having hard coverings, as well as to single oily or starchy kernels such as those of the almond, Brazil nut, cashew, chufa, coconut, lichee, peanut, piñon, and pistachio, which do not fit the more technical definition. Although in common parlance, the term nut implies edibility (1), nuts of many kinds are grown not only for food but also as sources of oil and for medicinal, ornamental, and other uses. Table 1 lists many nuts from various parts of the world.

With the exception of peanuts, most of the important nuts from around the world are borne on trees, many of them from native seedlings. Among the latter group are the beechnut, Brazil nut, butternut, chestnut, filbert, hickory nut, pecan, pine nut, and black walnut. The pecan, English walnut, filbert, and almond are the four principal edible tree nuts produced in the United States, where the term English walnut is used synonymously with the Persian or Carpathian walnut (2).

2. Physical Characteristics

Fruits and nuts vary considerably in structure. The kernel may be single and firm as in acorn, almond, chestnut, coconut, filbert, macadamia, piñon, pistachio, and tung; or it may be formed in distinct halves as in the hickory, pecan, butternut, peanut, and walnut; it may also be clustered within an outer husk as in the Brazil nut; or, oddly, formed outside of the fleshy part of the fruit as in the cashew. The shuck or husk covering the nut may be an extraneous growth such as the acorn cup of the oak or the spiny burr of the chestnut, a husk or fringe as in the hazel, or a prickly involucre as in the beechnut. The shuck of the pecan or hickory nut has definite sutures and splits into four parts when matured; shucks of the walnut and macadamia, however, remain entire throughout their growth. Brazil and paradise nuts are true seeds, borne in a hollow dry fruit that contains a number of the triangular nuts. The covering of the almond, ginkgo, and lichee is the dried pulp of the fruit. The shells encasing the kernels are usually hard cellular structures of varying thickness. Some are cracked easily, eg, English walnut, improved pecan, almond, chestnut, filbert, peanut, and pistachio; others can be broken only by a sharp blow, eg, eastern black walnut, hickory nut, Brazil nut, macadamia, and cashew. The cashew nut has a double outer shell containing an oily acrid fluid of a phenolic nature which has important industrial uses. The general shape of most nuts is globular, although some of these, such as the Brazil nut, pili, and beechnut, are triangular; other nuts are elongated or flattened like almond and pistachio nut, or comma-shaped like cashew nut, or curiously formed, like buffalo horns, for instance, in the case of water chestnut.

3. Chemical Composition

Most nuts for commercial use are characterized by high oil and protein contents as well as a low percentage of carbohydrates. However, some varieties, mostly inedible tree nuts such as acorn, horse chestnut, and chufa, contain at least as much sugar and/or starch as protein. The edible water chestnut is also in this category, as is the cashew nut, which contains starch in addition to a rich store of oil. The proximate composition of a number of nuts and of some nut products are given in Table 2 (3).

The edible portion of the nut ranges from as much as 73% by weight in the peanut to less than 15% in the butternut. The double shell of the cashew nut comprises about 70% of the nut. The unhusked coconut is roughly 43% fibrous husk, 15% shell, 30% kernel, and 12% milk; in contrast, the husked coconut is 27% shell, 55% kernel, and 18% milk. Moreover, the kernels of most oily nuts contain about 3% moisture; those of starchy nuts contain 50% or more water. The protein content of nut kernels can range from about 26% in the peanut and pignolia to 2.5% or less in the Chinese chestnut and lunau. A number of the most common edible nuts contain about 60% oil or fat. Pecan, pili, and macadamia, for instance, are all rich in fatty constituents and contain over 70% fat. In general, nuts are rather low in carbohydrates, especially starches. The nitrogen-free extract usually includes all constituents (mostly carbohydrates) not present in the ether extract (fats), protein ($N \times 6.25$), crude fiber, and ash. Ash constituents are usually less than 3% in the kernels of the nuts and consist largely of the oxides of potassium, calcium, magnesium, sodium, iron, sulfur, silicon, and phosphorus; they also contain smaller amounts of the mineral forms of manganese, copper, and zinc.

In the following discussion of chemical constituents, unless reported as approximate, the percentages given are representative rather than absolute, since they are based on the analysis of a limited number of samples. All results are reported on a moisture-free basis.

3.1. Proteins. Most edible nuts contain a high protein content; they also supply adequate amounts of various essential amino acids for growth and the maintenance of body tissues. The main proteins present in the following nut kernels are different types of globulins: glutelin (acorn), amandin (almond), excelsin (Brazil nut), castanin (chestnut), edestin (coconut), corylin (hazel nut and filbert), arachin and conarachin (peanut), and juglansin (butternut and walnut). Hydrolysis products, such as amino acids and ammonia, of some of these globulins are given in Table 3 (4,5). Ginkgoin, the glubolin of ginkgo, contains 60% of the seed's nitrogen and a large percentage of tryptophan; other proteins in the ginkgo kernel are albumin, glutelin, and prolamine. Feeding experiments indicate that arachin is deficient in tryptophan, in methionine, and possibly also in isoleucine (7). Conarachin, on the other hand, is an excellent protein for growth when fed as the only source of protein (8,9).

The average composition of several nut globulins is about 51% carbon, 6.9% hydrogen, 19.0% nitrogen, 0.8% sulfur, and 22.0% oxygen; total nitrogen in the globulin ranges from 18.4% in Brazil nut excelsin to 1.0% in almond and filbert globulins. From nitrogen distribution studies of several nut globulins, juglansin from English walnut was found to be the lowest in monoamino nitrogen (amino nitrogen in the alkali filtrate) but highest in lysine and arginine nitrogen. Protein precipitated from the alkali extract of pecan flour (10) contains notably higher arginine nitrogen and lower histidine nitrogen than that from the ground pecan kernel without previous extraction to remove the oil (11). The closest similarity between proteins from seeds of unrelated plants is presented by corylin from filbert and juglansin from Persian walnut, which are distinguished only by a slight difference in the nitrogen content.

The amino acid content of a variety of nuts is given in Table 4. Amino acid data have also been published on the Japanese chestnut, ginkgo, pine nut (13), acorn, breadnut, chirauli nut, gabon nut, hazel sterculia, kola, marking oyster, pistachio, and tropical almond (14). As many as 23 free amino acids have been identified in the English walnuts (15). Brazil nuts, on the other hand, have been shown to be one of the richest sources of sulfur-containing amino acids (16). The 2S albumin is about 30% methionine and cysteine. All three classes of Brazil nut proteins (2S, 7S, and 11S) have been characterized and sequenced (17–19).

3.2. Oil. Most nuts are characterized by a high oil or fat content, usually about 60%, but in certain varieties of pecans it can get as high as 76%. For the most part, oil is contained in the kernel or embryo of the seed, though it can also occur in the flesh of the ginkgo fruit and in the endosperm of coconut, palm, and pine nuts. Relative amounts of some fatty acids present in a few types of nuts are given in Table 5. Considerable variations in the percentages of fatty acids have also been reported in both pecan and peanut oils from a variety of sources (Table 6).

3.3. Carbohydrates. Carbohydrates from pecan kernel (21), coconut meal (22), English walnut (23), European chestnut (24), chufa, and the ivory nut (25) all include the following ingredients: reducing sugar, sucrose, raffinose, mannitol, dextrin, pentosan, amyloid, starch, cellulose, tannin, gum, wax, resin, and materials yet to be identified. Mannitol is the main sugar derivative in the milk of young coconuts however, it is not present in the milk of the mature nut, where the principal sugar is sucrose. Saccharose, on the other hand, is the predominant sugar in cashew nuts (26). The starch in peanuts (27) decreases during roasting.

3.4. Minerals. Nuts are considered to be a good source of minerals essential for nutrition, supplying elements of copper, manganese, iron, and sulfur. The values for the mineral constituents of many nuts shown in Table 2 are averages of available analytical data. Values for the mineral content of the peanut kernel (28) and ash constituents in the macadamia kernel (29) and cashew (26) have also been reported. Chufa nuts have a high silicon content.

Some nut trees accumulate mineral elements. Hickory nut is notable as an accumulator of aluminum compounds (30); the ash of its leaves contains up to 37.5% of Al_2O_3, compared with only 0.032% of aluminum oxide in the ash of the English walnut's autumn leaves. As an accumulator of rare-earth elements, hickory greatly exceeds all other plants; their leaves show up to 2296 ppm of rare earths (scandium, yttrium, lanthanum, dysprosium, holmium, erbium, thulium, ytterbium, and lutetium). The amounts of rare-earth elements found in parts of the hickory nut are kernels, at 5 ppm; shells, at 7 ppm; and shucks, at 17 ppm. The kernel of the Brazil nut contains large amounts of barium in an insoluble form; when the nut is eaten, barium dissolves in the hydrochloric acid of the stomach.

Deficiencies in minor mineral elements have been observed in the growing of nut crops; the main deficiencies are zinc in pecans, English walnuts, and almonds, and boron in peanuts and English walnuts. The disorder of pecan known as rosette used to threaten the growing crop until the cause was found to be a deficiency in zinc, which could be corrected by applying zinc salts to the tree by various means. For that matter, small almond leaf can also be corrected by zinc treatment (31). In studies on the deficiencies of several elements in pecan trees grown in sand cultures, no single abnormality is found to be sufficiently characteristic for identifying the deficiency of an element in the tree (32). Boron deficiency in peanut usually causes hollow heart; in English walnuts it causes shoots to die back (snakeheads) and nuts to fail to set on the tree. Such conditions can be corrected by applying 1.8–2.7 kg of borax for each English walnut tree; indeed, so great is the response to boron application that a walnut orchard previously noted for poor production has resulted in the setting of so many nuts that the trees were finally broken down by their weight (an average of 5.6 metric tons of green nuts per hectare) (33). Filberts, on the other hand, have never shown any deficiency symptom or response to boron treatment. In an intensive study of the boron content of almond and English walnut tree parts, the kernels of the almond were found to contain 15.6–57.7 ppm of boron, the shells 21.8–102.5 ppm, the husks 36.4–440.5 ppm, and the leaves 30.4–53.6 ppm (34). The walnut was found to contain 7.5–16.3 ppm of boron in the kernels, 13.6–15.4 ppm in the shells, 21.7–79.0 ppm in the husks, and 35.9–516.0 ppm in the leaves. Much of the boron in the almond husk is water soluble; that in the walnut husk is water insoluble.

