2 Structure and Composition

Structure

The fruits available commercially comprise various combinations of tissues that may include an expanded ovary, the seed and other plant parts such as the receptacle (apple, strawberry, cashew apple), bract and peduncle (pineapple). A dictionary definition of fruit is 'the edible product of a plant or tree, consisting of the seed and its envelope, especially the latter when juicy and pulpy'. However, a consumer definition of fruit would be 'plant products with aromatic flavours, which are either naturally sweet or normally sweetened before eating': they are essentially dessert foods. This consumer perception has resulted in various immature fruit such as zucchini, cucumber and beans, and even ripe fruit such as tomato, peppers (capsicum) and eggplant (aubergine) being considered as vegetables. These products, which have been referred to as fruit vegetables, may be consumed cooked or raw and are eaten either alone, in the form of a salad, or accompanying meat or fish dishes. However, as illustrated in Figure 2.1, common fruits are derived basically from an ovary and surrounding or associated tissues. Most of the exaggerated developments of certain parts of the fruit structure arose naturally but have been accentuated by breeding and selection to maximise the desirable features of each fruit and minimise the superfluous features. Naturally seedless cultivars of some fruits (e.g. banana, grape, navel orange) and others induced by breeding (e.g. watermelon) or management (e.g. persimmon) illustrate extreme development.

