2 Constituents of Food

2.1 Introduction

In order to process foods by converting raw materials into creative, desirable, attractive and appealing products that are both safe to consume and have year-round consistency, its essential that the food process engineer has a firm understanding of the food constituents and their interacting behaviour. Foods by their very nature are often complex and multi-component in composition. As well as water, foods also include carbohydrates, proteins, fats and oils. Also present in lesser but nonetheless important amounts are flavours, vitamins, minerals and additives such as preservatives. Not all foods contain all of these components nor in equal quantities.

2.2 Water

In many foods, water is the most abundant constituent. Fruit, vegetables, juices, milk, fish and meat all contain high levels of water. Cheese, bread, biscuits and cakes on the other hand, contain relatively less levels of moisture while dehydrated foods and powders contain virtually none. The presence of moisture is critical in the textural properties of a food but is often responsible for its microbial, enzymatic and chemical deterioration.

2.3 Carbohydrates

Carbohydrates provide much of the energy in our diets. Most is found in the form of polysaccharides as starch derived from plant cells. Simple sugars as mono or disaccharides are mainly derived from cane, beet sugar and honey which contribute to sweetness, texture and colour in foods.

The main constituents of starch are amylose and amylopectin. Starch in maize is entirely made up of amylopectin molecules, whereas in wheat a quarter is amylose with the remainder being amylopectin. Starch does not dissolve in cold water, but when heated to 60°C, water diffuses through the walls of the starch granules, causing swelling and the viscosity of the starch suspension to increase. Further heating causes the granules burst giving a viscous gel. Thick sauces and gravies are prepared using flour. When starch is heated in an acidic medium, however, the starch becomes partly hydrolysed to a mixture of sugars and dextrins causing a reduction in viscosity.

There are many types and derivations of sugar types. Many are used in the manufacture of confectionary. Non-crystalline confectionary includes caramels, brittles, marshmallows and gumdrops whereas crystalline confectionary includes fudge and fondants.

Candies are made of sucrose, water or some other liquids. Their manufacture involves producing a supersaturated sucrose solution. This involves heating the concentrated sugar solution and allowing it to cool undisturbed. Upon cooling the sugar crystallises. For crystallisation to occur, nuclei must form either spontaneously or by seeding to initiate crystallisation. The size of the resulting crystals depends on the number of nuclei, rate and temperature of crystallisation, agitation and impurities in the solution. Butter is often added to deliberately interfere with the formation of crystal growth.

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Caramelisation is the application of heat to the point that sugars dehydrate and breakdown and polymerize. This is called "*non-enzymatic browning*" because it does not involve enzymes. Caramel has a pungent taste and is often bitter. It is much less sweet than the original sugar from which it is produced, is non-crystalline, and is soluble in water. Both the extent and rate of the caramelisation reaction are influenced by the type of sugar being heated. Galactose, sucrose and glucose all caramelise around 160°C whereas fructose caramelises at 110°C and maltose at about 180°C.

The Maillard reaction is the reaction between the amino group of a protein or amino acid and the reducing group of a reducing sugar. The type of sugar and the type of amino acids influence the colour obtained which may range from yellow to red. Not all sugars are reducing sugars. The most effective reducing sugars are fructose, glucose, maltose, galactose and lactose. Note that the commonly used sugar sucrose is not a reducing sugar.

2.4 Fats and oils

As well as being a major source of energy in the diet, fats and oils play an important role in the palatability of foods. In terms of bakery properties both fats and margarine are important in that they:

- influence eating properties
- influence flavour release
- influence batter and baking properties
- provide coherence and consistency to doughs
- allow aeration to be possible
- contribute to colour
- provide a shining or glossy appearance to bread
- influence shelf-life through moisture loss reduction

The main difference between fats and oils is that oils are liquids at room temperature whereas fats are solid. The term "fat" is commonly used for lard (pork fat) or tallow (beef fat). The extraction of fats and oils is achieved by:

- Rendering: used mostly for fat tissue from slaughtered animals. This includes beef, pork, deer, sheep and fish.
- Pressing: used for oil-containing seeds and fruits. The colour, taste and aroma are specific to the type of seed or fruit. Oils include peanuts, olive, corn, sesame, soy, sunflower, rape and palm.
- Extraction: used for fat-containing material using organic solvents.

Most refined fats and oils are used as a raw material for the production of margarine, mayonnaise and fat for frying, baking and roasting. The process of changing their consistency includes:

- Hydrogenation: This hardening process gives a firmer consistency to oils.
- Fractionation: Used to separate fats into fractions with different melting points.
- Esterification: Used to give a suitable firmness and spreadability as fats.

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Edible fat is a mixture of animal and/or vegetable fats. The term "butter" is applied only for the fatty substance from milk, which has been obtained from the butter-making process. The term "margarine", on the other hand, is a copy of butter.

The type of fat or oil present directly affects the textural qualities of foods, including a smooth mouth-feel and the flavour of many dishes and foods. Chips cooked in a vegetable oil have a different flavour from those cooked in lard. The texture of a fat is dependent on its physical state; suet (beef fat) is hard at room temperature of 20ºC, whereas vegetable cooking oils are liquid and some margarines are soft at this temperature. The melting point of a fat or oil depends on the fatty acid chain length and their degree of saturation.

Chemically, fats and oils consist of glycerol esterified with three fatty acids to form a triglyceride. There are more than 50 different fatty acids and vary structurally in terms of chain length (2 to 24 carbon atoms) and the number of double bonds between the carbon atoms. Where there are more than one or more double bonds, they are termed mono or polyunsaturated fatty acids, respectively (see Tables 2.1 and 2.2).

The melting point of a fat increases with fatty acid chain length (Table 2.3). Suet, which is composed of stearic acid, has a higher melting point than butter, which contains butyric acid. The presence of double bonds lowers the melting point. Olive oil contains unsaturated oleic acid and melts at a lower temperature than stearic acid. Oleic acid can be converted by the addition of hydrogen into saturated stearic acid giving a harder fat.