3.5. Vitamins. Most nuts contain a good supply of vitamins A and B_1 but are usually lacking in other vitamins. Table 2 lists the vitamins in various nuts and their parts. Red palm oil is an important source of beta-carotene; it contains 30–40% of this vitamin. Peanut oil contains 0.03–0.05% of tocopherol (vitamin E). Immature English walnuts, mainly the pulp, contain a large amount of ascorbic acid (vitamin C), around 1300–3000 mg/kg, a much greater amount than is found in any other plant part except rose hips, which contain about 5000 mg/kg of ascorbic acid. Methods for extracting vitamin C from green walnuts have also been developed (35). Considerable vitamin C ($>$2000 mg/kg) has been reported in the buds and male catkins of English walnuts (36). Unfortunately, as the immature fruit ripens and the walnut forms, the vitamin also disappears. However, the large amounts of vitamin C apparently present in walnuts may in part be due to faulty analyses, as other reducing substances may have been present that interfered with the analyses. Thus, by isolating ascorbic acid in a new analysis, the large amounts of vitamin C previously claimed to be in green husks of walnuts could not be confirmed. In addition, vitamin C can be found in mature hazel nuts and almonds (37).

A considerable amount of vitamin B_1 (thiamine) has been found in the red skins of Virginia-type peanuts (38); vitamin B_1 has also been found in almonds and filberts, at levels of 114 and 570 mg/kg, respectively (39).

The nicotinic acid content of several nuts has been reported (in mg/kg) as follows: chestnut, 200; hazel nut, 600; almond, 1600; and sunflower seed, 5000 (40). The results of analyses for pantothenic acid are (in mg/kg): hazel nut, 380; almond, 75; sunflower seed, 620; and walnut, 600. Nuts also contain more biotin than most fruits and vegetables.

3.6. Phytin and Phospholipids. Phytin, an important organic phosphorus compound, as well as lecithin and cephalin, both phospholipids, are present in nuts. Phytin in food occurs mainly as a mixed calcium and magnesium salt of inositolphosphoric acid, $Ca_5Mg(C_6H_{12}O_{24}P_6{\cdot}3H_2O)$, and supplies phosphorus and calcium in a readily available form. The phytic acid phosphorus content in various nut kernels (in % of total P) is almond, 82%; Brazil nut, 86%; American chestnut, 18%; hazel nut, 74%; filbert, 83%; peanut, 57%; and English walnut, 42%. The phosphorus present in the protonated form of phytin, $C_6H_{18}O_{24}P_6$, is almond, 2.57%; Brazil nut, 2.96%; filbert, 1.66%; hickory, 1.57%; peanut, 1.67%; pecans, 1.46%; English walnut, 1.43%; and eastern black walnut, 2.03% (41). Peanuts are found to contain 0.5% of lecithin and cephalin; piñons 1.0% of lecithin. Choline is present in pecan, peanut, and peanut meal at levels of 0.53, 1.70, and 2.52 mg/g, respectively. Phytosterol is present in the oil of beechnut to the extent of 0.18% of total weight, in hazelnut 0.50%, and in piñon 0.40%. Cholesterol is present in detectable quantities in cashew nut oil (26).

3.7. Glycosides and Alkaloids. Saponins are sapogenin glycosides that usually contain triterpene or sterol nuclei. These are mainly amorphous, water-soluble compounds, and can form colloidal solutions that foam readily and reduce surface tension (Fig. 1). A saponin occurs in the pulp of soapnut to the extent of about 30% of the dry weight; horse chestnut contains 10–14% of bitter principle in the form of a saponin, argyrin, and a glycoside, esculin [531-75-9], $C_{15}H_{16}O_9$ 1. Esculin is hydrolyzed by enzyme to glucose and esculetin [305-01-1], $C_9H_6O_4$ 1. Amygdalin [29883-15-6], $C_{20}H_{27}NO_{11}$, 1 is the most important of the cyanogenetic glycosides that yield hydrogen cyanide on hydrolysis. It is found in all seeds of the rose family but more abundantly in the seed of bitter almond (2.5–3.5%); in addition, it is found in the seeds of apple, apricot, cherry, peach, pear, plum, and quince. Hydrolysis of amygdalin catalyzed by enzymes amydalase and prunase yields glucose and benzaldehyde as well as hydrocyanic acid. Intermediary products are mandelonitrile glucoside (prunasin) and mandelonitrile [532-28-5], C_8H_7NO 1. *Strychnus nuxvomica*, or poison nut, has as its chief constituent the alkaloids strychnine [57-24-9], $C_{21}H_{22}N_2O_2$ 1 (0.4%) and brucine [357-57-3], $C_{23}H_{26}N_2O_4$ 1 (90.2%) it also contains strychnic acid, sugar, fat, and the glycoside loganin [18524-92-2], $C_{17}H_{26}O_{10}$ 1. The Betel nut contains at least four alkaloids, of which arecoline is the primary constituent (42,43). Arecoline is an effective anthelminthic and vermifuge (42).

3.8. Tannins. Tannins are amorphous astringent substances that produce colors, eg, inks with ferric salts, and precipitate gelatin from solution (tanning). They are hydrolyzed by acids into various products such as sugar (*d*-glucose) and hydroxy acids. The process of tanning, involving both physical and chemical reactions, is the conversion of a hydrophilic gel into a relatively nonhydrophilic one, eg, leather. Tannins occur abundantly in certain nuts and parts of nut trees. The wood and bark of the chestnut are especially rich sources of commercial tannin. The integument of the pecan contains tannin at up to 25% of total weight, the outer shell, 6–8%; the almond hull, in contrast, contains only 4.5% of tannin. Both pecan shell waste and almond hulls from processing plants are a source of commercial vegetable tannin (44,45). The tannins of the English walnut are composed chiefly of four polyphenolic esters of glucosides (46).

3.9. Toxic Constituents. The seed coat of European beechnut contains an unidentified toxic substance that makes the feeding of beechnut cake to certain farm animals hazardous (47). A toxic concentration (up to 4000 ppm) of barium found in some Brazil nut kernels (30,48) has been reported to cause illness in children who ingest the nuts. Bethel nuts have also been shown to include constituents that are carcinogenic, embryotoxic, and immunotoxic (49–51). The liquid from cashew nutshells contains anacardic acid [18654-17-6], $C_{22}H_{32}O_3$ 2, a brown crystalline substance (47), and cardol, $C_{21}H_{32}O_2$ 2, a dark-brown phenolic oil; both of these substances are toxic, irritating, and can produce blisters on the skin similar to those caused by poison ivy (Fig. 2). Juglone [481-39-0], $C_{10}H_8O_3$ 2, has yellow-brown crystals (52) that stain the skin and occurs chiefly as its colorless reduction product, α-hydrojuglone [481-40-3], $C_{10}H_6O_3$ 2, in all green and growing parts of walnut trees and the unripe hulls of the nut. Juglone released from black walnuts can stunt the growth of nearby plants (Fig. 2). Some nuts contain glucosides that are disagreeable or toxic to some people; for example, bitter almonds contain cyanogenetic glucoside that releases hydrogen cyanide. The presence of allergens has been confirmed in Brazil nut, coconut, filbert, pecan, peanut, almond, and walnut. Tannins may also be disagreeable to some people for their unpleasant taste (53). A detailed study of the amino acid content of allergens isolated from almond, Brazil nut, filbert, peanut, and black walnut has been reported (54). Peanut seeds through a phenolic glycoside in the skin (55) can inhibit iodine uptake by humans (56). The glycoside is preferentially iodinated and deprives the thyroid of available iodine (57).

4. Nutritive Value of Nuts

Nuts are rich in protein and fat; most commercially important nuts supply about 28 MJ/kg (6600 kcal/kg) of kernel, more than most other foods (Table 2); cereals supply about 15 MJ/kg (3640 kcal/kg); meats about 7.5 MJ/kg (1790 kcal/kg); and fresh fruits less than 2.8 MJ/kg (660 cal/kg). The energy content in kilojoules (1 food calorie or cal = 4.184 kJ) per kilogram of food is calculated by the following formula:

$$171.61\,[\%\,\text{protein} + \%\,\text{total carbohydrates}\ (N-\text{free extract} + \text{fiber})] + 389.3\ (\%\ \text{fat}) \qquad (1)$$

One kilogram of nut kernels is equal in energy value to 5.1 kg of bread, 8.21 kg of steak, 27.1 kg of white potatoes, or 33.1 kg of oranges. A human male doing ordinary work requires 12.5 MJ/d (3000 kcal/d) for energy production: 75 g of protein, 85 g of fat, 0.67 g of calcium, 1.44 g of phosphorus, and 1.5 mg of iron. Thus, 45 g of oily nuts can supply all the food energy needed each day, ie, about 40% of the protein, 60% of the phosphorus, 30% of the calcium and iron, and four times the requirement for fat. Nuts, as a rule, contain considerable vitamin A and vitamin B complexes and are sources of iron, copper, manganese and sulfur, though they usually lack vitamin C and calcium. The peanut is an especially rich source of niacin. Nuts also contain the essential amino acids tryptophan, phenylalanine, lysine, valine, and leucine. Processing peanuts and other nuts by roasting or cooking in oil significantly reduces their vitamin content. For instance, cooking macadamia nuts in hot oil at 135°C for 12–15 minutes can cause a loss of 16% of the original thiamine content (58); similarly, modern commercial methods of roasting or processing peanuts in hot oils can destroy about 70–80% of the thiamine content (38).

The reaction of edible nuts in the diet is mainly basic, although some nuts, such as peanut, pecan, and English walnut, can also provoke an acid reaction. In a research experiment, young white rats were fed several nuts to obtain digestion coefficients of the protein and fat. Digestion coefficients for protein, in percentages, were as follows: pine nut, 95.12; almond, 90.17; peanut, 89.43; hazel nut, 82.91; and walnut, 79.49. For fat, the results, also in percentages, were the following: almond, 96.13; peanut, 95.50; hazel nut, 87.22; pine nut, 82.93; and walnut, 67.77 (59). For cashews, the chemical score of 59–67 is not high, but the protein score is high (60).

Nuts are a very concentrated food and may cause discomfort if they are not well masticated; digestibility, of course, can be increased if they are finely ground. Rather than as a basic diet, nuts are used chiefly as appetizers and seasoning ingredients to salads, cakes, candies, and cookies, or as emergency rations for persons expending great amounts of energy. However, a peanut-butter sandwich with 30 g (2 tablespoon) of peanut butter, a 237-mL (8 ounce) glass of milk, and an orange can supply about one-third of all the recommended daily allowances except those for iron and vitamin A (61). Incorporating moderate quantities of walnuts into a cholesterol-lowering diet can also decrease serum levels of total cholesterol and improve the lipoprotein profile in an average person (62). The advantages of nuts over meats are that the former do not have to be prepared for eating and that they are free from waste products such as uric acid formed from purines (as in meats). Also, nuts are relatively sterile; that is, they are free from putrifactive bacteria and parasites. A slight drawback is that mold is sometimes present. Another drawback is that the handling of nuts after shelling may introduce some microbiological contamination to nut kernels. But the chief disadvantage of nuts is that they do not supply the bulk for propulsion in the digestive system as meat and other foods are able to provide.

