Nuffield Advanced Chemistry

FOOD SCIENCE

Students' book

Contents

This students' book consists of the text of the Special Study with the experiments given separately at the end

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The examinable content of this Special Study is defined by the Edexcel specification. Clarification of the depth of treatment can be gauged from these downloadable chapters and instructions for experiments, published in the Special Study section of the *Re:act* website http:/www.chemistry-react.org

The content of the comment and case study boxes is not examinable.

Re:act provides study guides for each chapter, web-links, answers to frequently asked questions, and revision questions.

CHAPTER 1 INTRODUCING FOOD SCIENCE

1.1 Science and food

Food production is one of the world's most vital industries. Food production becomes essential once a community progresses beyond a nomadic culture. In subsistence communities, most people spend their working lives trying to produce enough food to feed their families. Any surplus, when they are lucky enough to produce a surplus, is sold to those not working on the land. In industrialised countries, most people are fed more than adequately by a minority who are involved in food production. In 1900, 30% of the labour force in the UK was involved in agriculture. By now, less than 10% of the population produce 60% of the food consumed. Nevertheless the food industry as a whole is still Britain's largest manufacturing industry.

During the last 100 years, annual world food production has increased continuously, and in some areas dramatically. This rapid increase has not been worldwide, but has largely been confined to the technologically developed countries of the northern hemisphere. The abundance of food in these countries is due in part to the application of science and technology to all stages of the food industry, from the sowing of the seed to the attractively packaged and displayed item on the supermarket shelf.

As the consumer becomes more and more detached from the producer and the producing areas, the importance of processing, preservation, and packaging increases. If these activities were not carried out, large urban populations would be unable to enjoy the range of good quality foods now available at affordable prices.

Food science

Food science is concerned with:

- the nature, composition, nutritional value, and behaviour of food materials,
- the biochemical and microbiological causes of spoilage and,
- the scientific principles of the methods of processing and preservation.

Food science embraces various aspects of chemistry, biochemistry, biology, bacteriology, physics, and chemical engineering. Chemistry is important because food is composed of chemical compounds. Processing and preservation techniques may involve the use of additives – which are also chemical compounds. Changes in food during processing, storing, cooking, and deterioration are mainly chemical changes.

1.2 Public concerns

The subject of food is never out of the public eye. There is a continuing debate about such matters as:

- the use of diet to control body weight
- the role of cholesterol
- the dangers of excessive salt content of food
- the acceptability of genetically modified food
- the use of vitamin supplements
- the cost and alleged superiority of organic food.

1.3 The nature and content of food

The six types of nutrients which must be present in a healthy diet are listed in figure 1.1 below. A lack of the minimum amount of any one of the six nutrients will result in malnutrition, though that level may vary for different people. A general deficiency of all six nutrients will lead to under-nutrition and eventually starvation.

After digestion and absorption, the three basic functions of nutrients are:

- to provide chemicals for growth and repair of tissues,
- to maintain the basic structure of the body, and
- to provide energy for external activity and for regulation of internal processes.

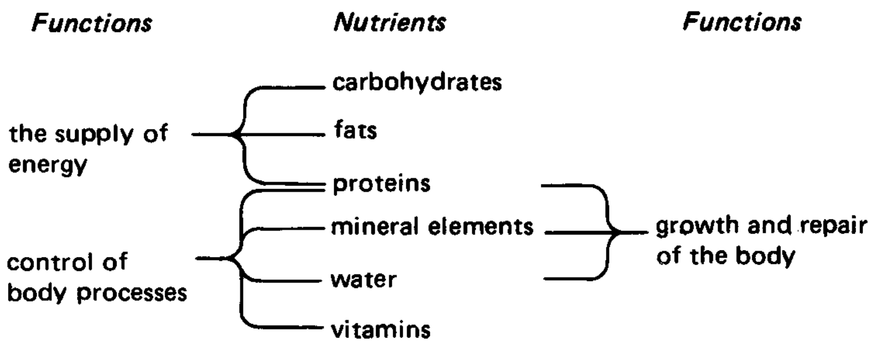


Figure 1.1 Essential nutrients

For a substance to be classified as a food, it must contain one or more of the six nutrients. Not everything that is eaten is primarily a food. Take, for example, salt and pepper, which are both widely used in our food. Salt is a food because it is essential in controlling some of the processes in the body. Pepper contains 12% water, 11% protein, 8% fat, and 40% carbohydrate, but it is consumed in such small amounts that it makes an insignificant contribution to the daily nutritional intake. Tea and coffee are both very popular beverages. Their nutritional value is due to the water, and milk and sugar if added. However, they are not drunk for their nutritional value, but for their flavour and for their caffeine content, which acts as a mild stimulant. If coffee and tea were eaten in sufficient quantities to be nutritionally significant, the physiological effects of their stimulant and flavour constituents would be dangerous.