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A high percentage of unsaturated fatty acids in triglycerides results in a more liquid consistency at room temperature while a high percentage of saturated fatty acids gives a more solid consistency (Table 2.4). In vegetable oils, the double bond present in the saturated fatty acids are called cis double bonds and can be transformed into the trans isomer as in the preparation of margarine. Trans fatty acids are said to increase the serum cholesterol and thus contribute to the causes of heart disease. The consumption of unsaturated fatty acids with cis double bonds, and in particular cis-cis linoleic acid, is therefore recommended in preference to animal fats in which trans fatty acids occur.

In addition to triglycerides, natural fats and oils contain other components. These include waxes, phospholipids and hydrolysis products (di- and mono-glycerides and fatty acids) as well as other non-related chemicals such as sterols, pigments such as carotenes and chlorophyll, and vitamins such as A, D, E and K.

With the exception of frying, there is a structural change to fats and oils during processing. With intense heating, fats are oils increase in viscosity with a darkening colour and the formation of polymeric compounds. With repeated heating, olive oil and other oils may undergo a reaction that leads to oxidative rancidity, associated with bitter "off" flavours and acrid odours, found in vegetable oils. Oxidative rancidity is affected by the presence of metals such as copper or iron, blue or ultra-violet light, moisture, salt and haematein compounds found in meat.

When fat is heated to a very high temperature as in frying, it begins to smoke. This smoke consists of gaseous products resulting from the breakdown of fats into glycerol and free fatty acids. Glycerol itself may break down to give a sharp smelling, irritant compound called propenal (or acrolein) which gives an unpleasant flavour to the cooked food. It is therefore desirable to use fats or oils with a high smoke point for frying. Even so, prolonged and repeated use results in rancidity and an increase in fat viscosity, as rancid products may combine with fats to increase the chain length of the fatty acids.

The term margarine applied to certain types of shortenings as well as spreads and is manufactured from vegetable oils that have been hydrogenated or crystallised to form the required spreading texture. The vegetable oils may also be blended with lesser quantities of animal fats. Like butter, there is a legal requirement for margarine to contain no less than 80% fat. Since oils are virtually all fat, water is added usually in the form of milk or cream to produce the desired water-in-oil emulsion. Emulsifiers are also added along with salt, butter flavour and a permissible level of preservatives such as sodium benzoate. Vitamins A and D may also be added.

In the manufacture of margarine, separate preparations are made of water and fat-soluble ingredients. The two mixtures are then emulsified with vigorous agitation to form a continuous phase and then chilled before passing into a crystalliser to solidify further and plasticise the fat. The semi-solid margarine is finally continuously extruded and packaged.

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Table 2.1 Saturated Fatty Acids

Molecular Formula	Common name	Systematic name
$C_2H_4O_2$	acetic	…
$C_3H_6O_2$	propionic	…
$C_4H_8O_2$	n-butyric	…
$C_6H_{12}O_2$	caproic	n-hexanoic
$C_8H_{16}O_2$	caprylic	n-octanoic
$C_9H_{18}O_2$	pelargonic	n-nonanoic
$C_{10}H_{20}O_2$	capric	n-decanoic
$C_{12}H_{24}O_2$	lauric	n-dodecanoic
$C_{14}H_{28}O_2$	mystric	n-tetradecanoic
$C_{16}H_{32}O_2$	palmitic	n-hexadecanoic
$C_{18}H_{36}O_2$	strearic	n-octadecanoic
$C_{20}H_{40}O_2$	arachidic	n-eicosanoic
$C_{22}H_{44}O_2$	behanic	n-docosanoic
$C_{24}H_{48}O_2$	lignoceric	n-tetracosanoic
$C_{26}H_{52}O_2$	cerotic	n-hexacosanoic

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Table 2.2 Unsaturated Fatty Acids

Molecular Formula	*Common name*	*Systematic name*
$C_{16}H_{30}O_2$	palmitoleic	9-hexadecenoic
$C_{18}H_{30}O_2$	linolenic	9,12,15-octadecatrienoic
$C_{18}H_{30}O_2$	γ- linolenic	6,9,12-octadecatrienoic
$C_{18}H_{30}O_2$	eleostearic	9,11,13-octadecatrienoic
$C_{18}H_{32}O_2$	linoleic	cis-cis-9,12-octadecadienoic
$C_{18}H_{34}O_2$	oleic	cis-9-octadecenoic
$C_{18}H_{34}O_2$	elaidic	trans-9-octadecenoic
$C_{18}H_{34}O_2$	vaccenic	11-octadecenoic
$C_{20}H_{32}O_2$	arachidonic	5,8,11,14-eicosatetaenoic
$C_{22}H_{34}O_2$	clupanodonic	4,8,12,15,19-docosapentaenoic

To determine the structural formula, the double bond is counted back from the carboxyl group in which the first carbon atom is counted as number 1.

Table 2.3 Melting Points and Occurrence of Some Fatty Acids

Formula	*name*	*Melting pt °C*	*Source*
$C_4H_8O_2$	n-butyric	-6	Butter
$C_6H_{12}O_2$	caproic		Butter
$C_8H_{16}O_2$	caprylic	16	Butter, coconut oil and palm nut
$C_{10}H_{20}O_2$	capric	31	Butter, coconut oil and palm nut
$C_{12}H_{24}O_2$	lauric	44	Coconut oil and palm nut
$C_{14}H_{28}O_2$	mystric	54	Coconut oil, nutmeg and lard
$C_{16}H_{30}O_2$	palmitoleic	33	Peanut oil
$C_{16}H_{32}O_2$	palmitic	63	Animal fats
$C_{18}H_{30}O_2$	linolenic		Linseed
$C_{18}H_{34}O_2$	oleic		Animal fats
$C_{18}H_{36}O_2$	strearic	69	Animal fats
$C_{20}H_{40}O_2$	arachidic		Peanut oil
$C_{24}H_{48}O_2$	lignoceric		Peanut oil
$C_{22}H_{34}O_2$	clupanodonic		Whale, cod liver and fish oil

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Table 2.4 Melting Points of Some Triglycerides

S-S-S	72 °C
P-P-P	65 °C
S-P-P	62 °C
E-E-E	42 °C
S-P-O	39 °C
P-O-P	37 °C
P-S-O	36 °C
S-O-P	35 °C
O-P-P	34 °C
O-O-S	23 °C
O-O-P	19 °C
O-O-O	5 °C
L-L-L	-10 °C

NB: S=Stearic, P=Palmitic, O=Oleic, E=Elaidic, L=Linoleic

2.5 Proteins

As well as providing nutritionally essential amino acids, proteins contribute to the acceptability of foods. Many of the properties if proteins are also utilised in many cooking processes. When meringue is made, for example, the egg white protein complex albumen is beaten allowing air to be incorporated. As the albumen foam is gently heated in an oven, the transparent liquid protein denatures, turns white and solidifies, thus ensuring that the structure of the meringue is held firm.