5. Chemical Changes during Development and Storage

5.1. Development. Several investigations have been made on the chemical changes taking place during the development of various nuts; for instance, in macadamia (63) (see Table 7), pecan (65), almond (66), English walnut (67), eastern black walnut (see Table 8), and tung (69). The levels of sugars and other carbohydrates decrease rapidly during oil synthesis, so that by the time the kernel is mature, most of the carbohydrates have disappeared. Since the decrease in carbohydrate levels in the kernel accounts for only a small proportion of the oil synthesized, it follows that the materials formed into oil come from other parts of the tree. For example, studies of the tung fruit at different stages of development show that even though all the carbohydrates are utilized for synthesis of oil in the kernel, a large part of the substances necessary for oil formation are brought in from outside the nut (69). The fat content in the eastern black walnut kernel increases out of proportion to any decrease in other constituents (68).

A systematic sampling of pecan nuts, at nine weekly intervals during kernel development, to determine changes in the oil, protein, and mineral constituents reveals that the most critical period in the filling of the kernel in the Northern Hemisphere is the three weeks prior to September 15, during which time 64% of the total oil, 71% of the protein, 43% of the ash constituents, and 63% of the dry weight are formed (70). Potassium, comprising 73% of all mineral elements in the shuck, accumulates at a rapid rate in the shuck and kernel during the early filling stage; likewise, phosphorus increases rapidly in the kernel during this stage. The vitamin C content of English walnut during development of the nut was found to increase to a maximum of 15% forty days after blooming and then to decrease to 1–2% at maturity (71); vitamin C made up 52% of the weight of an immature nut's hull, 32% of the tissue under the shell, 15% of the shell, and 1% of the kernel.

Respiration of the developing peanut is very rapid during fat synthesis but declines before maturity (72); studies of respiration indicate another decline about 8–10 hours after the harvest of peanuts (73).

5.2. Storage. Investigation of the effects of moisture, heat, and darkness on raw kernels of macadamia nuts found the stability of the kernels to decrease with increasing moisture content and increasing storage temperature (74). At 1.4% moisture, according to the investigation, only very small changes were found in flavor and chemical composition after 16 months, regardless of storage conditions. At high moisture levels and storage temperatures, total sugar levels decreased but reducing sugar and free fatty acid levels increased; light, on the other hand, had no effect on stability. The investigation found that stability is greatest at 1.4% moisture; but at 2.3% and 4.3% moisture, -18°C storage is recommended for kernel stability. A different study (75) on the roasted macadamia kernel gave results similar to those in the raw nut research. Moreover, an earlier study (76) indicated that supplemental protection by the application of antioxidants, elimination of oxygen, and shielding from ultraviolet radiation can further enhance kernel stability of the macadamia nut.

For the English walnut, the optimum moisture level for storage is 3.2–3.8%. Stability of the shelled nut is significantly reduced at higher or lower moisture levels (77,78). In addition, the skin colors of nuts are also important. A procedure was developed (77) to estimate the darkening rate of English walnuts during storage, which consists of the extraction of walnut kernels for 30 minutes with 65% aqueous methyl alcohol at reflux temperature, filtration, and photometric estimation at 400 μm of the absorbance of the clarified solution. An arbitrary numerical color scale has been devised to express the color values of shelled walnuts.

Because most edible nuts are high in oil, rancidity is one of the first signs of deterioration. There are two types of rancidity: oxidative, in which aldehydes and ketones are formed by the addition of molecular oxygen, and hydrolytic, in which hydrolysis of the glycerides forms free fatty acids. In nuts of the hydrolytic type, the glycerides hydrolyze in the presence of moisture and a fat-splitting enzyme. High temperature and humidity, as well as sunlight, favor the development of rancidity in nut kernels; consequently, the best storage conditions consist of low temperature, low humidity, and little or no light.

Considerable research has been done on the storage of nuts, especially of pecans, which have a high free fatty acid content (79). Most pecans are refrigerated at some time during storage and marketing. They may be held at 3°C for one year, at −4.5°C for three years, or at −17.5°C for more than five years (80). Most nuts cannot be held for more than three or four months at ordinary temperatures, especially during the summer, without developing rancidity; however, storage experiments have shown that nuts and nut products can be kept two to five years longer under refrigeration at 0–5°C (80). For instance, peanuts stored in the shell at 4.4°C have remained perfect for as many as six years with no detectable chemical changes (81). Nut kernels sealed in tins by a vacuum process also keep well. On the other hand, various tests with nuts stored in glass, plastic, or containers of other kinds, and sealed with nitrogen, carbon dioxide, or other gases have proved satisfactory only when the nuts are held under refrigeration. Slight ventilation must be provided in containers storing chestnuts because of the respiration of nuts.

An edible and nutritive coating of zein protects tree nuts and peanuts from developing rancidity, staleness, and sogginess during storage. Zein coatings, applied as alcohol solutions, contain an acetylated monoglyceride and antioxidants. The zein prevents the transfer of oil from the nut, whereas the monoglyceride prevents the transfer of moisture into the nut and at the same time plasticizes the zein. Antioxidants, on the other hand, prevent rancidity of oil on the nut surface at the time of coating. In an experiment, both coated and uncoated pecans were stored at 37.9°C. After one month the uncoated pecans were rancid, but the coated pecans stayed fresh for three months at 37.9°C and for six more months at room temperature. Similar results have been obtained with walnuts, almonds, peanuts, as well as nuts incorporated in chocolate bars (82).

Nuts are susceptible to infestation by weevils in storage, especially in warm weather. Infestation is usually prevented or controlled by placing the nuts in cold storage or by fumigating them either in the open with gas, such as methyl bromide or hydrogen cyanide, or under vacuum with a mixture of carbon disulfide and carbon dioxide. For example, phosphine and methyl bromide can be used to control insects in farmer's stock (in-shell) and shelled peanuts in transit (83), whereas pyrethrins are used to control insects in shelling plants. Malathion is also used to control insects in stored products but is in the process of being deregistered by the USDA (84). Methyl bromide used at the rate of 35 g/m^3 (1.0 g/ft^3) or liquid hydrogen cyanide at 18 g/m^3 (0.5 g/ft^3) for eight hours at 16°C or above is sufficient to kill all insects and rodents. In contrast, a 0.48-kg/m^3 (13.6 g/ft^3) dosage of an ethylene oxide–carbon dioxide mixture for 1–2 hours provides excellent control in vacuum fumigation of nut kernels. However, the carbon disulfide–carbon dioxide mixture has proved unsatisfactory for pecan, Brazil nut, and cashew (85).

Although the storage of peanut butter is influenced by temperature (86), the extent of roasting, hydrogenation, and addition of salt have little effect on product stability if packages are sealed properly. This is because oxygen in the headspace is the main factor in reducing stability; consequently, peanut butter for the retail trade is packed in air-tight containers or under vacuum. Metalloproteins as well as iron and copper salts are the chief catalysts of fatty acid peroxidation in peanut butter; however, certain chelating agents can retard or reduce this catalytic effect (87). Autoxidation in peanut butter is relatively rapid at first but soon decreases in speed so that staleness and rancidity develop slowly over an extended period of storage. The product can remain in good condition for two years at room temperature, provided that the oil has not separated and oxygen is not present for free-radical reactions.

5.3. Aflatoxins. Mycotoxins are toxic compounds elaborated by fungi. The Greek words *mykes* means fungus and *toxikon* poison. Although mycotoxins have been know to exist for many years, they have been studied less intensively than bacterial toxins in foods. Interest in the effects of mycotoxins was renewed in recent years after the discovery that aflatoxins were the causative agents in turkey X disease (88), which killed thousands of turkeys in England in 1960. Poultry (eg, ducks, turkeys, and chickens) are especially susceptible to aflatoxins, which induce liver damage (89). In humans, aflatoxins are carcinogenic, hepatotoxic, and teratogenic. Dietary intake of aflatoxin-contaminated products (maize and peanuts) is associated with hepatitis, Indian childhood cirrhosis, and liver cancer (90).

Aflatoxins are fluorescent toxic factors elaborated by the common mold *Aspergillus flavus* during its growth on nuts or grains. Peanuts may be invaded by toxigenic strains of *A. flavus* present in the soil, which allows aflatoxins to be produced during the pre- and post-maturity stages in the field, during post-harvest drying, or in storage (91). Over 18 aflatoxins belong to the mycotoxin group. The two principal toxins are aflatoxins B_1 and G_1 (92), so named because they showed blue and green fluorescence, respectively. Aflatoxin B_1 is the most common of the aflatoxins (93) as well as the most potent hepatocarcinogen known (94).

Toxins have similar structures and form a unique group of highly oxygenated, naturally occurring heterocyclic compounds that fluoresce when exposed to fluorescent light (95). This fluorescence is used for detection in thin-layer chromatographic separations (96). Increasingly, aflatoxins are detected, using high performance liquid chromatography (hplc) (97,98) or enzyme-linked immunosorbent assay (elisa) (99,100). Tolerances for total aflatoxin or aflatoxin B_1 range from 1 to 50 μg/kg (97). In the United States, the allowed level of total aflatoxin for products intended for human consumption, dairy animals, or immature animals is 15 μg/kg (97,101). Levels greater than 100 μg/kg may be acceptable for breeding cattle, breeding swine, finishing swine, and feedlot beef cattle (101).

Although other mycotoxins have been and are being discovered, aflatoxins retain a position of importance because of their high toxicity and common natural occurrence in such foods as cereal grains, oilseeds, and oilseed meals stored under adverse conditions. Almost all agricultural commodities and foods support the development of aflatoxins if conditions are favorable for the growth of *A.*

flavus (102). Severe and prolonged drought, for instance, promotes aflatoxin formation in peanuts (103). Mathematical models have been developed to describe mold growth and aflatoxin formation under field conditions (104).

Four main approaches are used to control the problem of aflatoxin in peanuts: (*1*) the development of cultivars that resist the invasion of aflatoxin-producing fungi; (*2*) cultural practices minimizing insect damage that facilitates fungal invasion; (*3*) detoxification of contaminated nuts and their products; and (*4*) separation of contaminated nuts (105). Generally, most aflatoxin production occurs during the harvest period after the nuts have been dug and begun to dry but before the moisture level best suited for storage is obtained. As a result, nuts must pass through this critical moisture zone quickly. Storage of the nuts under proper temperature and humidity conditions can prevent further contamination (70).

One effective step to ensure a wholesome product is to divert from edible use any contaminated lots of nuts as early in the food processing chain as possible. In the United States, the peanut industry has been a leader in detecting and diverting mycotoxin-containing peanuts, which are kept out of the food and feed channels. In addition, sampling instructions (106) for in-shell and shelled peanuts require that three 21.8-kg samples of shelled peanuts be ground and tested for certification. Such a large sample size is required because of the difficulties in obtaining a representative sample of peanuts for aflatoxin analysis (107). However, the necessity for a large sample size also makes the sampling of expensive nuts such as the cashew almost prohibitive.