Attitudes to food

A substance can only be defined as a food if, in addition to providing the various nutrients, it is accepted as being a food by the community concerned. Throughout history, and in various parts of the world, social, religious, and psychological factors have prevented the consumption of some nutritional and edible materials. These factors cannot be dismissed, although in some cases the reason behind the taboos and beliefs is not always understood.

British people would not normally contemplate eating grubs and insects, snakes or dogs but they are eaten as food in some parts of the world. In severe conditions such things might be eaten in the western world. We expect our food to be appetising as well as nutritious. Factors such as flavour, texture, colour, aroma, presentation and, in some cases, the environment in which we eat, all contribute to the appeal of food.

Energy from food

In addition to the six nutrients mentioned, we need a continuous supply of oxygen. Ingested food (carbohydrates, fats, and proteins) undergoes oxidation and provides energy for all living cells. Not all the energy from oxidation ends up heating the surroundings. Some heat is necessary to maintain the body temperature. Some of the energy is needed to perform mechanical work in muscles; some is needed for the synthesis of cell constituents. Oxidation of ingested food is needed to provide enough energy to enable the body to perform both internal and external activities.

Even during sleep, when the body is in its least active state, energy is consumed. The minimum energy required to maintain the essential bodily functions – expansion and contraction of lungs, pumping action of the heart, and temperature regulation – is called the **energy of basal metabolism**. The minimum energy required for these vital functions varies according to sex, age, and size, but is about 6700 kJ per day for an average adult. Expenditure of energy varies with activity and between individuals doing the same activity. Nevertheless, figure 1.2 below gives approximate figures calculated for the average person.

Activity	**Example**	**Energy expenditure** / kJ minute^{-1}
Sedentary	school or college work	8
Light	house work	15
Medium	football, netball	25
Heavy	manual work, e.g., digging	33

Figure 1.2 Activity and energy expenditure.

1.4 What is in the food we eat?

The British Nutrition Foundation recommends that about 35% of the energy intake should be in the form of fats (about half of this to be as unsaturated fat), about 15% in the form of protein, and about 50% in the form of carbohydrates.

In addition to the energy requirement, a balanced diet contains a minimum quantity of protein, minerals, and vitamins. The minimum requirements vary with age and sex, as figure 1.3 shows.

Age	**Energy /MJ**		**Proteins /g**		**Iron /mg**		**Calcium /mg**		**Thiamin (a B vitamin)** /mg		**Nicotinic acid (a B vitamin)** /mg		**Ascorbic acid (vitamin C)** /mg	
	M	F	M	F	M	F	M	F	M	F	M	F	M	F
1–3 years	5.2	4.9	15	15	7	7	350	350	0.49	0.47	0.6	0.6	30	30
15–18 years	12	9	55	45	11	15	1000	800	1.1	0.9	8.1	7.9	40	40
19–49 years: low activity	11	8	56	45	9	15	700	700	1.0	0.8	17	13	40	40
moderately active	13	9	56	45	9	15	700	700	1.2	0.9	20	15	40	40
very active	14	10	56	45	9	15	700	700	1.4	1.0	23	16	40	40
pregnancy (additional)		+0.8		+6		+15		+400		–		–		+10
lactation (additional)		+2.4		+11		–		+400		+1.1		+2.3		+30

Figure 1.3 Nutrient intake per day. These amounts of selected nutrients are enough for almost every individual. M = male, F = female.

A national food survey is carried out in the UK regularly and the results are published by the Department for the Environment, Food and Rural Affairs, generally known as DEFRA.

The statistics for 2002-03 show that in the UK the major sources of energy are meat, 14%; bread, 12%; and cereals, 22%, with significant contributions from a wide variety of sources. Surprisingly, only 3% is from alcoholic drinks, 4% from confectionery, and 4% from sugar and preserves. 35% of energy comes from fats including oil and butter.

61% of our protein in the UK comes from meat, on average.

Vitamin C is obtained mainly from fresh and preserved fruits, but there are important contributions totalling 18% from potatoes and other vegetables.