Meat is a major dietary source of protein, which consists of muscle cells held in a matrix of connective tissue, composed of the protein collagen. This is usually dispersed throughout the muscle, but forms major concentrations as gristle near skeletal joints. When meat is cooked the collagen of the connective tissue is hydrolysed to gelatine. Gelatin, in common with other proteins, has the ability to imbibe water and swell. It dissolves in warm water to form a colloidal solution, but gels when cooled, as occurs when jellies are made, or when the juice from roast meat is allowed to cool and set. Muscle proteins also have the ability to hold water in a bound form; this is termed the water binding capacity of the protein. When meat is cooked this capacity is reduced, so that the muscle proteins lose water and shrink. As this occurs, so the muscle fibres themselves become tougher, although the connective matrix softens as a result of gelatinisation.

Plant and animal proteins are composed of amino acids, which can be combined in a variety of ways to form muscle, tendons, skin, fingernails, feathers, silk, haemoglobin, enzymes, antibodies and hormones. Proteins are therefore polyamides and the order in which amino acids are sequentially joined together in a protein molecule is called the primary structure. Unsurprisingly, the word protein is derived from the Greek *proteios,* which literally means *primary*.

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The shape into which a protein molecule folds its backbone is called the secondary structure. Further folding of the backbone upon itself by molecular forces to form a spherical structure is called the tertiary structure. The secondary and tertiary structures are collectively referred to as the higher structure of the protein. The functional properties of a protein are due specifically to the higher structure.

The precise shape or conformation of a protein molecule is due to weak non-covalent intermolecular forces across the higher structure. These include hydrogen bonding between side chains, disulphide cross-links, and salt bridges (ionic bonds such as $RCO_2^- \, {}^+H_3NR$ between side chains). The most stable higher structure is the one that has greatest number of stabilising interactions.

The orderly and distinguishable secondary structure consists of α helical structures and β (or pleated) sheets. Helical structures involve hydrogen bonds between one amide-carbonyl group and an NH group while the sheet arrangement consists of single protein molecules are lined up side by side and held together by hydrogen bonds between the chains.

Milk and egg white are soluble globular proteins. Their solubility is due to their tertiary structure. Polar hydrophilic side chains are positioned on the outside of their spherical structure increasing water solubility while non-polar hydrophobic side chains are arranged on the inside surface where they may be used to catalyse non-aqueous reactions. The unique surface of globular proteins enables them to recognise certain complementary organic molecules. This recognition allows enzymes to catalyse certain reactions but not others.

Protein denaturation is the loss of the higher structural features caused by disruption of hydrogen bonding and the non-covalent forces that hold it together. The result is the loss or change in many of the functional properties of the protein. Pressure, temperature, pH, detergents, radiation, oxidising or reducing agents can also cause denaturation. Boiling an egg is an example of an irreversible denaturation in which the colourless albumins unfold and precipitate resulting in a white solid. Likewise, when milk sours, the change in pH arising from lactic acid formation causes curdling or precipitation of soluble proteins.

Some proteins are quite resistant to denaturation, while others are more susceptible. Denaturation may be reversible if a protein has been subjected to only mild denaturing conditions. Under certain conditions a protein may resume its natural higher structure in a process called renaturation. Renaturation, however, may be very slow or may not actually occur at all.

2.6 Vitamins and Minerals

Vitamins and minerals are substances normally present in many different foodstuffs in very small amounts and are essential in the diet to maintain normal growth and development of the human body. The vitamin and mineral requirement of the human body is usually adequately met by a balanced diet. A lack of vitamins and minerals cause a number of different unpleasant deficiency symptoms to occur which disappear again as soon as the vitamin or mineral is supplied in sufficient quantity. Deficiency symptoms can also be caused by stress and disease. People nowadays are increasingly taking vitamin and mineral supplements in pill form with the notion that by taking them it will prevent these symptoms from occurring and strengthen their immune systems as well as cure cancer and prevent rheumatism. Little, however, is known about exactly how vitamin pills affect the body. New functions of vitamins in the body are still being discovered.

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Minerals are the constituents left in biological materials after incineration. They are classified into being either abundant or trace quantities as shown in Table 2.5.

Table 2.5 Abundant and Trace Minerals in the Human Body

Abundant Mineral	$g.kg^{-1}$	Trace Mineral	$mg.kg^{-1}$
Calcium	10-20	Iron	70-100
Phosphorus	6-12	Zinc	20-30
Potassium	2-2.5	Copper	1.5-2.5
Sodium	1-1.5	Manganese	0.15-0.3
Chlorine	1-1.2	Iodine	0.1-0.2
Magnesium	0.4-4	Molybdenum	0.1

Within the body, vitamins behave as biological catalysts starting chemical reactions without themselves becoming involved. Some vitamins, however, are only a part of a catalyst. Vitamin K, for example, is important for the blood's ability to clot, or coagulate. New-born babies, whose intestinal bacteria are not yet fully developed, are sometimes given an injection of vitamin K shortly after birth to enable their blood to coagulate normally.

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Perhaps surprisingly, most vitamins were only first discovered a hundred years ago. It was the Polish biochemist Casimir Funk in 1911 who claimed that food generally contained vital substances which provided the necessary protection against the diseases beriberi, pellagra, rickets and scurvy. These he called *vitamins:* a word he derived from *vita* meaning *life* and *amine* based on the fact that they contain nitrogen.

Since the isolation of vitamin A, from butter and eggs in 1913, all 13 vitamins have been extracted from foods and can now be synthesised in the laboratory. Of these, four are fat soluble (A, D, E and K) with the rest being water soluble (C and the B vitamins). All with the exception of B12 can be synthesised with a total annual world production of vitamins in the order of 123,000 tonnes in an industry worth in excess of $ 5.0 billion with Hoffman-La Roche and BASF being the world's major producers.