Although aflatoxins are stable during heating and cooking (108), they are sensitive to strong acids and bases at elevated temperatures. For example, alkali-refining and washing destroys aflatoxins in peanut oil (109,110) as does ammonia fumigation for corn (111). For powdered materials, eg, corn flour or peanut cake, treatment with $NaClO_2$ or $(NH_4)_2S_2O_8$ at 60°C followed by washing is effective in degrading and removing aflatoxin (112). However, rheological properties are affected unfavorably by this method (113). Biological detoxification using *Flavinobacterium aurantiacum* is also effective for milk, oil, peanut butter, peanuts, corn, or peanut milk but unfortunately dyes the product a bright orange-pink (108,112–115). Fungicides and food preservatives may also be used to control microbial growth (115–117). Separation of damaged aflatoxin-containing nuts by flotation or electronic sorting has also been found effective for peanuts (112,118). Most of these methods, however, have not been approved by the FDA or USDA for production of human or animal food.

6. Processing

6.1. Shelling, Cracking, and Bleaching. Very elaborate machinery is used for cleaning, grading, bleaching, cracking, and packing edible tree nuts such as pecan, English walnut, filbert, and almond. For other nuts, the processing remains at least in part a hand operation.

Shelled in India, cashews are heated in cashew nutshell liquid before being shelled to make the shells brittle and to extract the toxic liquid from the shell; this cashew nutshell liquid or oil, which should not be confused with the fatty oil from the kernel, is recovered for many industrial uses (119), including its use in sweet-tasting salad oil (47). After heating, the nuts are cracked and the inner seed coat is removed by hand. They are then packed and shipped in such a way that cashew kernels are protected against spoilage and insect infestation. Tin cans, for instance, are vacuumed through a small hole in the lid and charged with an inert gas such as carbon dioxide or nitrogen.

Babassu presents a problem in cracking. The shell of this nut is extremely hard. Because a cracking machine has yet to be perfected, most of the extracting is done by hand. Macadamia also has a hard shell and requires the use of special cracking machinery (68). In contrast, although piñon nuts are hard-shelled, they are very small (2600–4400 per kg). The invention of a shelling and separating machine has greatly increased the commercial value of this nut in the United States. Brazil nuts are soaked in water for 24 hours and then placed in boiling water for 3–5 minutes prior to cracking, which is done in hand-operated machines. Special care must be taken not to damage the kernels. In some cases, the hulls of English walnuts are loosened after harvest by exposure to ethylene (1:1000 parts of air), a process said to preserve the natural color of the kernel. This treatment prevents hulls from sticking to and staining the shells. Dehydration of English walnuts by artificial heat has to a large extent superseded sun-drying. After hulling and washing, the walnuts are placed in bins and dried to less than 10% water content by warm air not over 43°C.

Bleaching of almonds is usually accomplished by exposure to steam for 20 minutes and then to sulfurous fumes in an airtight chamber for 20–30 minutes (burning sulfur at the rate of 1.5 kg sulfur per metric ton of almonds). English walnuts are bleached for market by dipping for 5–10 seconds in 100 liters of water, combined with a small amount of sulfuric acid. Pecans (in-shell) are sometimes bleached in sodium hypochlorite solution and occasionally dyed; however, for the most part they are marketed in their natural color. Large in-shell Virginia-type peanuts are sometimes bleached with sodium hypochlorite solution, dried, and whitened by sprinkling with marble dust.

6.2. Blanching, Salting, and Roasting. Some of the nut kernels processed for market and for various nut products are blanched, ie, the skin or membrane covering the white meats is removed. Pecan meats, in contrast, are not blanched. Almonds are soaked in hot water until the skin slips off readily; they are dehydrated subsequently. Salted almonds are prepared by immersion in hot peanut or coconut oil at 149°C followed by salting (120). Since hot-water treatment is insufficient to loosen and remove the skins from the wrinkled surface of English walnuts, the kernels of these nuts are blanched by immersion in lye solution followed by a dilute acid rinse; this process yields a white nonastringent product (10). In an improved glycerol–alkali process for blanching almonds, Brazil nuts, filberts, and other nuts, which better preserves the flavor and texture of the nuts, the kernels are passed through a heated solution of 7.4 g of glycerol and 45 g of sodium carbonate per liter of water; the skins are removed with a stream of water; the kernels are dipped in a weak citric acid solution to neutralize any alkali retained by the kernels (121). Pistachio nuts are salted and roasted with the shell partially open; however, the method of treatment to make the shell milk-white is proprietary. In addition, several plants in the United States and Europe are processing peanuts that are salted in the shell before roasting. Usually, the peanuts are impregnated with salt by using a saturated brine solution and vacuum (122). A great increase in peanut consumption in the 1990s has been due to the popularity of dry roasted peanuts. The shelled peanuts are heated for blanching; then blanched and coated with a mixture of proprietary ingredients consisting of gum, zein, acetylated monoglycerides, spices, an antioxidant, and a coloring agent; finally the coated peanuts are roasted for maximum flavor. These vacuum-packed products have excellent flavor and long shelf life.

Peanut seed cotyledons consist of epidermal, vascular, and parenchymal tissues. Processors are chiefly concerned with the parenchymal cells that form the majority of the cotyledon. The main subcellular organelles of the parenchymal cells are lipid bodies, protein bodies, and starch grains (Fig. 3). Seed maturity, environmental conditions, and processing all significantly affect peanut seed microstructure (123). For instance, drought stress can result in cracking and fissuring of parenchymal tissue; both oil-cooking and oven-roasting can result in disruption of the cytoplasmic network, bursting of lipid bodies, and distension of the protein bodies, but cause little damage to starch grains. Microscopic examinations of raw and roasted peanuts, cashews, and almonds found cell walls to be less plastic and more brittle (124).

6.3. Peanut Butter. By federal regulation, at least 90% of commercial peanut butter consists of shelled roasted peanuts that are ground and blended with salt, sweeteners, and emulsifiers. No artificial flavors and sweeteners, chemical preservatives, natural or artificial color, purified vitamins, or minerals are allowed (125). To meet consumer demand for low fat products, several U.S. manufacturers have created products in which the peanut content has been partially replaced by maltodextrins, corn syrup solids or similar starches, and soy protein (126–128). Reduced fat peanut butters are available which provide a fat reduction of 25% (129). As of the mid-1990s the FDA is still considering modifying the standard of identity, in accordance with the Nutrition Labeling and Education Act of 1990 (130), to permit the adding of vitamin as well as the display of nutrient content claim (eg, “reduced fat”) to an existing standardized term (peanut butter). This has met with opposition from growers’ associations. As of April 1, 2006 synthetic flavors, artificial sweeteners and chemical preservatives are not allowed.

Commercial manufacture of peanut butter varies considerably. The influence of roasting time on sensory attributes and on chemical measurements of flavor components can be found in Reference 39. Shelled peanuts are heated to an internal temperature close to 145°C (81) to obtain the proper roasted flavor. At this temperature, free amino acids and sugar in the peanut react to form pyrazines, the main roasted-flavor components (131). The peanut is then quickly cooled to stop the cooking at a definite point to produce a uniform product. Next, blanching is used to remove the peanut skins and hearts. Peanut hearts (embryonic axes) should be removed from the kernels prior to peanut butter manufacture because they impart a gray color and bitter flavor to the product (109); likewise, defective nuts should also be removed. Finally, a coarse or medium grind is made and the ingredients added and blended, in which both salt (about 2%) and sugar (0–6%) impart flavor. Oil separation in peanut butter products can be prevented by adding partially hydrogenated vegetable oils at levels of 3–5%; it may also be controlled by keeping the product at about 10°C (109). The final grind, at a temperature sufficient to obtain a melt of the stabilizer, produces the desired texture: smooth, creamy, or chunky; old-fashioned peanut butter, however, does not contain a stabilizer. The small amount of stabilizer used does not contribute trans fatty acids to the product (129). Air is removed by vacuum, and the mixture is cooled to about 32°C before packaging to ensure longer shelf life and proper crystallization of the fat. The vacuum or gas-flushed final package should remain undisturbed for about 12–24 hours to allow complete crystallization which prevents cracking, shrinking, or pulling away from the container.

6.4. Nut Products. Peanut products include peanut flour, lipoprotein, protein, milk, and partially defatted peanuts (109). Pecan butter is made from dry roasted meats, ground to a very fine state, and mixed with salt (2% of final weight), hydrogenated fat (1.5%), and the antioxidant butylated hydroxyanisole (BHA) (132).

The press cake and ground kernels from bitter almond and other fruit pits contain glycoside amygdalin. Hydrolysis of amygdalin is accomplished by heating the cake or powder at 50°C with an excess of water; steam is passed through, and oil of bitter almonds is driven off together with hydrocyanic acid. Benzaldehyde thus collects in the condensate as a heavy lower layer, which is then drawn off. If the oil is to be used for flavoring, it is refined by heating with slaked lime and iron salt or with sodium bisulfite.

Research has shown that ascorbic acid can be produced from hulls of immature walnuts by extracting the hull with 0.2% sulfur dioxide solutions, and purifying the extract by adsorption on and elution from anion-exchange resins. Eluates from the anion-exchange step are concentrated, purified by organic solvent fractionations, decolorized, and crystallized (35).

7. Economic Aspects

The United States is among the top producers and consumers of tree nuts in the world. Tree nuts account for 13% of all farm cash receipts for all agricultural crops. U.S. principal products are almonds, walnuts, and pecans. Table 9 gives data on tree nut production in the leading producer countries in the world (133). Table 10 give U.S. supply and disappearance of important nuts from 2001–2005 (134).

7.1. Almonds. The United States is the world's leading producer of almonds, with almost all of the production concentrated in California. Following heavy plantings in the late seventies to early eighties, California's production continued to grow rapidly. While continuing to grow, although at a slower pace in the nineties and early 2000s, California's crop accounted for almost half of the world's production in 2004. The initial forecast for 2007 is 1.31×10^9 pounds (shelled) which would be a 17% increase over 2006 (135). U.S. has fewer acres in almond production than Spain and Tunisia, but has higher yields likely due to the higher tree density per acre. U.S. yields are not as high as some traditional almond producers, such as Syria and the United Arab Emirate. Since 2000, prices have been increasing 20% annually, although production has slowed to

6% a year. Increasing demand has helped growers maintain strong prices See Fig. 4.

Of the 2.86 pounds of tree nuts consumed by the average American, almond consumption accounted for 36% of the total.

As the world's biggest producer, the U.S. is also the biggest exporter. In 2003, the U.S. accounted for three-fourths of all in-shell exports. Syria was the second biggest exporter, with its share of the market at 4%, followed by Spain, China/Hong Kong, and Australia. The major importers of in-shell almonds are usually lower income countries that use almonds in their cooking, eg, India, Pakistan. Biggest importers of shelled almonds are Spain and Germany. Both countries have a strong demand for almond paste to be used in confectionary products.