In addition to providing valuable nutrients, vegetables also provide our main source of dietary fibre (roughage), which is essential in a healthy diet. Dietary fibre is primarily composed of carbohydrates, principally cellulose, which are not absorbed by the human body and add bulk to the faeces. Because of its water-binding capacity, dietary fibre assists the passage of waste products through the intestine.

CHAPTER 2 THE NUTRIENTS IN FOOD

2.1 Fats

Fats belong to a group of compounds called lipids, which are soluble in non-polar solvents. Fats are esters of propane-1,2,3-triol (glycerol) and long chain carboxylic acids, which are called fatty acids. Since propane-1,2,3-triol has three hydroxyl groups, it can form mono-, di-, or triesters known as mono-, di- and triglycerides respectively.

The chemical and physical properties of the triglycerides depend on the nature of the R-group. The R-group is a fatty acid chain and may have different degrees of saturation. Highly unsaturated fats tend to be liquids, and occur naturally in vegetable oils. Highly saturated fats are more viscous, and are likely to be solids at room temperature.

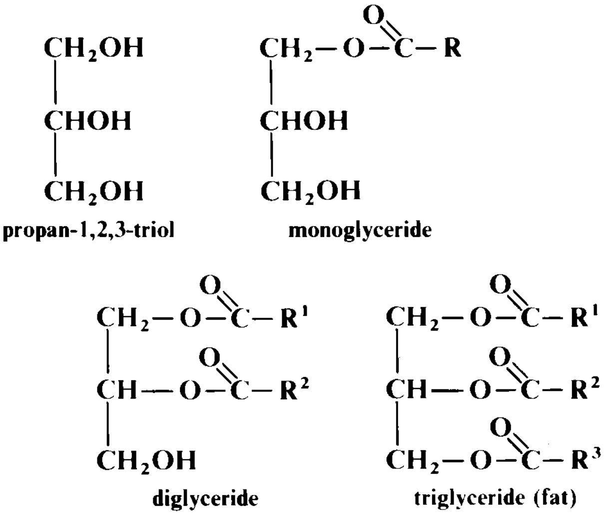


Figure 2.1 Structural formulae of glycerides.

Fats in the diet

A correct proportion of fats is essential in a balanced diet. Fats provide the most concentrated source of energy. Certain fats provide **essential fatty acids** such as linoleic, linolenic, and arachidonic acids. The absence of any one of these essential fatty acids in the diet may result in disorders such as eczema.

Fats are also necessary because fat-soluble vitamins such as A, D, E and K are essential for a healthy diet. Stored fat, apart from acting as a nutritional reserve, serves as thermal insulation and physical protection. Some organs, such as the kidneys, are protected against injury and heat loss by a layer of fat.

The main sources of fat in the UK diet are butter, margarine, meat and milk.

In the UK people eat solid fat, in butter or margarine, spread on bread or other foods. Until 1910, when the process of hardening fats by hydrogenation was perfected, almost 95% of fat consumption was animal fat. Since then the production and consumption of vegetable oils have increased dramatically.

Fat/oil	Main fatty acids
Palm	oleic (45%) palmitic (40%)
Groundnut	oleic (57%) linoleic (23%) palmitic (12%)
Olive	oleic (80%) linoleic (10%)
Lard	oleic (56%) palmitic (28%) stearic (8%)
Butter fat	oleic (30%) palmitic (30%) stearic (11%) myristic (10%)

Figure 2.2 Composition of some lipids.

Figure 2.3
Average fat content of some raw foods (g/ 100 g).

Food	milk	cheese	eggs	beef	bacon	chicken	white fish	butter	potatoes	white bread
Fat content	4	34	17	17	40	7	1	81	0	2

Chemistry of fats

Unsaturated fats can be hardened by reducing the proportion of unsaturated fatty acids, principally oleic acid. Oils may be hardened by hydrogenating the oleic acid, and converting it to stearic acid.

$$\underset{\text{oleic acid}}{CH_3(CH_2)_7CH{=}CH(CH_2)_7CO_2H} \xrightarrow[\text{nickel catalyst}]{H_2} \underset{\text{stearic acid}}{CH_3(CH_2)_{16}CO_2H}$$

The nickel catalyst, which is usually in a finely divided state and freshly reduced, is added to the oil at about 180 °C. The oil is stirred and the hydrogen bubbled through. After hydrogenation the oil is separated from the catalyst by filtration. In addition to hardening the oil, hydrogenation increases its stability.