A recommended daily allowance (RDA) serves as a useful guide for evaluating the adequacy of a person's nutritional intake. The RDA values vary from one country to another but do allow consumers to estimate whether their daily intake meets recommended levels. The amount of a vitamin in a food product is expressed on the food label as a percent of the RDA.

Even though severe vitamin deficiency can lead to classical deficiency diseases such as scurvy, deficiency symptoms do not always present themselves immediately. Marginal vitamin C deficiency may weaken the body's immune system long before the signs of scurvy appear. Symptoms of marginal vitamin B deficiency may include a loss of appetite and irritability.

It is sometimes wrongly assumed that exceeding the RDA solves the problems of deficiency. Generally, the intake of vitamins is safe beyond the RDA. Fat-soluble vitamins require fat to be absorbed in the intestine and is the reason why they should be taken at meal times. Excessive amounts of fat-soluble vitamins are stored in the body's fatty tissues so it is important not to overdose on this form of vitamin. Harmful side effects or poisoning can result by taking too high a dosage over a long period. Ten times the RDA for vitamin A, for example, is considered safe but above that it can cause damage to the liver, spleen, cause weakness and fatigue as well as cause poor vision and weight loss.

Water-soluble vitamins do not present the same risk since any excess is excreted in the urine. On the other hand, vitamin deficiencies occur more easily within this group.

2.6.1 Fat Soluble Vitamins

Vitamin A: Found in liver and milk, vitamin A is necessary for maintaining the mucous membranes of the respiratory and digestive systems, and the cells of the skin in a healthy condition. Vitamin A is also involved in the visual cycle chromo proteins in the blue, green and red cone cells and the rods in the retina. The chromo proteins are formed in the dark. In the light they break down releasing energy, which cause impulses in the sight nerves. A lack of vitamin A impairs vision making it harder to see in the dark. The magical effects of liver have been known for millennia. The ancient Egyptians ate liver to be able to see better in poor light while the Greek physician Hippocrates (460-377 BC) was reputed to have cured night blindness with ox liver. Fritz Lipmann (Germany) was awarded the Nobel Prize for Medicine in 1953 for the discovery of the coenzyme A.

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Retinol acid, a form of vitamin A, is effective in the treatment of acne since it opens the pores of the skin. Cream preparations, which contain retinol acid, however, also increase the skin's sensitivity to ultraviolet light causing the skin to become easily irritated on exposure to the sun.

Beta-carotene is a preliminary stage of vitamin A or pro-vitamin and occurs as the orange colouring in certain vegetables, and in particular, carrots. It was originally thought that the vitamin might be effective against lung cancer.

Vitamin D: The main function of vitamin D is to help the body to absorb phosphorus and deposit calcium in the bones so that they become hard and strong. A lack of the vitamin may therefore be the reason for a higher occurrence of broken hips in the elderly. Children and young people require additional calcium to build up their bones, otherwise there is a risk that they could develop rickets. The symptoms of rickets are a hollow chest, curved back, bow legs and loose teeth. Vitamin D is considered the most poisonous of all vitamins. Excessive doses can cause nausea, thirst, loss of weight and a risk of kidney failure.

Vitamin D is found in oily fish, cod-liver oil and fish oil, and is also created in the skin when it is exposed to the sun. People who live in countries with little sunshine do not always produce sufficient amounts of vitamin D to cover their needs.

Vitamin E: An important antioxidant in that it neutralises free radicals within the body. Solar radiation, air pollution and the degradation of proteins are the cause of free radicals and reactive oxygen compounds are constantly being formed within the body. Unless controlled, free radicals can destroy cell membrane as well as alter genetic material (DNA) increasing the risk of cancer. Like other antioxidants vitamin E can prevent this damage from occurring.

Vitamin E is responsible for regulating the balance of certain hormones in the body. The male sex hormone testosterone depends on vitamin E to produce sperm in the testicles while the female hormones oestrogen and progesterone need both vitamin E and B to be biologically active. Vitamin E is therefore important for normal pregnancy and may lead to sterility in men if deficient. Found widely in wheat, cereal, peas and lettuce it is an approved food additive.

Vitamin K: A derivative of 2-methyl 1,4 napthequinone and is essential in blood-clotting mechanisms, vitamin K is found in green vegetables such as kale, spinach, cauliflower and nettles. Deficiency causes reduced activity of prothrombin resulting in haemorrhage. Henrik Dam (Denmark) and Edward Doisy (USA) were awarded the Nobel Prize for Medicine in 1943 for the discovery of vitamin K.

2.6.2 Water Soluble Vitamins

Vitamin B: Perhaps the first case of using vitamin B in treatment was in 1867 when a young Dutch doctor, Christian Eijkmann, travelled to Java to identify the cause of a mysterious illness. The illness was particularly prevalent amongst soldiers, mine-workers and prisoners which failed to respond to any kind of medical treatment. The symptoms of the illness were fatigue, paralysis and respiratory difficulties resulting in death. Dr Eijkmann called the disease beriberi which, in Singhalese, means *tired-tired*.

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Dr Eijkmann noticed that chickens when fed on the leftover polished rice of those suffering from the disease began to show the same symptoms. He was quick to draw the connection between the chicken feed and the disease and was able to then prepare an extract from the husks of the rice, which he successfully used as a medicine. Christian Eijkmann was awarded the Nobel Prize for Medicine in 1929 for the discovery of the antineuritic vitamin.

Vitamin B consists of a group of related substances. For practical reasons the individual B_3 vitamins were numbered B_1, B_2, B_3, B_6 and B_{12}. The gaps in the numbering are due to other substances that scientists once (wrongly) thought were B vitamins. Three other B vitamins have a name instead of a number: pantothenic acid, biotin and folic acid.

The B vitamins each function differently. Some affect the metabolism of the cells in the body and the production of energy, while others are responsible for the formation of red blood corpuscles and DNA. The classical deficiency disease of vitamin B_3 (niacin) is pellagra, which affects the skin, digestion and nervous system. Pellagra in Latin literally means *coarse skin.* In extreme cases deficiency causes dementia and emaciation to occur and, if untreated, can be fatal.