7.2. Walnuts. Walnut growers in the United States produced 325,000 t of walnuts in 2004. The value of this crop was $\$439 \times 10^6$. English and Persian walnuts are the most popular. Since 2000, the U.S. accounts for 35–40% of all exports. China is the world's largest producer with the U.S. as second largest. China exports very little. U.S. consumption reached a record high of 20.54 lb/person in 2004–2005. Bigger crops and increased information about the health benefits of walnuts has helped increase demand (137).

7.3. Hazelnuts. Hazelnuts, also called filberts, grow in the Black Sea and Mediterranean regions. Turkey produces 60% of the world's total; Italy is second, the U.S. is third, followed by Spain. Production in the U.S. is concentrated in Oregon. Hazelnuts are an important crop for Oregon. Between 2003 and 2005, cash receipts averaged $\$62 \times 10^6$. The industry has been battling Eastern Filbert Blight, a fungal disease that eventually kills the trees. The industry is trying to develop fungus-resistance trees. Hazelnuts in-shell bring the highest price. Turkey and Italy play critical roles in the establishing world price. In 2004 and 2005, U.S. prices rose because of a shortage of product in Turkey. Turkey's crop returned to normal in 2006 and the U.S. value of its crop fell to $\$45.1 \times 10^6$, lower than the previous year, but still the third highest on record. In the U.S. an average of half of the years supply is exported. Hong Kong is the major exporter, accounting for 50% of exports. Germany averages 13% of total shipments. Hazelnut consumption in low in the U.S. averaging about 0.06 lb/per capita. Use in imported confectionaries is not included in this amount (135).

7.4. Peanuts. In 2005, U.S. peanut production was 2.2×10^6 t ($4{,}822 \times 10^6$ lb) up from 1.9×10^6 t ($4{,}288 \times 10^6$ lb) in 2004, (138) (See Table 11).

Unlike other countries where the end products are peanut oil, cake and meal, the prime market for U.S. peanuts is in edible consumption, and the marketing and production focus is in that direction. Only 15% of U.S. production is normally crushed for oil. Peanuts are the 12th most valuable cash crop grown in the United States with a farm value of over $\$1 \times 10^9$.

Most or the U.S. peanut crop is used in domestic edible products each year. Peanuts, peanut butter and peanut candy are some of the most popular products in the United States. American consumers eat more than 6 lb or 2.7 kg (kernel basis) of peanut products each year, worth more than $\$2 \times 10^9$ at the retail level.

Peanut butter accounts for approximately half of the U.S. edible use of peanuts accounting for $\$850 \times 10^6$ in retail sales annually.

World peanut production totals approximately 29×10^6 metric tons per year, with the U.S. being the world's third largest producer, after China and India. Worldwide peanut exports are approximately 1.25×10^6 metric tons. The U.S. is one of the world's leading peanut exporters, with average annual exports of between 200,000 and 250,000 metric tons. Argentina and China are other significant exporters, while origins such as India, Vietnam, and several African countries periodically enter the world market depending upon their crop quality and world market demand.

Canada, Mexico, and Europe account for over 80% of U.S. exports. The largest export markets within Europe are the Netherlands, the U.K., Germany, and Spain.

Demand for peanuts in North America and Europe has been steady, although competition within a dynamic snack market continues to put pressure on peanuts to compete with a growing range of products (potato chips, extruded snacks, tree nuts, and baked snacks). In addition quality specifications, food safety concerns and import requirements continue to require the implementation of improved monitoring and quality control standards at origin. In response to customer demands, U.S. producers, shelters and processors implement oversight and inspection procedures at each stage of production to ensure that the highest quality standards are achieved.

7.5. Cashew and Brazil Nuts. Although cashews are native to northeastern Brazil, they have been introduced to India, Tanzania, Kenya, and Mozambique, which became their principal producers (139). The United States imports over half of the world exports of cashews, mostly from India, because cashews produced in Africa are exported to India for shelling. In fact, almost all of the processing, a complicated procedure requiring much hand labor, is done in India. Most of the cashews are used by the nut-salting trade, but these nuts are becoming increasingly popular in the confectionery trade as well.

The principal producer and exporter of the Brazil nut is Brazil, where the trees grow wild. However, small quantities of the shelled nuts are also imported from Bolivia, Peru, and other South American countries. In-shell Brazil nuts are sold in in-shell nut mixtures, primarily during the Christmas holiday season. Shelled Brazil nuts are used by nut salters and candy manufacturers. Total imports of both cashews and Brazil nuts depends largely on the price these nuts bring in New York markets.

7.6. Macadamia. Macadamia nuts are native to Queensland, Australia, but are also grown commercially in South Africa and Guatemala. In the United States, production of macadamia nuts in Hawaii has increased threefold since 1971. Macadamia nuts are also grown in small plantings in California.

7.7. Pistachios. Pistachios have been commercially produced in the United States since the late 1960s (140). The United States has displaced Turkey as the number two producer; Iran is the number one producer.

8. Uses

8.1. Nuts and Nut Products. Nuts are used mainly as edible products and marketed either with or without the shell, as the demand requires. The most popular nuts in the shell are English walnut, filbert, almond, Brazil nut, peanut, pistachio, and the improved, or paper-shell, pecan; the most popular salted and roasted nut kernels include these as well as the cashew, macadamia, and pignolia. Each year more nuts are shelled in centrally located plants and marketed as meats.

For convenience, meats are rated and sold by sizes and grades. Nut kernels are used extensively in confections and in the baking industry as ingredients in pies, cakes, cookies, and other products. Various nut products include salted and roasted nuts, nut butters such as peanut and almond butter, macaroon paste and powder from almonds, specialty oils, and various confections, notably pralines, peanut brittle, and nut bars (124). Filberts are also widely used in the baking industry (141,142). Hazelnut butters may include added margarine to improve flavor and acceptability (143). Nuts such as pistachio, walnut, pecan, and almond are used extensively in the manufacture of ice cream. Nut flours, manufactured to a limited extent, offer a satisfactory supplement to wheat flour. Peanut flour manufactured from the finer grades of peanut meal is wholesome and nutritious, containing over four times as much protein, eight times as much fat, and nine times as many mineral ingredients as wheat flour. Acorn flour has been used extensively in Europe and is still used to a limited extent in making bread in the southwestern United States. Yeasted peanut butter containing 20% pasteurized brewer's yeast is said to have superior dietetic value because it contains a significant amount of the vitamin B complex group. The kola nut supplies ingredients for popular cola beverages in the United States.

8.2. Peanuts. Its popularity, together with the obvious potential for increased worldwide production, seems to make peanuts a prime candidate for meeting world food needs (144). However, peanuts are one of the three most important oil-bearing seed crops in the world, and the majority of their world production is crushed for the manufacture of peanut oil. Most of the countries with high levels of peanut production have very limited process and storage facilities for the manufacture and handling of other peanut products. The United States is an exception. More than half of the peanuts grown in the United States are used as peanut-food products. Only the surplus and mold-contaminated peanuts are crushed for oil. In 2005, for example, peanut oil amounted to only 15% of the total farmers' stock. Future patterns of distribution, utilization, and export are expected to depend to a large extent on changes in federal support and acreage policies.

Nearly half of the U.S. domestic food consumption of peanuts in 2005 was as peanut butter; salted peanuts, and peanut candy (138). Peanut butter is a popular sandwich spread, particularly for children, and it is both nutritious and economical. Peanut butter is high in plant protein, contains no cholesterol, and has many important vitamins and minerals, including niacin, vitamin E and other antioxidants, and natural folic acid.

The other half of U.S. edible consumption is divided equally between snack nuts and confectionery. Peanuts are consumed as snack nuts in a variety of ways: roasted inshell, roasted kernels, or in mixed nuts. Snack nuts often are salted, spiced, or flavored with a variety of coatings.

New research funded by The Peanut Institute shows that daily consumption of peanuts may have favorable effects on consumer health. This research includes prevention of heart disease and the promotion of weight-loss and maintenance.

Many of the top-selling confectionery products in the U.S. contain peanuts or peanut butter. They are most popular in combination with chocolate Peanuts and peanut butter also are used in a variety of cookies and baked goods. Peanut oil is considered a premium, high quality cooking oil in the U.S., is able to withstand higher cooking temperature than many other oils and does not retain the flavor of foods cooked in it.

Value-Added Products. New value-added products have been developed which have a number of applications including bakery, confectionery, and the general consumer market. Among these are (129).

Peanut Flour. Flour made from raw peanuts which have been cleaned, blanched and electronically sorted to select the highest quality peanuts, the nuts are then roasted and naturally processed to obtain a lower fat peanut flour with a strong roasted peanut flavor.

Peanut flour is used in confectionery products, seasoning blends, bakery mixes, frostings, fillings, cereal bars and nutritional bars. Because the flour is partially defatted, it works well as a fat binder in applications such as confection centers. Using peanut flour at a level of 4–8% in a formulation has been found to extend the shelf life of confections and can contribute a peanut flavor to the product. Peanut flour, because of its high protein content (45%–50%), is a good protein source in addition to its function as a flavoring agent.

Peanut Oil. Peanut oil is extracted from shelled and crushed peanuts by one or a combination of the following methods: hydraulic pressing; expeller pressing; and/or solvent extraction.

Highly aromatic 100% peanut oil and peanut extract also are available. These products have a strong roasted peanut flavor and aroma. Suggested applications for these products include flavoring compounds, confections, sauces and baked goods.

Roasted Peanuts. Roasted peanuts are available in several different packages and roast variations. Different coatings can be applied to the peanuts prior to and after roasting to provide a variety of products including such flavors as honey, smoked, sweet, hot and spicy, and salty.

Peanut Butter. A variety of different peanut butter products is currently available. Peanuts are roasted, blanched and sorted before grinding into a creamy consistency. Peanut butter produced in the U.S. contains a minimum of 90% peanuts; sweeteners and salt can be added to enhance flavor while small amounts of stabilizers are used to prevent oil separation. The small amount of stabilizer used does not contribute trans fatty acids to the product. Peanut pieces can be added to provide a crunchy style. Custom formulations also can be developed to modify the texture or sweetness or to add flavoring.

Reduced fat peanut butters are also available which provide a fat reduction of at least 25%. Several different varieties are sold for both consumer and industrial use with varying peanut content depending on the flavor and consistency of the product needed. Other modified formulations for peanut butter, peanut spreads and peanut paste are available from most manufacturers.

Peanut butter is available in consumer-ready packaging or in institutional/catering containers for use in bakery and confectionery products. Peanut paste which is 100% ground peanuts, is used in a variety of industrial food recipes and is available from processors.

8.3. Partially Defatted Nuts. There is considerable demand for nuts and nut products of reduced fat content. Almond meal and peanut meal are examples of products having low fat content achieved by pressing oil from the nuts and by grinding the cake. Much of the flavor is in the oil; defatted nuts are thus less tasty.