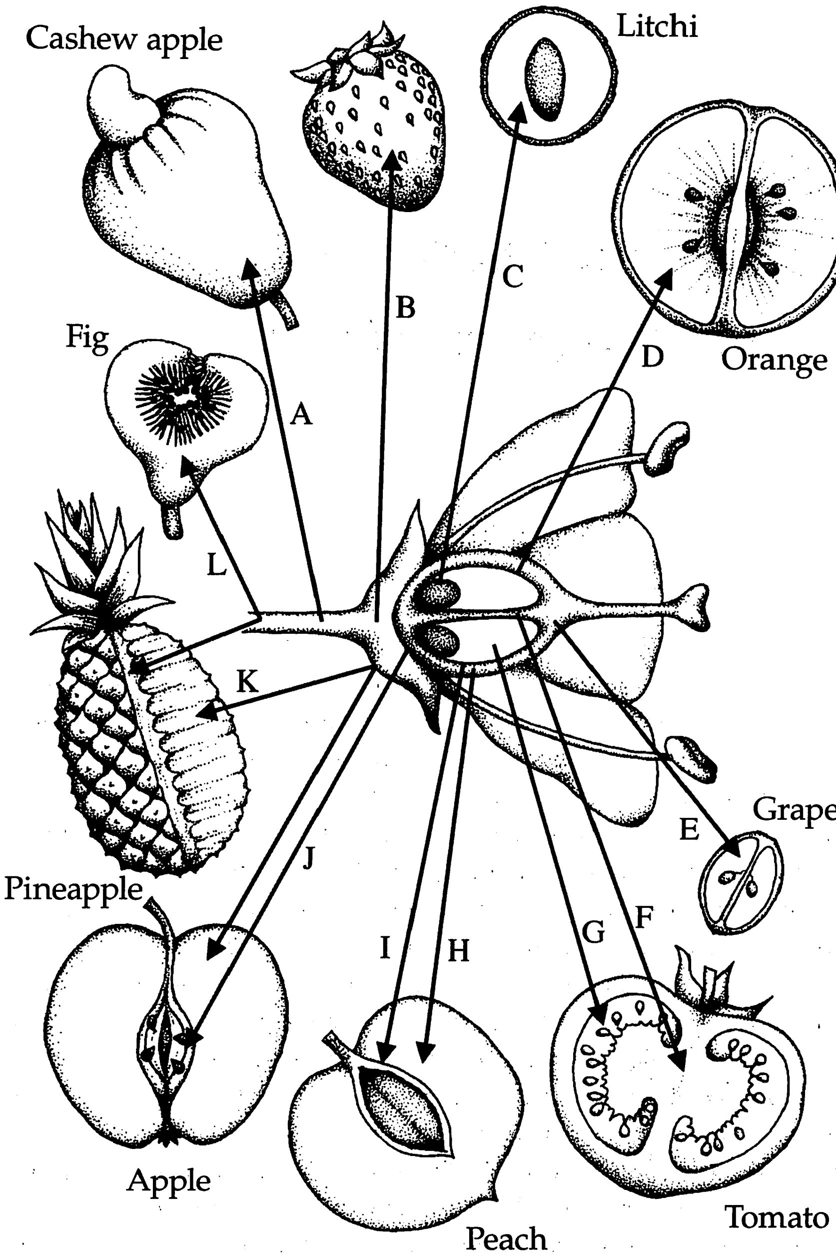


Figure 2.1 Derivation of some fruits from plant tissue. The letters indicate the tissues that comprise a significant portion of the fruit illustrated: (A) pedicel, (B) receptacle, (C) aril, (D) endodermal intralocular tissue, (E) pericarp, (F) septum, (G) placental intralocular tissue, (H) mesocarp, (I) endocarp, (J) carpels, (K) accessory tissue, (L) peduncle.

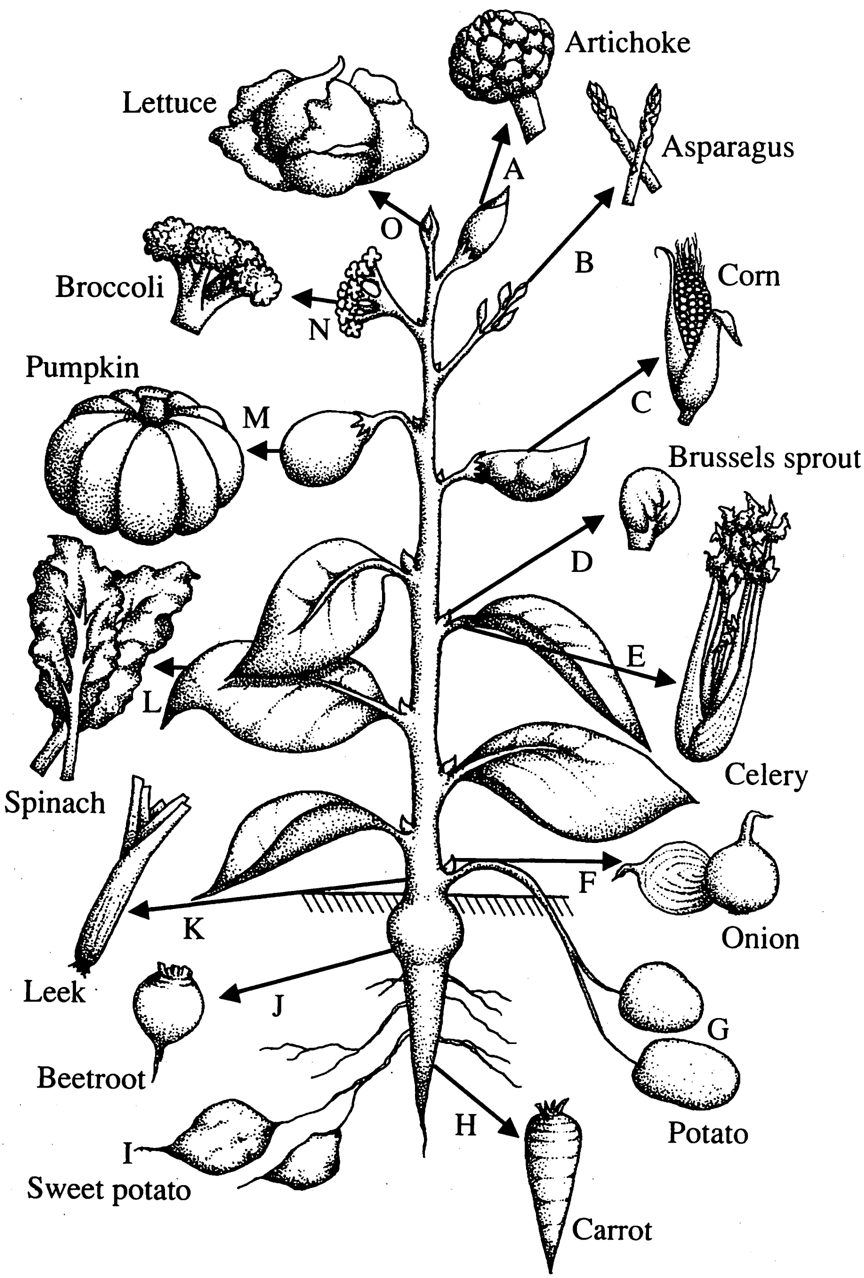


Figure 2.2 Derivation of some vegetables from plant tissue. The letters indicate the principal origins of representative vegetables as follows: (A) flower bud, (B) stem sprout, (C) seeds, (D) axillary bud, (E) petiole, (F) bulb (underground bud), (G) stem tuber, (H) swollen root, (I) swollen root tuber, (J) swollen hypocotyls, (K) swollen leaf base, (L) leaf blade, (M) fruit, (N) swollen inflorescence, (O) main bud.