Once a worldwide problem, pellagra was thought to have been caused either by a fungus or by bacteria. The connection between the illness and vitamin B_3 deficiency was established in 1930. Pellagra is still common in certain parts of the world today, particularly in areas where maize or millet is the staple diet.

Vitamin B_1 (Thiamin): Essential for the well-being of the nervous system and the digestion of carbohydrates in food. Thiamin is the coenzyme, which helps to break up carbohydrates. Severe deficiency leads to beriberi, a loss of muscle function as well as neurological and cardiac problems. It is found in yeast, the germ of cereals and potatoes.

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Vitamin B_2 (Riboflavin): Promotes growth and healthy skin and eyes. It forms complex molecules which act as hydrogen carriers in oxidation-reduction (redox) reactions and is part of the two co-enzymes which are responsible for catalysing a series of chemical reactions necessary for energy formation in the mitochondria. The vitamin is widely distributed in foods such as liver, eggs, cheese and green vegetables. Deficiency symptoms are therefore rare although a symptom is cracking of the skin.

Vitamin B_3 (Niacin): Responsible for maintain the healthy skin and the intestinal tract vitamin B_3 is found as the co-enzyme nicotinamide adenine dinucleotide (NAD) or its phosphorylated form NADP+ which are important to the cells' energy production. Deficiency leads to pellagra. Symptoms include dermatitis, diarrhoea and mental disturbance. Occurs in food as nicotinic acid and found in yeast, meat, liver and cereals.

Vitamin B_6 (Pyridoxine): B_6 is vital for the normal breakdown of proteins in food as well as maintaining healthy skin and nervous system. Deficiency leads to epilepsy, dermatitis and anaemia.

Vitamin B_{12} (Cyanocobalamin): Like folic acid, B_{12} is important for the formation of the genetic material DNA. It is the only vitamin not to be synthesised but is instead derived from animal sources with an annual world production of around 14 tonnes of which 55% is used for animal nutrition. There are deficiency problems for people on vegan diets (no meat or fish or products of animals such as milk or eggs). A symptom of deficiency is pernicious anaemia.

Pantothenic acid: Essential for metabolism of carbohydrates, proteins, and fats, and the formation of certain hormones. Deficiency includes nervous and intestinal disorders. Widely distributed in foodstuffs.

Biotin: Produced by intestinal bacteria and important in fatty acid biosynthesis and gluconeogenesis. It is essential to many chemical systems in the body. Deficiency rarely occurs although symptoms include dermatitis and loss of hair. This is sometimes referred to as B_8 or vitamin H.

Folic acid: Important for synthesis of the component comprising the genetic material DNA. It is recommended that expectant mothers supplement their diets in the early stages of pregnancy. It is also vital for the correct functioning of the blood-forming organs. Deficiency symptoms are intestinal disorders and anaemia.

Vitamin C: Scurvy is a vitamin-deficiency disease brought on by a lack of fresh vegetables and fruit and was once a widespread and fatal disease. For centuries, the dreaded disease plagued seafarers on long sea voyages. When the fifteenth century Portuguese mariner Vasco da Gama opened up a sea route to India by sailing around the Cape of Good Hope, 100 of his crew of 160 died from the illness. The Portuguese-born explorer Ferdinand Magellan - born in 1480 and known as the greatest explorer of his age - was also no newcomer to the appalling disease. A member of one of his expeditions wrote in his chronicle, "We were three months and twenty days without getting any kind of fresh food. We ate biscuits which was no longer biscuit but powder of biscuits swarming with worms", adding, "The gums of both the lower and upper teeth of some of our men swelled, so that they could not eat under any circumstances and therefore died."

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Over two centuries later, in 1747, the Scottish naval surgeon Dr James Lind performed an experiment on a group of sailors suffering from scurvy. Dr Lind showed that by taking a daily supplement of oranges and lemons the disease could be prevented from occurring. His claims were met with much scepticism and disbelief. British maritime explorer Captain James Cook, however, was quick to realise the value of a diet of fresh fruit and vegetables on long sea voyages and was almost militant in enforcing dietary rules to prevent scurvy amongst his crews. In spite of Captain Cook's success in his battle against the disease, it took a further fifty years for the British Admiralty to prescribe a daily ration of lemon juice for all sailors in the Navy. By the beginning of the 19th century scurvy was no longer a threat to the British fleet.

Even though citrus fruits were known to have prevented scurvy, it was not until the Hungarian Nobel Prize winner for Medicine Albert Szent-Györgyi (1937) successfully isolated the vitamin. He named it ascorbic acid as an abbreviation of *anti-scorbutus*, which is Latin for *against scurvy*.

Ascorbic acid has many important roles in the body and is particularly concerned with the growth and repair of body cells and tissue helping to fight infection, and with the absorption of iron from food. Iron is required in the manufacture of haemoglobin; the red pigment in the blood which transports the vital oxygen from the lungs to the rest of the body. The vitamin is also important for the formation of the protein collagen, which strengthens the cells that build up bones.

A severe deficiency leads to scurvy which causes bleeding in the skin and joints, around the bones and from gums and can lead to death. Potatoes, green vegetables and citrus fruits such as oranges and lemons are the commonest sources and blackcurrant and rosehip extracts are particularly rich.

Dietary studies have shown that by eating large quantities of fresh fruit and vegetables that are rich in vitamin C the risk of contracting certain diseases reduces. There are also claims that high doses of vitamin C can help fight cancer cells. There are no studies, however, that unequivocally support this claim.

Taking large quantities of vitamin C in tablet form over a long period of time can cause a risk of kidney stones; the excess vitamin is turned into oxalate which, when combined with calcium, is transformed into kidney stones.

2.6.3 Vitamin Loss

Vitamins in fruit and vegetables may be destroyed or lost in several ways between harvesting and consumption. The water-soluble vitamins of the B-complex and vitamin C tend to be more unstable during cooking and processing than the fat-soluble vitamins (Table 2.6). In addition, both water-soluble vitamins and minerals may be lost by diffusion from the food into the cooking medium. In some cases these nutrients may still be consumed, as the cooking water may be used for making sauces or gravy. Similarly, the liquid syrup from canned fruit is normally consumed, but in many cases the cooking water is discarded.