The process for the defatting of whole peanuts can be found in References 109 and 145. Whole kernels are roasted at 305°C for eight minutes, or partly roasted at 215°C, and then extracted with hexane at room temperature for various amounts of time, after which the rate of oil removal is determined. Fully roasted nuts lose 81% of their oil content and have the best appearance after extraction for 120 hours. Solvent removal requires forced draught or vacuum conditions for 9–10 hours of drying. Salting is achieved by dipping into saturated brine or, preferably, by dipping into water followed by sprinkling with salt.

A process has been developed (146) whereby up to 80% of the oil can be removed from whole, raw peanuts without the use of solvent. In this process, the blanched peanuts are brought to a proper moisture content, pressed mechanically, and then reshaped or reconstituted by dipping in hot water; subsequently they can be roasted and salted, or used in confections or other formulations. Defatted peanuts may also be ground into meal and added to cookies, cakes, and many other products, where they impart a distinctly nutty flavor and crunchy texture. On the other hand, the resulting high grade oil is refined and employed in cooking and industrial products. This process can also be used for pecans, walnuts, almonds, Brazil nuts, cashews, and other nuts (147–149).

Defatted peanuts are high in protein, low in moisture, contain only 20% of the naturally occurring fat, and have better stability than whole peanuts. Monosodium glutamate (MSG) has been used as a flavor enhancer for defatted nuts, but the result has not been entirely satisfactory as the addition of MSG produces a meaty rather than nutty flavor. This meaty flavor is more compatible with salted butter and nuts than with candy.

8.4. Oil. A considerable quantity of oil can be extracted from waste material from shelling and processing plants, eg, the inedible kernels rejected during shelling and fragments of kernels recovered from shells. About 300 t of pecan oil and 300–600 t of English walnut oil are produced annually from such sources. The oil is refined and used for edible purposes or for the production of soap; the cake is used in animal feeds. Fruit-pit oils, which closely resemble and are often substituted for almond oil, are produced on a large scale for cosmetic and pharmaceutical purposes (150). For instance, leaves, bark, and pericarp of walnut may be used to manufacture vitamin C, medicines, dyes and tannin materials (151).

Cashew nutshell liquid or oil, obtained by heat treatment, contains about 10% cardol and 90% cardanol. The latter is a vesicant oily liquid from the decarboxylation of anacardic acid and its polymers. Formerly a waste product of the cashew kernel industry in southern India, cashew nutshell oil has become a valuable raw material in the manufacture of many industrial products.

8.5. Meal. The meal or press cake from oil extraction of pecan, walnut, almond, and other nuts is usually bitter because it contains skins and pieces of shell; when refined, however, it can be used in the baking industry and, more commonly, in animal feed. Almond, peanut, babassu, and other nut cakes and meals are extensively used in such feeds; in addition, ivory nut meal, a by-product of the button industry, also provides a valuable animal feed since most of its cell wall carbohydrate (92.5% mannose) can be converted into hexose sugar or its equivalent. Indeed, sheep and cows can digest and utilize as much as 84% of the dry matter and 92% of the nitrogen-free extract. Various methods have been developed for preparing mannose from the ground-meal waste from button manufacture. Attempts have also been made to utilize the horse chestnut, which contains a high percentage of starch. The conversion of starch by enzymes and fermentation, however, is made difficult by the presence of saponins which make up 10–14% of the raw meal.

8.6. Shells and Hulls. Nutshell waste from shelling and processing plants is used extensively for a variety of non-food purposes.

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Table 1. **Botanical Classification, Occurrence, and Uses of Nuts Worldwide**

Common name	Botanical name	Principal geographic occurrence	Uses
	Edible tree nuts		
acorn			
oak	*Quercus spp*	Europe, North America	feed for animals
edible	*Pasania cornea*	China	food
almond			
sweet	*Prunus amygdalus*	southern Europe, North America	food and oil
bitter	*Prunus amygdalus*	southern Europe	food and oil
beechnut			
American	*Fagus grandifolia*	North America	food and oil
European	*Fagus sylvatica*	Europe	food and oil
Brazil (pará)	*Bertholletia excelsa*	South America	food and oil
bread	*Brosimum alicastrum*	West Indies	food
buriti	*Mauritia flexuosa*	tropical America	food and oil
butternut	*Juglans cinerea*	North America	food
cashew	*Anacardium occidentale*	India, Africa	food and oil
chestnut			
American	*Castanea dentata*	North America	food
European	*Castanea sativa*	Europe	food
Chinese	*Castanea mollissima*	China, North America	food
Japanese	*Castanea crenata*	Japan	food
chinquapin	*Castanea pumila*	North America	food
coconut	*Cocos nucifera*	tropics	food and oil
filbert, hazel, cob	*Corylus avellana*	Europe, North America	food
hazel	*Corylus americana*	North America	food
hickory	*Carya* spp.	North America	food and oil
jojoba	*Simmondsia californica*	southwest U.S.	food
Java almond (Kanari)	*Canarium commune*	Sunda Isles	food and oil
lunau	*Otophora fruticosa*	Philippines	food
Luzon nut	*Canarium buconicum*	Pacific islands	food
macadamia	*Macadamia ternifolia*	Australia, Hawaii	food
palm	*Elaeis guineensis*	tropical Africa	oil
paradise	*Lecythis ollaria*	South America	food and oil
pecan	*Carya illinoensis*	North America	food and oil
pignolia	*Pinus spp*	southern Europe	food
pine, araucarian	*Araucaria angustifolia*	Chile	food
piñon (pine)	*Pinus edulis and other spp*	southwest U.S.	food and oil
pistachio	*Pistacia vera*	southern Europe, U.S.	food
torreya (kaya)	*Torreya nucifera*	China, Japan	food
tropical almond	*Terminalia catappa*	southern Asia	food and tannin
walnut			
eastern, black	*Juglans nigra*	eastern North America	food and oil
northern, California, black	*Juglans hindsii*	northern California	food and oil
Japanese	*Juglans sieboldiana*	Asia	food

(*continued*)

Table 1. *Continued*

Common name	Botanical name	Principal geographic occurrence	Uses
Persian (English)	*Juglans regia*	southern Europe, North America	food and oil
		Edible ground and aquatic nuts	
ar or earth	*Bunium flexuosum*	western Europe	food
bambarra groundnut	*Voandzeia subterranea*	tropics, Africa	food
chufa (ground almond)	*Cyperus esculentus*	southern Europe, North America	feed for animals
fox	*Euryale ferox*	eastern India	food and medicine
ground	*Apios americana*	North America	food
ground	*Panax trifolium*	North America	food
hawk	*Bumium bulbocastanum*	western Europe	food
horned chestnut			
China	*Trapa bicornis*	Asia	food
Europe	*Trapa natans*	southern Europe	food
peanut	*Arachis hypogaea*	tropics, Asia, U.S.	food and oil
singhara	*Trapa bispinosa*	Asia, Africa	food
water chestnut	*Eleocharis dulcis*	China	food and starch
water chinquapin	*Nelumbo lutea*	North America	food
		Nonedible tree nuts	
ben	*Moringa oleifera*	tropical Asia	oil for perfume
bladder	*Staphylea trifolia*	U.S.	ornamental
bomah	*Pycnocoma macrophylla*	Africa	tanning
bonduc	*Guilandina bonduc*	India	medicine and beads
clearing	*Strychnos potatorum*	India	clearing water
coquilla	*Attalea funifera*	South America	turnery and buttons
cumara	*Dipteryx odorata*	South America	perfume
horse chestnut	*Aesculus hippocastanum*	Europe, U.S.	starch
ivory (tagua)	*Phytelephas seemanni*	Central America	turnery and buttons
manketti	*Ricinodendron rautanenii*	southwest Africa	oil for soap and paint
marking	*Semecarpus anacardium*	Asia, India	ink and varnish
murumuru	*Astocaryum murumuru*	Brazil	oil
oiticica	*Licania rigida*	Brazil	paint
physic	*Jatropha curcas*	tropical America	medicine
poison	*Strychnos nux-vomica*	India, Australia	medicine
portia	*Thespesia populnea*	tropics	oil and illuminant
snake	*Ophiocaryon paradoxum*	Guyana	curiosity
soap	*Sapindus saponaria*	tropics	soap
soft lumbang	*Aleurites triloba*	South Sea islands	paint and varnish
tallow	*Sapium sebiferum*	China	substitute for tallow

(*continued*)

Table 1. *Continued*

Common name	Botanical name	Principal geographic occurrence	Uses
tucum	*Astrocaryum rulgare*	Brazil	oil
tung (China wood)	*Aleurites fordii*	China or southern U.S.	paint and varnish
	Nuts with secondary or supplemental food uses		
babassu	*Orbignya martiana*	Brazil	oil for soap, marg-arine shortening
betel	*Areca cathecu*	South Sea islands	chewing
candlenut (kukui)	*Aleurites moluccana*	Hawaii and the Philippines	food and drying oil
hyphaene	*Hyphaene crinita*	Malagasy Republic	spice
kola	*Kola acuminata*	western Africa	stimulant in beverage
nutmeg	*Myrustica fragrans*	East Indies	spice
oyster	*Telfairia pedata*	eastern Africa	food
ravensara	*Agathophyllum aromaticum*	Malagasy Republic	spice
sunflower	*Helianthus annuus*	Europe, U.S.	food
watermelon	*Citrullus vulgatis*	Africa, Asia, U.S.	food

Table 2. **Composition of Nuts**[a]

Name	Refuse, wt %	Water, wt %	Protein, g	Fat, g	Total carbohydrate, g	Fiber, g	Ash, g	Calcium, mg	Phosphorus, mg
acorns, raw		27.9		23.9	40.8	2.6	1.4	41.0	79
almond	49								
dried, blanched		5.4	20.4	52.5	18.5	2.3	3.1	2.5	532
dry roasted, unblanched		3.0	16.3	51.6	24.2	4.9	4.9	282.0	548
meal, partially defatted		7.2	39.5	18.3	28.9	2.3	6.1	424.0	914
beechnut, dried	39	6.6	6.2	50.0	33.5	3.7	3.7	1.0	
Brazil nut, dried unbleached	50	3.3	14.3	66.2	12.8	2.3	3.3	176.0	600
butternuts, dried		3.3	2.5	57.0	12.1	1.9	2.7	53.0	446
cashew nut, dry roasted		1.7	15.3	46.4	32.7	0.7	4.0	45.0	490
chestnut, European	19								
fresh, raw, peeled		52.0	1.6	1.3	44.2	1.0	1.0	19.0	38
dried, peeled		9.0	5.0	3.9	78.4	5.0	3.6	64.0	137
coconut									
cream, expressed liquid		53.9	3.6	34.7	6.6		1.1	11.0	122
meat, fresh		47.0	3.3	33.5	15.2	4.3	1.0	14.0	113
meat, dried and unsweetened		3.0	6.9	64.5	23.7	5.3	1.9	26.0	206
meat, dried, sweetened, and shredded		12.6	2.9	35.5	47.7	2.2	1.4	15.0	107
milk, expressed		67.6	229.0	23.8	5.5		0.7	16.0	100
hazelnut (filberts) dried, unblanched	53	5.4	13.0	62.6	15.3	3.8	3.6	188.0	312
hickory nut	80	2.7	12.7	64.4	18.3	3.2	2.0	61.0	336
macadamia nut, dried	69	1.7	7.3	76.5	12.9	1.7	1.7	45.0	200
peanut									
kernels, dried		6.7	25.7	49.2	16.2	4.9	2.3	58.0	383
butter, added salt		13.0	28.5	51.1	15.8	3.3	3.3	33.0	374
flour, defatted		7.8	52.2	0.6	34.7	4.1	4.8	140.0	1290
salted, oil-cooked		2.0	26.8	49.2	18.5	2.4	3.6	18.5	506
pecans, dried	56	4.8	7.8	67.6	18.2	1.6	1.6	36.0	291
pilinut		0.8	10.8	79.6	4.0	2.8	2.9	145.0	575
pinenut									
pignolia		6.7	24.0	50.7	14.2	0.8	4.4	26.0	508
piñon		5.9	11.6	61.0	19.3	4.7	2.3	8.0	35
pistachio nut, dried	70	3.9	20.6	43.4	24.8	1.9	2.4	135.0	503
walnuts, black	78	4.4	24.4	56.6	12.1	6.5	2.6	58.0	464
walnuts, English or Persian	55	3.7	14.3	61.9	18.3	4.6	1.9	94.0	317

[a] 100 g portions are used for the calculations; Ref. 3.
[b] To convert J to cal, divide by 4.184.