The vegetables do not represent any specific botanical grouping, and exhibit a wide variety of plant structures. They can, however, be grouped into three main categories: seeds and pods; bulbs, roots and tubers; flowers, buds, stems and leaves. In many instances, the structure giving rise to the particular vegetable has been highly modified compared with that structure on the 'ideal' plant. The derivation of some vegetables is shown in Figure 2.2. The plant part that gives rise to the vegetable will be readily apparent when most vegetables are visually examined. Some are a little more difficult to categorise, especially the tuberous organs developed underground. The potato, for instance, is a modified stem structure, while other underground storage organs, such as the sweet potato, are simply swollen roots.

The structural origins of fruit and vegetables have a major bearing on the recommendations for their postharvest preservation. Generally, above-ground structures develop natural wax coatings as they mature, which reduce transpiration, whereas roots do not develop such coatings and therefore should be stored at high relative humidity (RH) to minimise water loss. Tuberous vegetables are equipped with a special capability to heal wounds caused by natural insect attack. This property is useful for minimising damage inflicted on tubers during harvesting.

Species of flowering plants used commercially as cut flowers have been selected for their visual appeal. At both the practical and botanical levels, cut flowers are variations of inflorescences. Although there is a wide range of variation in flower structure, the basic structure of an inflorescence is stem, including pedicels and peduncles, bract and flower. Figure 2.3 illustrates the range of variation in flower types. The range includes solitary to multiple inflorescences, where all inflorescences develop at about the same rate or where there is a gradation from mature to juvenile flowers as the inflorescence develops. It is important to recognise the variations in the structure of inflorescences, because they have a major bearing on postharvest handling strategies. Generally, inflorescences have a low carbohydrate reserve compared to most fruits, although it can be similar to that of many leafy vegetables. In many flower types, improved vase or storage life can be achieved by providing the cut flower with sugar through an absorbed solution. Because of their enormous surface area compared to their mass, cut flowers transpire at much higher rates than most fruit.