Essential fatty acids are unsaturated. The proportion of unsaturated to saturated fatty acids in the diet is also important nutritionally.

Common name	**Chemical name**	**Formula**	**Type**
Myristic	tetradecanoic	$CH_3(CH_2)_{12}CO_2H$	saturated
Palmitic	hexadecanoic	$CH_3(CH_2)_{14}CO_2H$	saturated
Stearic	octadecanoic	$CH_3(CH_2)_{16}CO_2H$	saturated
Oleic	octadec-9-enoic	$CH_3(CH_2)_7CH{=}CH(CH_2)_7CO_2H$	unsaturated
Linoleic	octadec-9,12-dienoic	$CH_3(CH_2)_4CH{=}CHCH_2CH{=}CH(CH_2)_7CO_2H$	unsaturated

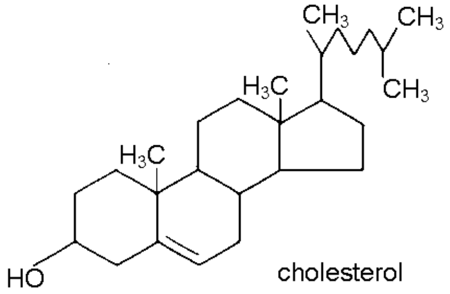
Figure 2.4 Names and formulae of some fatty acids.

The degree of unsaturation is measured by the **iodine value** of the oil. When iodine is added to a triglyceride, formed from an unsaturated fatty acid, it reacts with the double bonds in the molecule. The degree of unsaturation may be calculated from the amount of iodine absorbed:

$$CH_3(CH_2)_7CH{=}CH(CH_2)_7CO_2H + I_2 \longrightarrow \underset{\text{oleic acid}}{CH_3(CH_2)_7\ CHI{-}CHI(CH_2)_7CO_2H}$$

One molecule of iodine is used to saturate each double bond. The result is expressed as the iodine value, which is the number of grams of iodine required to saturate 100 g of oil or fat. In practice, the measurement is carried out using Wij's solution. This consists of iodine monochloride dissolved in an inert solvent. Iodine monochloride reacts more readily than iodine.

COMMENT: Cholesterol



This widely-misunderstood compound is a member of the steroid family. It has the molecular formula $C_{27}H_{46}O$ and the structural formula shown on the right.

In its pure state, cholesterol is a waxy but crystalline substance with no odour or taste. Cholesterol is an essential component of the membrane which surrounds each cell. It is also the starting material from which the human body synthesises such things as bile acids, some hormones, and vitamin D. Some cholesterol is made by the liver and some is taken in with food.

There appears to be a regulatory mechanism, by which increased dietary intake of cholesterol results in a lowering of its synthesis by the liver.

Cholesterol is insoluble in water. You would expect this from its structural formula. It cannot be transported in the bloodstream as it is. It is made soluble by forming an association with lipoproteins which, for this purpose, come in two kinds: low density lipoprotein (LDL) and high density lipoprotein (HDL). LDL transports cholesterol from the liver to the various synthesis sites in the body. Excessive LDL cholesterol results in a condition called atherosclerosis where fatty material is deposited in the blood vessels. These deposits harden and constrict blood flow, resulting in increased risk of heart attacks and strokes.

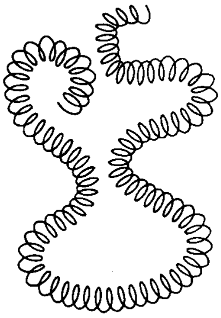
HDL cholesterol is thought to transport excess cholesterol back to the liver, where it is converted to bile acids and excreted.

Total cholesterol levels may be monitored by blood tests. The results of these tests are usually given in units of millimoles per cubic decimetre. A concentration of cholesterol of about 5 mmol dm^{-3} is considered normal and acceptable. The test measures total cholesterol concentration; those with a high concentration would be tested for the LDL cholesterol contribution, this being the harmful variety.

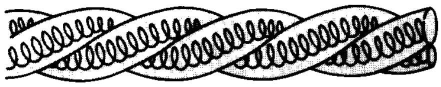
There is some evidence that unsaturated fatty acids may lower LDL cholesterol concentration.