Table 3. **Products from Hydrolysis of Nut Proteins**[a,b]

Hydrolysis product	Amandin (almond)	Excelsin (Brazil nut)	Edestin (coconut)	Globulin (spruce)	Arachin (peanut)	Conarachin (peanut)
alanine	1.40	2.33	4.11	1.80	4.11	
ammonia	3.70	1.80	1.57		2.03	1.90
arginine	11.85	16.02	15.92	10.90	13.51	14.60
aspartic acid	5.42	3.85	5.12	1.80	5.25	
cystine	0.85	1.84	1.54		1.08	3.00
glutamic acid	23.14	12.94	19.07	7.80	16.69	
glycine	0.51	0.60		0.60		
histidine	1.58	1.47	2.42	0.62	1.88	1.83
leucine	4.45	8.70	5.96	6.20	3.88	
lysine	0.70	1.64	5.80	0.25	4.98	6.04
methionine					0.67	2.12
phenylalanine	2.53	3.55	2.05	1.20	2.60	
proline	2.44	3.65	5.54	2.80	1.37	
serine		0.00	1.76	0.10	5.20	4.99
tryptophan	1.37	2.59	1.25	present	0.88	2.13
tyrosine	1.12	3.03	3.18	1.70	5.50	
valine	0.16	1.51	4.21	present	1.13	
Total	*61.22*	*65.50*	*79.50*	*27.77*	*70.76*	*36.61*

[a]Refs. 4–6.
[b]Values are % of total.

Table 4. **Essential Amino Acid Content of Nuts**[a,b]

Amino acid	Almond	Brazil nut	Butternut	Cashew	Chestnut, European	Coconut	Filbert	Peanut	Pecan	Pilinut	Pinenut, pignola	Pinenut, piñon	Pistachio	Walnut, black
arginine	2.495	2.390	4.862	1.741	0.173	0.546	2.155	3.456	1.105	1.516	4.668	2.251	2.186	3.661
histidine	0.558	0.402	0.808	0.399	0.067	0.077	0.327	0.748	0.227	0.255	0.575	0.277	0.536	0.680
isoleucine	0.866	0.601	1.179	0.731	0.095	0.131	0.568	0.997	0.322	0.483	0.933	0.450	0.975	0.978
leucine	1.552	1.187	2.199	1.285	0.143	0.247	1.100	1.928	0.520	0.890	1.730	0.834	1.677	1.704
lysine	0.666	0.541	0.770	0.817	0.143	0.147	0.399	0.992	0.292	0.369	0.901	0.434	1.278	0.721
methionine	0.227	1.014	0.611	0.274	0.057	0.062	0.162	0.263	0.186	0.395	0.430	0.207	0.381	0.473
phenylalanine	1.113	0.746	1.442	0.791	0.102	0.169	0.686	1.467	0.409	0.497	0.919	0.443	1.184	1.107
threonine	0.739	0.460	0.940	0.592	0.086	0.121	0.448	0.743	0.253	0.407	0.761	0.367	0.722	0.730
trytophan	0.358	0.260	0.366	0.237	0.027	0.039	0.216	0.310	0.199		0.303	0.146	0.283	0.322
valine	1.028	0.911	1.541	1.040	0.135	0.202	0.662	1.161	0.386	0.701	1.241	0.598	1.410	1.286

[a]Refs. 3 and 12.
[b]Values given are in g/100 g of edible food.

Table 5. **Oil and Fatty Acid Content of Commercial Nuts**[a,b]

Nut	Oil, %[c]	16:0	16:1	18:0	18:1	18:2	20:0	20:1	22:0	24:0
almond	46.6	6.50		1.17	63.82	28.42	0.04	0.05	0	0
Brazil nut	62.9	12.84		8.72	27.94	50.21	0.21	0.06	0.02	0
cashew	47.1	10.07		9.26	60.67	19.05	0.55	0.18	0.10	0.12
filbert	58.6	4.57		1.85	79.17	14.18	0.07	0.15	0	0
macadamia	65.8	8.43	17.90	3.02	61.21	2.50	2.62	2.81	0.8	0.32
pecan	70.2	6.41		2.44	55.87	34.93	0.09	0.25	0.01	0
pistachio	43.4	11.82		1.05	51.68	35.00	0.08	0.33	0.06	0
sunflower	43.6	5.38		3.83	15.59	74.00	0.21	0.12	0.70	0.20

[a]Values for fatty acids are % of total fatty acid content.
[b]Fatty acids are represented as *x:y*, where *x* is the carbon chain length and *y* is the number of double bonds.
[c]On a basis of total dry weight.

Table 6. **Fatty Acid Analysis by Gas–Liquid Chromatography of Pecan Oils and Peanut Oils**[a,b]

Type of oil	Palmitic acid	Stearic acid	Oleic acid	Linoleic acid	Linolenic acid	Arachidic acid	Iodine value (IV)	
							glc	Wijs
				Pecan oil				
Big Z	5.9	2.9	59.7	30.3	1.6	1.6	108.0	110.0
Curtis	6.1	3.1	71.8	18.1	0.8	0.8	95.9	98.3
Frotcher	6.5	2.5	63.9	25.5	1.3	1.3	102.5	105.9
Mobile	7.1	2.7	56.8	31.4	1.8	1.8	107.9	111.2
Moneymaker	6.3	2.6	51.0	37.8	1.7	1.7	114.0	118.0
Randall	6.0	2.9	61.3	28.2	1.5	1.5	105.2	107.2
Stuart	6.6	2.2	68.8	21.0	1.1	1.1	98.8	101.3
Success	4.5	2.9	76.5	13.5	1.3	1.3	92.6	94.5
Tesche	6.1	3.0	63.4	25.7	1.3	1.3	102.4	105.3
Van Deman	5.1	2.9	74.6	16.0	0.9	0.9	94.2	96.2
Average	*6.0*	*2.8*	*64.8*	*24.8*	*1.3*	*1.3*	*102.2*	*104.8*
				Peanut oil				
Dixie Runner	9.3	3.1	58.3	22.4	1.1	0.7	92.0	91.1
Early Runner	9.7	3.1	55.6	24.7	1.1	1.0	93.5	92.9
Florida 393-47	7.3	4.3	63.5	17.7	1.4	1.1	88.9	87.4
Florigiant	10.3	4.1	55.7	22.9	1.6	0.7	91.8	90.3
Georgia Bunch 119-20	11.1	4.1	54.4	23.2	1.4	1.1	90.7	90.7
North Carolina 2	10.5	4.3	51.9	26.2	1.3	0.6	93.4	92.3
Spanette	109.0	3.7	52.5	25.7	1.3	0.7	93.4	92.0
Spanish 18-38-47	12.9	4.5	43.1	32.5	1.5	0.7	97.5	101.8
Virginia 56R	9.6	4.4	54.5	23.8	1.4	0.9	92.3	90.8
Virginia Bunch G2	10.1	3.7	55.7	23.7	1.3	0.7	92.4	91.3
Virginia Runner G-26	10.3	4.7	52.3	25.1	1.5	0.9	92.9	92.0
Average	*19.1*	*4.0*	*54.3*	*24.4*	*1.4*	*0.8*	*92.6*	*92.1*

[a]Ref. 20.
[b]Values are % of total fatty acid.

Table 7. **Carbohydrate, Nitrogen, and Oil Levels in Macadamia Embryos as a Function of Age**[a,b]

	Days after flowering				
Component	90	111	136	185	215
total sugar	7.54	27.28	22.98	9.60	5.80
reducing sugar	1.47	3.21	1.07	0.41	0.30
sucrose	6.07	24.07	21.91	9.19	5.50
total nitrogen	4.88	3.04	2.19	1.72	1.70
soluble nitrogen	2.92	1.13	0.61	0.33	0.27
insoluble nitrogen	1.96	1.91	1.58	1.39	1.43
acid-hydrolyzable matter	4.54	4.88	3.85	2.56	2.16
soluble solids in 80% alcohol	60.10	39.92	28.36	14.82	9.88
ether- and alcohol-insoluble matter	36.43	28.88	23.69	17.89	16.68
petroleum-ether extract	3.46	31.19	47.94	67.28	73.44

[a]Ref. 64.
[b]Values are percentages of total dry weight.

Table 8. **Seasonal Change in Composition of Black Walnut Kernels**[a,b]

Component	June 15	July 15	July 29	August 12	August 26
total solids	3.510	4.128	20.487	38.325	68.110
ether extract	0.123	0.556	8.043	19.592	42.176
total nitrogen	0.182	0.290	0.818	0.892	1.044
amino nitrogen	0.111	0.145	0.290	0.312	0.466
protein nitrogen	0.071	0.145	0.528	0.580	0.578
pentosans		present	0.775	0.758	0.940
ash		0.502	1.336	1.321	1.570
potassium	0.312	0.253	0.485	0.675	
calcium	0.266	0.048	0.072	0.071	0.044
phosphorus	0.127	0.086	0.055	0.091	0.051
magnesium		0.011	0.079	0.098	
acidity	acid	acid	neutral	neutral	neutral

[a]Ref. 68.
[b]Values are % of total dry weight.