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Table 2.6 Stability of Water-Soluble Vitamins during Cooking and Processing

Vitamin	*Alkaline*	*Neutral*	*Acid*	*UV-light*
Thiamin, B_1	unstable	unstable	stable	stable
Ribflavin, B_2	unstable	stable	stable	unstable
Niacin, B_3	stable	stable	stable	stable
Pyridoxine, B_6	stable	stable	stable	stable
Cyanocobalamin, B_{12}	unstable	stable	stable	stable
Folic acid	unstable	unstable	stable	stable
Pantothenic acid	unstable	stable	unstable	stable
Ascorbic acid, C	unstable	unstable	unstable	unstable

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The fat-soluble vitamins are more stable than the water-soluble vitamins under normal conditions. Vitamin D is completely stable; both vitamin A and carotene, from which it can be derived, are stable below 100°C. However, both forms suffer losses during frying, exposure to sunlight, dehydration and during the storage of dehydrated food.

The tocopherols (vitamin E) are natural antioxidants, but in protecting fats and vitamin from oxidation during storage, cooking and processing are themselves oxidised. The most unstable fat-soluble vitamin is vitamin K, which is destroyed in the presence of acids, alkalis, oxidising agents or sunlight and by prolonged heating.

The exact amount of vitamins lost during boiling of vegetables depends on the type of vegetables being boiled (Tables 2.7, 2.8 and 2.9).

Table 2.7 Vitamin Loss (%) During Boiling of Vegetables

Vegetable Type	**B_1**	**B_2**	**B_3**	**C**	**Folic acid**
Leafy	40	40	40	70	70-100
Seeds & Fruit	30	30	30	50	70-100
Roots	25	30	30	40	70-100

Table 2.8 Thiamin Loss (%) in Cooked Meats

Meat	*Cooking Method*	*Loss (%)*
Beef	Roast	40-60
	Stewed	50
	Fried	0-45
	Canned	80
Pork	Roast	30-40
Ham	Baked	50
	Fried	50
	Canned	50-60
Bacon	Fried	80
Poultry	Roast	30-45
Fish	Fried	40

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Table 2.9 Vitamin C Loss (%) in Juices (After 12 Months of Processing)

Beverage	*Vit. C Remaining (%)*
Carbonated juice	54-64
Apple juice	58-74
Cranberry juice	78-83
Grapefruit juice	73-86
Pineapple juice	74-82
Tomato juice	64-93
Vegetable juice	66-69
Grape drink	65-94
Orange drink	75-83
Evaporated milk	70-82

Example

A series of experiments were conducted to determine the rate of degradation of vitamin C in processed orange juice. If the degradation follows first order kinetics, determine the rate constant.

Time (mins)	Vitamin C (mg per 100 mL)
0	47
10	38
20	31
30	25

Solution:

The first order reaction is given by

$$\frac{dV}{dt} = -kV$$

Rearranging, the amount of vitamin C remaining, *V*, at time *t* is

$$-k\int_0^t dt = \int_{V_o}^{V} \frac{dV}{V}$$

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Integrating and rearranging

$$kt = \ln\left[\frac{V_o}{V}\right]$$

For the date provided:

$$k = \frac{\ln\left[\frac{47}{38}\right]}{10} = 0.021s^{-1}$$

$$k = \frac{\ln\left[\frac{47}{31}\right]}{20} = 0.021s^{-1}$$

$$k = \frac{\ln\left[\frac{47}{38}\right]}{10} = 0.021s^{-1}$$

The consistency of the rate constant confirms first order kinetics.

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2.6.4 Macro Minerals

Calcium: Required for hard bones, transmission of nerve impulses, activates certain enzymes, necessary for maintenance of membrane potential and muscle contraction. 99% in skeleton, remainder in extracellular fluids, intracellular structures and cell membranes.

Men's RDA	15-24 years-1200mg	25-50 years - 800mg
Woman's RDA	15-24 years-1200mg	25-50 years - 800mg

Found in dairy products, sardines, clams, oysters, turnip/mustard greens, broccoli and legumes. Excess leads to constipation, hypocalcaemia, kidney stones. High levels may inhibit intestinal absorption of iron, zinc, other nutrients. Deficiency leads to risk of bone injury and osteoporosis, especially in females.

Magnesium: Co-factor of enzymes in energy metabolism, maintenance of electrical potentials in muscles and nerves, component of bone. Most found in muscles and soft tissue, 1% in extracellular fluid, remainder in skeleton.

Men's RDA	15-18 years - 400mg	19-50 years - 350mg
Woman's RDA	15-18 years - 300mg	19-50 years - 280mg

Found in nuts, legumes, unmilled grains, soybeans, chocolate, corn, peas, carrots, seafood, brown rice and lima beans. Excess leads to nausea and vomiting. Deficiency is rare and leads to muscle weakness.

Phosphorus: Component of bone, buffer in body fluids, component of ATP, nucleotides and co-enzymes. 85% in skeleton, remainder in soft tissue and blood.

Men's RDA	15-24 years -1200mg	25-50 years - 800mg
Woman's RDA	15-24 years-1200mg	25-50 years - 800mg

Found in protein-rich food, milk, meat, poultry, fish, eggs, nuts, legumes, cereals. Excess leads to lowering of blood calcium. Deficiency is rare.

2.6.5 Trace Minerals

Zinc: Co-factor of several enzymes in energy metabolism, immune function, possible anti-oxidant, wound healing, taste and smell. Found in bones and muscle, liver, kidney and brain.

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Male RDA	15-50 years - 15mg
Woman's RDA	15-50 years - 12mg

Found in oysters, wheat germ, beef, calf liver, dark meat in poultry and whole grains. Excess leads to gastro-intestinal irritation, impaired copper absorption and reduction in high-density lipoproteins. Deficiency leads to appetite loss, poor wound healing, abnormal taste and smell, changes in hair and skin.

Copper: Required for proper use of iron, role in development of connective tissue, co-factor to oxidases. Found in liver, heart, kidney, spleen and brain.

Male RDA	11+ years -1.5-2.5mg	Adult - 1.5-3.0mg
Woman's RDA	11+ years -1.5-2.5mg	Adult - 1.5-3.0mg

Found is organ meats, shellfish, whole grains, legumes, chocolate and nuts. Excess is rare but is potentially toxic. Deficiency is rare leading to anaemia.