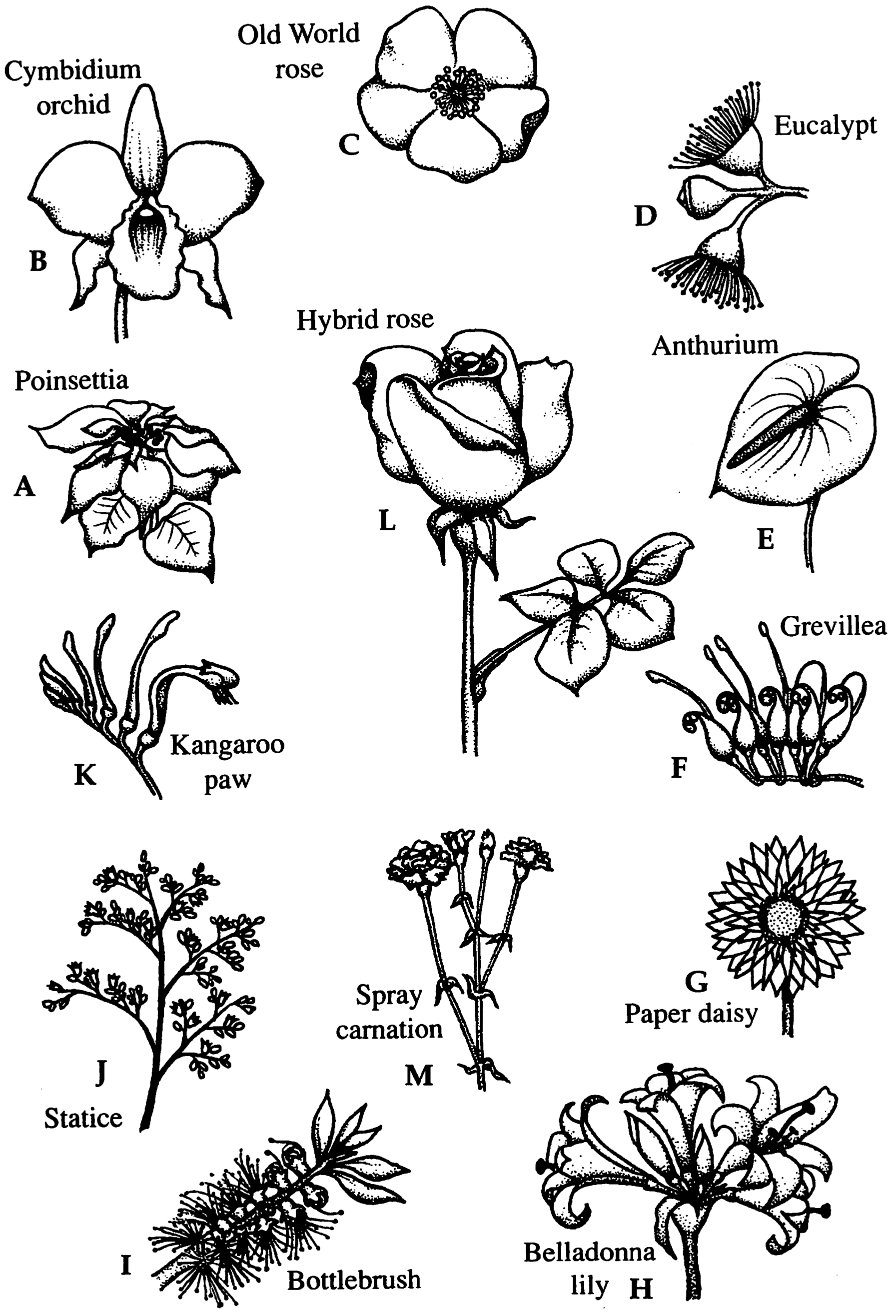
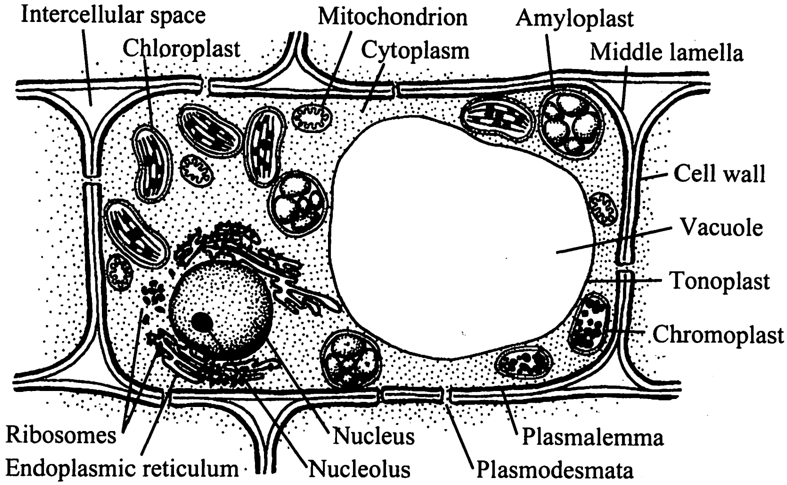


Figure 2.3 Examples of variations in the structure of flowers. (A) bract, (B) modifications and fusions, in which the labellum is a median modified petal and the column is comprised of fused stamens and pistils, (C) complete, single whorl of petals, (D) prominent feature (stamens), (E) spadix plus spathe, (F) raceme, (G) head, (H) umbel, (I) spike, (J) panicle, (K) syme, (L) solitary, (M) corymb.

Figure 2.4 Diagrammatic representation of a plant cell and its constituent organelles



Cellular components

The cells of fruit and vegetables are typical plant cells, the principal components of which are shown in Figure 2.4. A brief outline of the essential features or functions of these components will be given; more detailed explanations can be found in specialised texts.

Plant cells are bounded by a mostly rigid cell wall composed of cellulose fibres, and other polymers such as pectic substances, hemicelluloses, lignins and proteins. A layer of pectic substances forms the middle lamella and acts to bind adjacent cells together. Adjacent cells often have small communication channels, called plasmodesmata, linking their cytoplasmic masses. The cell wall is permeable to water and solutes. Important functions of the wall are to support the cell membrane, the plasmalemma, against the hydrostatic pressures of the cell contents, which would otherwise burst the membrane; and to give structural support to the cell and the plant tissues.