Table 9. **Tree Nut Production in Leading Countries and the World, short tons × 10^3 2001 to 2005**[a,b]

Country	2001	2002	2003	2004	2005
			Almonds		
United States	672	882	867	843	735
Spain	281	308	236	248	225
Syria	55	153	143	143	143
Italy	124	116	101	116	116
Iran	107	118	88	88	88
Morocco	90	91	78	77	77
others	382	374	382	387	403
World	*1,710*	*2,041*	*1,895*	*1,902*	*1,788*
			Cashew nuts		
Viet Nam	323	568	725	910	912
India	496	507	518	507	507
Brazil	137	181	202	201	277
Nigeria	204	205	230	235	235
Indonesia	101	128	130	132	134
Tanzania	134	110	110	110	110
others	392	378	394	401	401
World	*1,787*	*2,077*	*2,310*	*2,497*	*2,576*
			Hazelnuts (filberts)		
Turkey	689	661	529	386	551
Italy	132	132	92	158	142
United States	50	19	38	38	28
Spain	29	29	14	28	25
Azerbajan	18	18	22	6	22
others	56	61	62	60	56
World	*973*	*920*	*757*	*675*	*824*
			Pistachios		
Iran	274	243	204	209	209
United States	81	152	60	174	154
Syria	41	58	55	44	66
Turkey	33	39	99	33	66
China	29	31	33	35	37
others	19	17	18	19	19
World	*477*	*539*	*469*	*514*	*553*
			Walnuts		
China	278	378	434	457	463
United States	305	282	326	325	340
Iran	185	196	165	165	165
Turkey	128	132	143	139	147
Ukraine	61	63	87	100	77
other	437	438	467	441	452
World	*1,394*	*1,490*	*1,623*	*1,627*	*1,644*

[a]Refs. 133.
[b]Included both fresh and processed production.
Source: Food and Agriculture Organization, United Nations.

Table 10. **U.S. Supply and Disappearance of Important Nuts**[a,b]

Year	U.S. population, January 1 of following year	Supply				Disappearance			
								Food disappearance	
		Marketable production	Imports	Beginning stocks	Total supply	Exports	Ending stocks	Total	Per capita
				Almonds					
2001	286.856	800,700	882	107,266	908,848	585,723	80,922	242,203	0.84
2002	289.708	1,063,500	1,993	80,922	1,146,415	673,616	162,045	310,754	1.07
2003	292.538	1,011,100	3,248	162,045	1,176,393	698,896	148,940	328,557	1.12
2004	295.547	958,117	6,750	148,940	1,113,806	712,680	137,684	263,443	0.89
2005	298.048	875,275	10,677	137,684	1,023,636	728,204	138,664	156,768	0.53
				Walnuts					
2001	286.856	256,711	203	46,218	303,132	103,420	80,004	119,708	0.42
2002	289.708	243,098	195	80,004	323,296	113,966	73,419	135,911	0.47
2003	292.538	278,571	372	73,419	352,363	124,904	82,145	145,313	0.50
2004	295.347	281,491	638	82,145	364,275	136,795	70,110	157,369	0.53
2005	298.048	315,099	1,133	70,110	386,342	205,886	54,349	126,106	0.42
				Pecans					
2001	286.856	145,580	32,038	86,084	263,701	22,292	104,772	136,637	0.48
2002	289.708	78,444	40.318	104,772	223,534	31,541	68,385	123,608	0.43
2003	292.538	116,968	60,255	68,385	245,608	31,365	92,400	121,843	0.42
2004	295.347	82,552	77,143	92,400	252,095	34,322	70,245	147,529	0.50
2005	298.048	112,600	71,507	70,245	264,352	33,476	77,223	153,653	0.52
				Hazelnuts (Filberts)					
2001	286.856	38,088	15,195	1,398	54,681	22,529	2,543	29,609	0.10
2002	289.708	15,262	16,387	2,543	34,192	9,929	2,447	21,815	0.08
2003	292.538	29,490	10,902	2,447	42,838	25,589	2,046	15,203	0.05
2004	295.347	27,189	12,768	2,046	42,004	21,687	1,945	18,372	0.06
2005	298.048	20,023	12,215	1,945	34,482	25,919	1,073	7,490	0.03

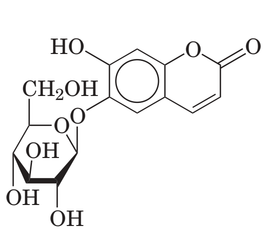
				Macadamia Nuts					
2001	286.856	12,718	11,608		24,325	3,011		21,314	0.07
2002	289.708	12,042	9,744		21,787	3,410		18,377	0.06
2003	292.538	12,039	14,612		26,651	2,516		24,135	0.08
2004	295.347	12,834	20,243		33,078	1,147		31,931	0.11
2005	298.048	13,631	15,614		29,245	1,708		27,537	0.09
				Pistachio Nuts					
2001	286.856	80,733	532	33,329	114,594	44,744	12,425	57,426	0.20
2002	289.708	149,513	764	12,425	162,702	44,449	56,180	62,073	0.21
2003	292.538	56,217	1,459	56,180	113,857	35,551	22,941	55,365	0.19
2004	295.347	170,515	798	22,941	194,254	74,550	42,317	77,387	0.26
2005	298.048	139,003	912	42,317	182,233	69,319	56,066	56,847	0.19
				Other[c]					
2001	286.856		274,842		274,842	64252		210,590	0.73
2002	289.708		291,803		291,803	51,929		239,874	0.83
2003	292.538		337,535		337,535	41,458		296,077	1.01
2004	295.347		381,678		381,687	61,596		320,081	1.08
2005	298.048		316,888		316,888	51,879		265,009	0.89

[a]Refs. 134.
[b]All weights in 10^3 lb. Per capita data are in pounds. Population $\times 10^6$
[c]Includes Brazil nuts, pignolia nuts, chestnuts, and mixed nuts.

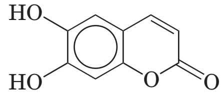
Table 11. **U.S. Supply and Disappearance of Peanuts**[a,b]

Year	U.S. population, January 1 of following year	Supply				Disappearance					Food disappearance	
											Kernel basis	
		Production	Imports	Beginning stocks	Total supply	Exports	Seed, loss, shrinkage, and residual	Crush	Ending stocks	Farmers stock basis	Total	Per capita
2001	286.856	4,277	203	1,097	5,577	700	483	693	1,476	2,225	1,673	5.8
2002	289.708	3,321	75	1,476	4,872	490	409	857	875	2,241	1,685	5.8
2003	292.538	4,144	38	875	5,057	516	428	536	1,121	2,456	1,847	6.3
2004	295.347	4,288	37	1121	5,446	491	547	393	1,415	2,600	1,955	6.6
2005	298.048	4,870	32	1415	6,317	491	498	542	2,167	2,618	1,968	6.6

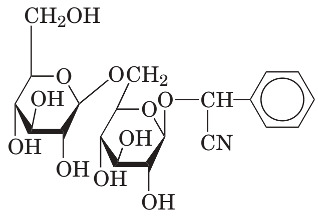
[a]Refs. 134.
[b]Weights in 10^6 lb. Population $\times 10^6$



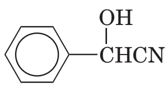
(**1**)



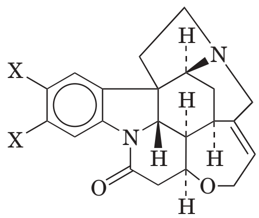
(**2**)



(**3**)

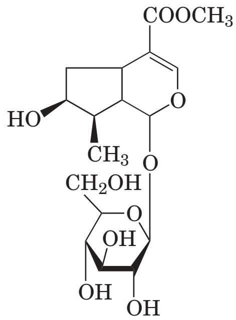


(**4**)



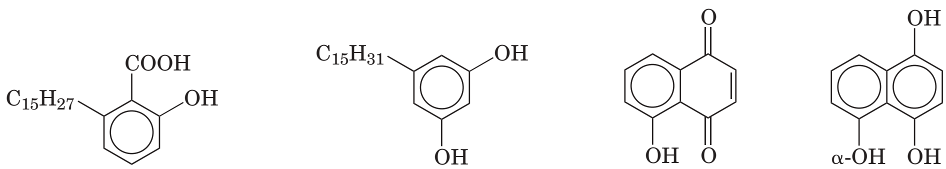
(**5**) X = H

(**6**) X = OCH_3



(**7**)

Fig. 1. Glycosides (**1**, **3**, and **7**), their hydrolysis products (**2** and **4**), and alkaloids (**5** and **6**) derived from nuts and seeds. See text.



(**8**) (**9**) (**10**) (**11**)

Fig. 2. Toxic compounds found in cashew nuts (**8** and **9**) and in walnuts and walnut trees (**10** and **11**). See text.

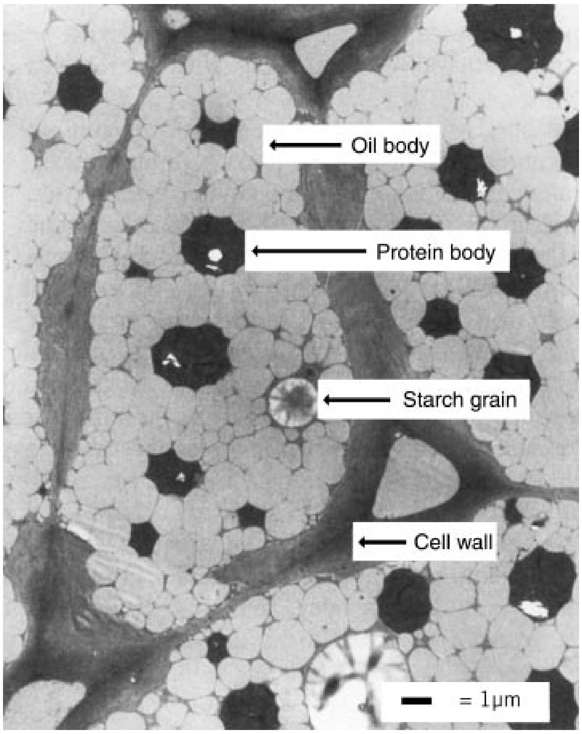


Fig. 3. Peanut seed parenchymal cell.

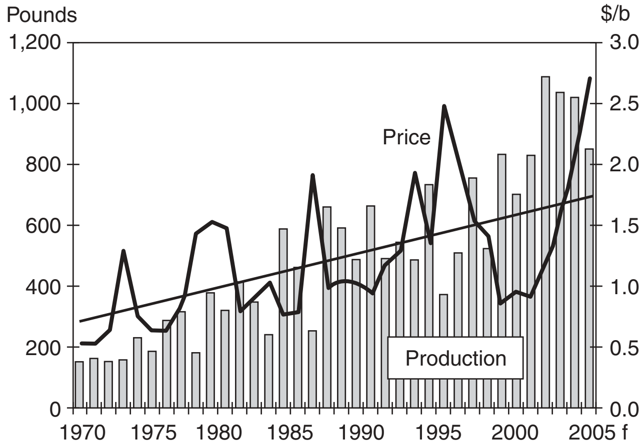


Fig. 4. U.S. almond production and grower price, 1970–2005, F = forecast (136). Source: National Agricultural Statistics Service, USDA.