Selenium: Anti-oxidant, co-factor of glutathione peroxidase. Stored in liver and kidneys.

Men's RDA	15-18 years - 50µg	19-50 years-70µg
Woman's RDA	15-18 years - 50µg	19-50 years-55µg

Found in grains, meat, poultry, fish, dairy products. Excess is not known although hair loss, nausea and diarrhoea are possible. Deficiency is not known although myalgia and cardiac myopathy are possible.

Chromium: Enhances effectiveness of insulin.

Men's RDA	11+ years - 50-200µg
Woman's RDA	11+ years - 50-200µg

Found in mushrooms, prunes, nuts, asparagus, organ meats, whole grain bread and cereals. Excess is not known. Deficiency is not known although impaired glucose tolerance anaemia is possible.

Iron: Necessary component of haemoglobin, myoglobin transport of oxygen, facilitates transfer of electrons in electron transport system. 60-70% found in haemoglobin with the remainder in bone marrow, muscle, liver and spleen.

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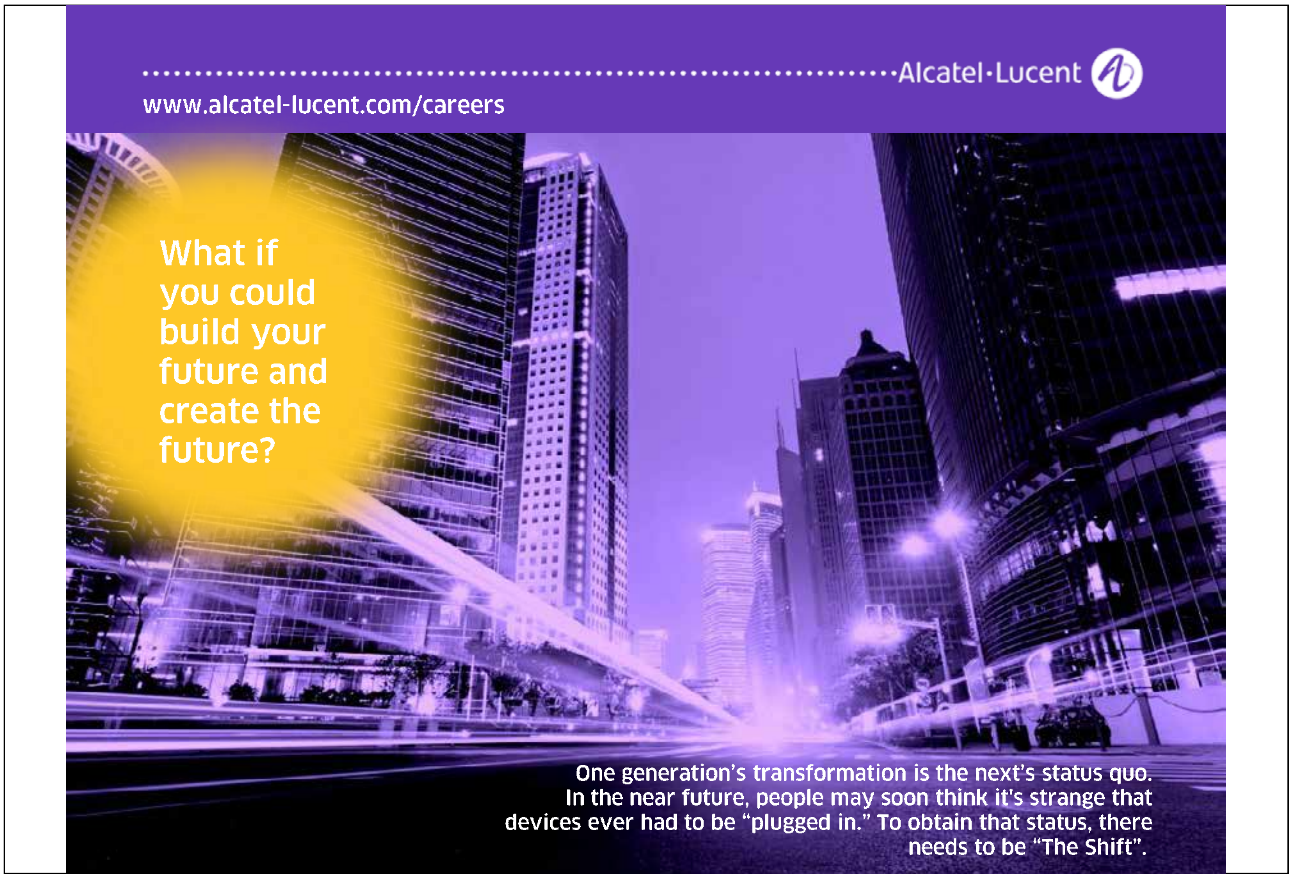
Men's RDA	15-18 years-12mg	19-50 years-10mg
Woman's RDA	15-50 years-15mg	

Found in meats, black strap molasses, clams, oysters, dried legumes, nuts and seeds, red meats, dark green leafy vegetables. Excess is rare causing liver damage. Deficiency leads to anaemia and fatigue.

2.7 Flavours and Aromas

The term "flavour" is used to describe the quality of food but it is neither very well defined nor properly understood. In fact, flavour describes the complex and interacting set of sensations experienced when food is consumed. Flavour is a distinctive taste and savour and may be defined as "that quality of something which affects the sense of taste or gratifies the palate: savour is the blend of taste according to smell sensations evoked in a substance in the mouth."

Flavour is a subtle combination of the four distinguishable elements of sweetness, sourness, bitterness and saltiness. In recent years, a fifth distinguishable flavour has become accepted. It is best known in the form of monosodium glutamate (MSG). The Japanese named this new taste *umami*, which means roughly "savoury" in English.



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Natural products contain many aroma chemicals. Tarragon essential oil, for example, contains up to 77 components and coffee over 800. Others, on the other hand, contain fewer major components. Vanilla, for example, contains the major ingredient vanillin, which was first synthesized in 1874. Whilst some synthetic flavourings are prepared by using such major components as the key ingredient, the majority are complex mixtures of the many important aroma chemicals found in nature.