Within the plasmalemma, the cell contents comprise the cytoplasm and usually one or more vacuoles. The latter are fluid reservoirs containing various solutes, such as sugars, amino and organic acids, and salts, and are surrounded by a semipermeable membrane, the tonoplast. Together with the semi-permeable plasmalemma, the tonoplast is responsible for maintaining the hydrostatic pressure of the cell, allowing the passage of water, but selectively restricting the movement of solutes or macromolecules, such as proteins and nucleic acids. The resulting turgidity of the cell is responsible for the crispness in fruit and vegetables.

The cytoplasm comprises a fluid matrix of proteins and other macromolecules and various solutes. Important processes that occur in this fluid part of the cytoplasm include the breakdown of storage reserves of carbohydrate by glycolysis (see Chapter 3) and protein synthesis. The cytoplasm also contains several important organelles, which are membrane-bound bodies with specialised functions as follows:

1. The nucleus, the largest organelle, is the control centre of the cell and contains the genetic information in the form of DNA (deoxyribonucleic acid). It is bounded by a porous membrane that has distinct holes, which can be observed through an electron microscope. These holes permit the movement of mRNA (messenger ribonucleic acid), the transcription product of the genetic code of DNA, into the cytoplasm where mRNA is translated into proteins on the ribosomes of the protein synthesising system (see below).
2. Mitochondria contain the respiratory enzymes of the tricarboxylic acid (TCA) cycle (see Chapter 3) and the respiratory electron transport system, which synthesise adenosine triphosphate (ATP). Mitochondria utilise the products of glycolysis for energy production. Thus they form the energy powerhouse of the cell.
3. Chloroplasts, found in the cells of green parts of a plant, are the photosynthetic apparatus of the cell. They contain the green pigment chlorophyll and the photochemical apparatus for converting solar (light) energy into chemical energy. As well, they have the enzymes necessary for fixing atmospheric carbon dioxide to synthesise sugars and other carbon compounds.
4. Chromoplasts develop mainly from mature chloroplasts when the chlorophyll is degraded. They contain carotenoids, which are the yellow-red pigments in many fruits.
5. Amyloplasts are the sites of starch grain development, although starch grains are also found in chloroplasts. Collectively chloroplasts, chromoplasts and amyloplasts are known as plastids.
6. The Golgi complex is a series of plate-like vesicles that bud off smaller vesicles that are probably of importance in cell wall synthesis and secretion of enzymes from the cell.
7. The endoplasmic reticulum is a network of tubules within the cytoplasm. Some evidence suggests they may act as a transport system in the cytoplasm. The endoplasmic reticulum often has ribosomes attached to it, which are the sites of protein synthesis. Other ribosomes are found free in the cytoplasm.

Chemical composition and nutritional value of fruit and vegetables

As a result of the importance of fruit and vegetables to health, there is now considerable information on their composition, particularly in terms of constituents with nutritional value. This data can be readily accessed through the many national and regional tables of food composition available on paper or electronically. However, care should be taken in applying such data due to the considerable differences in composition between cultivars and the effects of maturity, season, locality and storage. All of the following values are expressed on a fresh weight basis.

Water

Most fruits and vegetables contain more than 80 g of water per 100 g, with some tissues, such as cucumber, lettuce and melons, containing about 95 g/100 g. The starch tubers and seeds, for example yam, cassava and corn, contain less water, but even they usually comprise more than 50 g/100 g. Quite large variations in water content can occur within a species, since the water content of individual cells varies considerably. The actual water content depends on the availability of water to the tissue at the time of harvest, which varies during the day in response to fluctuations in temperature and relative humidity. For most produce, it is desirable to harvest when the maximum possible water content is present, as this results in a crisp texture. Hence the time of harvest can be an important consideration, particularly with leafy vegetables, which exhibit large and rapid variations in water content in response to changes in their environment.

Carbohydrates

Carbohydrates are generally the most abundant group of constituents after water. They can be present across a wide molecular weight range, from simple sugars to complex polymers that may comprise many hundreds of sugar monomeric units. Carbohydrates can account for 2–40 g/100 g of produce tissue, with low levels being found in some cucurbits, for example cucumber, and high levels in vegetables that accumulate starch, for example cassava.