Many flavours are the result of specific chemical processes such as fermentation (cheese, yogurt, alcoholic drinks) or roasting and frying (meat, chocolate, toast, deep-fat-fried food). Fermentation, roasting and toasting create specific chemical reactions in foods. The sweet caramelly taste of fried onions, gravy, or the crackling on pork involves a chemical reaction between proteins and carbohydrates in a non-enzymatic brown reaction first discovered by the French chemist, L.C. Maillard, in 1912.

Variations on the browning reaction produce many of the most desirable flavours. Examples include allylpyrazine which gives a roasted nut-like flavour; methoxypyrazines earthy vegetables; 2-isobutyl-3 methoxypyrazine gives green pepper, and acetyl-l-pyrazines popcorn; 2-acetoxy pyrazine produces toasted flavours. During World War II two scientists, H.M. Barnes and C.W. Kaufman, discovered that the reactions between sugars and proteins could produce not only the off-flavours but also desirable flavours. In 1947 a maple syrup flavour was patented as the first Maillard reaction flavour.

Flavours are additives that create or improve flavours and many, depending on the strength of the flavour desired, range from 0.01% to 2%. The usage in foods can correspondingly range from a few kilogrammes per year to several thousand tonnes. These may be either natural (ie obtained from plant or animal sources), natural identical (ie chemically synthesised but chemically identical) or artificial (ie not produced in plants or animals).

Alcohols, aldehydes, ketones, esters and lactones are classes of compounds that occur most frequently in nature and artificial flavours. The majority of flavours have molecular masses of around 200 and are rarely above 300.

Table 2.10 Examples of Synthesised Flavours:

Type	Name	Formula	m_w	bp (^oC)	Aroma
Ketone	3-hydroxy-2-butanone (Acetoin)	$C_4H_8O_2$	88	148	Butter
Ketone	1-(4-hydroxyphenyl)-3-butanone	$C_{10}H_{12}O_2$	164	83	Raspberry
Ester	Isoamyl acetate	$C_7H_{14}O_2$	130	142	Banana
Ester	Ethyl acetate	$C_4H_8O_2$	88	77	Brandy
Ester	Ethyl butyrate	$C_6H_{12}O_2$	116	122	Pineapple
Aldehyde	Hexanal	$C_6H_{12}O$	100	128	Unripe fruit
Lactone	δ Decalactone	$C_{10}H_{18}O_2$	170	156	Peach
Lactone	γ Decalactone	$C_{10}H_{18}O_2$	170	120	Coconut

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Example:

Ethyl ethanoate, b.p. 88°C, has the characteristic aroma of brandy and can be made by condensing together ethanol, b.p.78.5°C, and ethanoic acid, b.p. 118°C. The reaction is reversible. Write a balanced equation for the formation of ethyl ethanoate from ethanol and ethanoic acid. Suggest a way in which the rate of reaction can be increased and why distillation is not a suitable process for purifying the ester.

Solution:

$$CH_3COOH + C_2H_5OH \Leftrightarrow CH_3COOC_2H_5 + H_2O$$

The reaction can be promoted by the addition of a suitable acid. Distillation is not suitable since ethanol has the lowest boiling point and therefore drives the reaction in favour of the reactants and not the products.

Example:

The hydrolysis of a favour ester can be catalysed by hydrochloric acid for which, at a given temperature, the pseudo first order reactions with added acid are shown.

Conc^n*. HCl* $mol.dm^{-3}$	k s^{-1}
0.025	2.75×10^{-5}
0.050	5.5×10^{-5}
0.100	1.1×10^{-4}

Determine the catalytic coefficient if the reaction rate can be related to the amount of catalyst by

$$k = k_{cat}[catalyst]$$

Solution:

$$k_{cat} = \frac{k}{[catalyst]}$$

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For the three concentrations

$$k_{cat} = \frac{2.75\times10^{-5}}{0.025}0.0011 mol.dm^{-3}.s^{-1}$$
$$k_{cat} = \frac{5.5\times10^{-5}}{0.050}0.0011 mol.dm^{-3}.s^{-1}$$
$$k_{cat} = \frac{1.1\times10^{-4}}{0.100}0.0011 mol.dm^{-3}.s^{-1}$$

Thereby concluding that the pseudo first order reaction applies.

2.8 Additives and Antioxidants

The European Food Safety Authority (EFSA) is the keystone of European Union (EU) risk assessment regarding food safety working in close collaboration with national authorities has produced a list of permissible food additives. The so-called E-numbers are a systematic way of identifying different food additives. The E-number is only given to an additive that has passed all the necessary food safety checks.

Many food additives are anti-oxidants and used to preserve or enhance certain foods. All foodstuffs are vulnerable to oxidation. The most familiar examples are the browning of cut apples or potatoes when exposed to air. The use of lemon juice demonstrates the principle of anti-oxidation since lemon juice contains vitamin C (E300), which is one of the most potent antioxidants.

Atmospheric oxygen is not the only oxidizing agent. It is combined in the form of oxides and peroxides in atmospheric pollution, cigarette smoke and in some normal bodily processes. Oxidation can cause breaks in DNA (and hence the risk of cancers), oxidise polyunsaturated fatty acids, and thus contribute towards heart disease and strokes and can damage proteins. The proteins in the eye are particularly vulnerable because light also assists the oxidation process. Increasing the intake of antioxidants has a preventative effect against both cancer and heart disease. The oxidation of lipids is one factor in the development of heart disease.

Besides all their other advantages, antioxidants confer huge economic and environmental benefits in preventing wastage of food.

Acids are a major component of natural foods. Zest is a highly desirable attribute in food, and sharpness of flavour is always due to acids. Phosphoric acid (E338) gives the sharpness in cola drinks. All fruits contain characteristic acids such as citric in lemons, malic in apples, tartaric in grapes. The acids that are added to food are all, except phosphoric acid, found in natural foodstuffs. Besides imparting sharpness of flavour, acids are used because the overall acidity of foods can be crucial.

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Acids also have preservative and antioxidant properties. In jam-making the acidity of the fruit determines its setting properties The most commonly used acid is citric acid (E330). Originally derived from citrus fruits it is now produced by fermentation of molasses by an aspergillus mould. Besides adding tartness, it is also an antioxidant and a preservative. Phosphoric acid (E338) is the next most commonly used acid.

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