The main sugars present in fruit and vegetables are sucrose, glucose and fructose, with the predominant sugar varying in different produce. Glucose and fructose occur in all produce and are often present at a similar level, while sucrose is only present in about two-thirds of produce. Produce with the highest sugar levels (Table 2.1) is mainly tropical and sub-tropical fruit, with grape the only temperate fruit listed and no vegetables listed. Beetroot contains the highest sugar content among the vegetables at about 8 g/100 g, with sucrose the only sugar present. Much of the sensory appeal of fruit is due to the sweet taste produced by sugars, which is considered to be one of the universal innate human taste preferences.

Table 2.1 Fruit and vegetables with the highest sugar levels (g/ 100 g)

Produce	Total sugars	Glucose	Fructose	Sucrose
Banana	17	4	4	10
Jackfruit	16	4	4	8
Litchi (lychee)	16	8	8	1
Persimmon	16	8	8	0
Rambutan	16	3	3	10
Grape	15	8	8	0
Custard apple	15	5	6	4
Pomegranate	14	8	6	0
Carambola	12	1	3	8
Mango	12	1	3	8

NOTE Some differences arise between values given for total sugars and the total of individual sugars, due to rounding of data given in R.B.H. Wills (1987) Composition of Australian fresh fruit and vegetables. *Food Technology Australia* 39, pp. 523–6.

Humans can digest and utilise sugars and starch as energy sources, hence vegetables with a high starch content are important contributors to the daily energy requirement of people in many societies. Produce such as cassava and yam commonly contain >20 g/100 g as starch, with other starchy produce containing >10 g/100 g starch. While an over-dependence on starchy vegetables is undesirable, as they cannot supply enough of certain essential nutrients, consumers in developed countries are being encouraged to eat more starch, or complex carbohydrate as it is now called, although in these countries cereals rather than fruit and vegetables are the major source of dietary starch.

Concern over the rise of diabetes in many societies has focused attention on the amount and type of carbohydrates in the diet and how they affect blood glucose levels. A glycaemic index (GI) of foods is now well established, and on this scale a pure glucose solution is rated as 100. The GI of fruit and vegetables varies widely and ranges from 22 (cherries) to 97 (parsnip). An interesting fact is that white bread, a common source of starch in Western countries, has a GI of 70 whereas starchy vegetables such as potato and sweet potato have a GI of 55–60.

A substantial proportion of carbohydrate is present as dietary fibre, which is not digested in the human upper intestinal system but is either metabolised in the lower intestines or passes from the body in the faeces. Cellulose, pectic substances and hemicelluloses are the main carbohydrate polymers that constitute fibre. Lignin, a complex polymer of aromatic compounds linked by propyl units, is also a major component of dietary fibre. Dietary fibre is not digested, as humans are not capable of secreting the enzymes necessary to break down the polymers to basic monomeric units that could be absorbed by the intestinal tract. Starch and cellulose have the same chemical composition, as they are synthesised from D-glucose units, but the bonding between the monomers differs. Starch comprises α-1,4 linkages, which are hydrolysed by a range of amylase enzymes secreted by humans; cellulose is formed with ß-1,4 linkages, however, the cellulase enzymes are not produced by humans. Similarly the enzymes necessary to hydrolyse the pectins and hemicelluloses to smaller units are lacking in humans. Dietary fibre was once considered to be an unnecessary component in the diet, although it was known to relieve constipation. But increased consumption of dietary fibre is now actively promoted by health agencies.

Protein

Fresh fruit and vegetables generally contain about 1 g/100 g protein in fruit and about 2 g/100 g in most vegetables, with the most abundant protein sources being the Brassica vegetables, which contain 3–5 g/100 g, and the legumes at about 5 g/100 g protein. The protein is mostly functional, for example in enzymes, rather than a storage pool as in grains and nuts. The relatively low level of protein means that fresh fruit and vegetables are not an important protein source in the diet.

Lipids

Lipids comprise less than 1 g/100 g of most fruit and vegetables and are associated with protective cuticle layers on the surface of the produce and with cell membranes. The avocado and olive (used as a fresh vegetable) are exceptions, having respectively about 20 and 15 g/100 g lipid present as oil droplets in the cells. The generally low lipid content of fruit and

Table 2.2 Levels of vitamin C, vitamin A and folic acid in some fruits and vegetables

Commodity	Vitamin C (mg/100 g)	Commodity	Vitamin A ß-carotene equivalent (mg/100 g)	Commodity	Folic acid (μ g/ 100 g)
Black currant, guava	200	Carrot	10.0	Spinach	80
Chilli	150	Sweet potato (red)	6.8	Broccoli	50
Broccoli, Brussels sprout	100	Parsley	4.4	Brussels sprout	30
Papaya	80	Spinach	2.3	Cabbage, lettuce	20
Kiwifruit	70	Mango	2.4	Banana	10
Citrus, strawberry	40	Red chilli	1.8	Most fruits	<5
Cabbage, lettuce	35	Tomato	0.3		
Banana, potato, tomato	20	Banana	0.1		
Apple, peach	10				

vegetables is seen as a positive factor in combating the rise of heart disease, and increased consumption of these foods is extensively promoted by health authorities. Even produce, such as avocado, with a relatively high lipid content contains mostly monounsaturated fatty acids. In recent years, monounsaturated fatty acids have been upgraded in nutritional importance because the 'Mediterranean diet', which is associated with a high consumption of olive oil, and hence of monounsaturated fatty acids, is now considered protective against heart disease.

Organic acids

Most fruit and vegetables contain organic acids at levels in excess of that required for the operation of the TCA cycle and other metabolic pathways. The excess is generally stored in the vacuoles away from other cellular components. Lemon, lime, passionfruit and black currant often contain over 3 g/100 g of organic acids. The dominant acids in produce are usually citric and malic acids. Other dominant organic acids in certain commodities include tartaric acid in grapes, oxalic acid in spinach and isocitric acid in blackberries. Apart from their biochemical importance, organic acids contribute greatly to taste, particularly of fruit with a balance of sugar and acid.

Table 2.3 Relative concentration of ten vitamins and minerals in fruit and vegetables and the relative contribution of vitamins and minerals these commodities make to the US diet

Nutrient concentration		Contribution of nutrients to diet	
Crop	**Rank**	**Crop**	**Rank**
Broccoli	1	Tomato	1
Spinach	2	Orange	2
Brussels sprout	3	Potato	3
Lima bean	4	Lettuce	4
Pea	5	Sweet corn	5
Asparagus	6	Banana	6
Artichoke	7	Carrot	7
Cauliflower	8	Cabbage	8
Sweet potato	9	Onion	9
Carrot	10	Sweet potato	10
Sweet corn	12	Pea	15
Potato	14	Spinach	18
Cabbage	15	Broccoli	21
Tomato	16	Lima bean	23
Banana	18	Asparagus	25
Lettuce	26	Cauliflower	30
Onion	31	Brussels sprout	34
Orange	33	Artichoke	36

SOURCE Adapted from C.M. Rick (1978) The Tomato. *Scientific American* 239(2), pp. 66–76.

Vitamins and minerals

Vitamin C (ascorbic acid) is only a minor constituent of fruit and vegetables but is of major importance in human nutrition for the prevention of the disease scurvy and for its possible protective antioxidant properties. Virtually all human dietary vitamin C (approximately 90%) is obtained from fruit and vegetables. The daily requirement for vitamin C is about 50 mg, and many commodities contain this amount of vitamin C in less than 100 g of tissue.

Fruit and vegetables may also be important nutritional sources of vitamin A and folic acid, commonly supplying about 40 per cent of daily requirements. Vitamin A is required by the body to maintain the structure of the eye; a prolonged deficiency of vitamin A can eventually lead to blindness. The active vitamin A compound, retinol, is not present in produce, but some carotenoids such as ß-carotene can be converted to retinol by humans. Only about 10 per cent of the carotenoids known to be in fruit and vegetables are precursors of vitamin A. All other carotenoids, such as lycopene, the main pigment in tomato, have no vitamin A activity but may be important as antioxidants.

Folic acid is involved in RNA synthesis, and a deficiency will result in anaemia. Folic acid deficiency during early pregnancy has been associated with foetal spina bifida, and various countries have moved to fortify certain foods with folic acid to minimise the risk. Green leafy vegetables are good sources of folic acid, with the intensity of green colour acting as a good guide to the folic acid content. Table 2.2 (page 23) shows the range of levels of vitamins C and A and folic acid in some fruit and vegetables. Maintenance of these vitamins during handling and storage should be a major concern, particularly when the produce will be consumed by people on marginally sufficient diets.

The major mineral in fruit and vegetables is potassium, which is present at more than 200 mg/100 g in most produce. The highest levels are in green leafy vegetables, with parsley containing about 1200 mg/100 g, but about 20 vegetables contain 400–600 mg/100 g. Health authorities in many countries are urging increased consumption of potassium to counter the effects of sodium in the diet, and fruit and vegetables are the richest natural food source of potassium.

Many other vitamins and essential minerals are present in fruit and vegetables, but their contribution to total dietary requirements is generally of minor importance. Iron and calcium may be present at nutritionally significant levels, although often in a form that is unavailable for absorption by humans; for example, most of the calcium in spinach is present as calcium oxalate, which is only poorly absorbed.

The nutritional value of various fruits and vegetables depends not only on the concentration of nutrients in the produce but also on the amount of such produce consumed in the diet. An attempt to equate these factors and show the relative concentration of ten major vitamins and minerals in some fruits and vegetables and their importance in the typical US diet in the 1970s is shown in Table 2.3. Tomatoes and oranges contain a relatively low concentration of nutrients but make the major contribution of all produce to the US diet because of the large per capita consumption.

Volatiles

All fruit and vegetables produce a range of small molecular-weight compounds (molecular weight less than 250) that possess some volatility at ambient temperatures. These compounds are not important quantitatively (normally less than 10 mg/100 g are present), but they are important in producing the characteristic flavour and aroma of fruit, and to a lesser extent of vegetables. Aroma constituents of many ornamentals have found application as perfumes for human use or as background odours in manufactured products. Most fruits and vegetables and many ornamentals each contain more than 100 different volatiles, and the number of compounds identified in particular produce is continually increasing as the sensitivity of the analytical techniques for their identification improves. The compounds are mainly esters, alcohols, acids and carbonyl compounds (aldehydes and ketones). Many of these compounds, such as ethanol, are common to all fruit and vegetables, while others are specific to an individual or species; esters, for example, are common constituents of most ripe fruits, while sulphur-containing volatiles are present in Brassica vegetables and tomatoes.

Definitive studies correlating consumer recognition of the produce with the volatile profile emanating from the produce have shown that only a small number of compounds are responsible for consumer recognition of that commodity. In most fruit and vegetables the characteristic aroma is due to the presence of one or two compounds. Table 2.4 gives the key compounds claimed to be responsible for the characteristic aromas of some fruit and vegetables. Practically all the compounds mentioned in Table 2.4 are minor components of the aroma fraction. The olfactory senses are thus extremely sensitive. The threshold concentration – the minimum concentration – at which the odour of ethyl 2-methylbutyrate, the main characteristic odour of apple, can be detected organoleptically was found to be 0.001 μL/L; that is, an apple weighing 100 g is recognised if 0.01 μg of ethyl 2-methylbutyrate is present. For the characteristic odour to be desirable, it must also be in the correct concentration. At different stages of maturation, different compounds become the dominant component of flavour. Thus a blindfolded subject would be able to detect the stage of development of a particular commodity by sniffing the aroma. Some examples of typical aroma compounds are given in Table 2.4.

Table 2.4 Distinctive components of the aroma of some fruits and vegetables

Product		Compound/s
Apple	ripe	Ethyl 2-methylbutyrate
	green	Hexanal, 2-hexenal
Banana	green	2-hexenal
	ripe	Eugenol
	overripe	Isopentanol
Grapefruit		Nootakatone
Lemon		Citral
Orange		Valencene
Raspberry		l-(π-hydroxyphenyl)-3-butanone
Cucumber		2,6-nonadienal
Cabbage	raw	Allyl isothiocyanate
	cooked	Dimethyl disulphide
Mushroom		l-octen-3-ol, lenthionine
Potato		2-methoxy-3-ethyl pyrazine, 2,5-dimethyl pyrazine
Radish		4-methylthio-*trans*-3-butenyl isothiocyanate

SOURCE Adapted from D.K. Salunkhe and J.Y. Do (1977) Biogenesis of aroma constituents of fruits and vegetables. *CRC Critical Reviews of Food Science and Nutrition* 8, pp. 161–90.