2.2 Proteins

The nature of amino acids and proteins are described in Topic 18 in the Nuffield Chemistry Students' book. The amino acid sequence is the primary structure of a protein. The protein chain is often coiled into a spring-like shape known as the α-helix. This is an example of the secondary structure of a protein which is held in this form by extensive hydrogen bonding (see Topic 9). The folding or coiling of the α-helix gives rise to the tertiary structure. The tertiary structure is maintained by hydrogen bonding, and also by ionic bonding between $-NH_3^+$ and $-CO_2^-$ groups.



a **globular proteins**



b **fibrous proteins**

Figure 2.5 Two different types of tertiary structure in proteins.

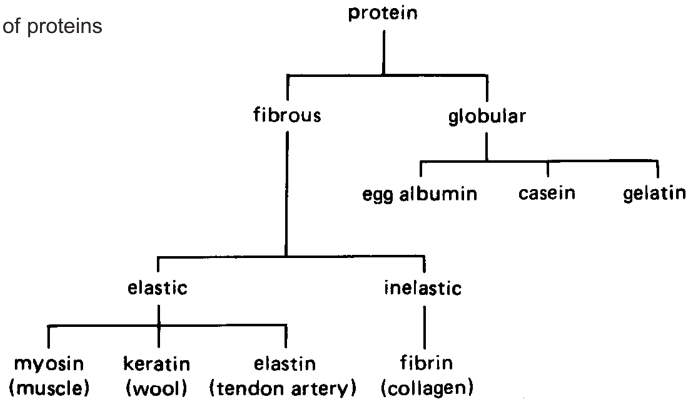
Protein structure

Structurally, proteins may be classified into two groups – fibrous and globular. Fibrous proteins may be further sub-divided into elastic and inelastic.

In inelastic proteins, the polypeptide chains are held together by cross-links. They are in the form of extended helical strands, and are not readily further extended. In elastic proteins, the polypeptide is in the form of an unextended coil, the loops being held in place by hydrogen bonds.

Globular proteins are more complicated than fibrous proteins. In globular proteins the α-helix chain is folded and twisted to form a ball-like structure.

Figure 2.6
Classification of proteins



Protein properties

The properties of fibrous proteins are very different from those of globular proteins. Fibrous proteins are insoluble in water, resistant to dilute acids and dilute alkalis, and unaffected by moderate temperatures. Globular proteins, on the other hand, are relatively soluble. Also, they are affected by extremes of pH and by high temperatures; these disrupt the hydrogen bonding which maintains their tertiary structure.

Protein functions

Proteins fulfil many important functions.

Structural functions

Proteins form part of the structure of the body. An example is the collagen in bone and cartilage. In eggs the albumen acts as a food store. In blood, haemoglobin acts as an oxygen carrier. Another important function of proteins is that they act as enzymes, the catalysts in cell reactions.

Proteins as buffers

Proteins can be very effective buffers – they can combine with both acids and alkalis, and prevent the pH from changing. The buffering action is important, particularly when a protein is acting as an enzyme, when the pH must be maintained within a narrow range.

Enzyme proteins

The complex activities needed to sustain life in the human body take place within the cells. Biochemical processes involve many steps, each controlled by a specific enzyme. The specific action of enzymes is due to their tertiary structure. This is maintained by hydrogen bonds and dipole–dipole interactions.

Consequently enzymes are very sensitive to changes in temperature and pH. All enzyme action is destroyed on boiling.

In general, plant enzymes work best at 5 °C. Enzymes in warm-blooded animals are most effective at about 37 °C. An increase in temperature usually increases the rate of a chemical reaction, but in the case of an enzyme-catalyzed reaction, it will eventually lead to inactivation of the enzyme.

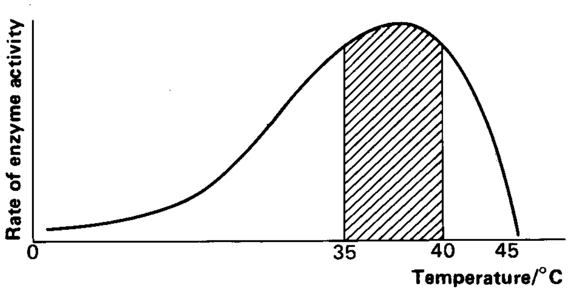


Figure 2.7
Temperature and enzyme activity. The shaded region shows the optimum temperature range for animal enzyme activity.

Enzyme activity is also dependent on the pH of the medium in which it acts. Most enzymes operate in environments of pH 7. Some, like pepsin, can only function in acidic conditions.

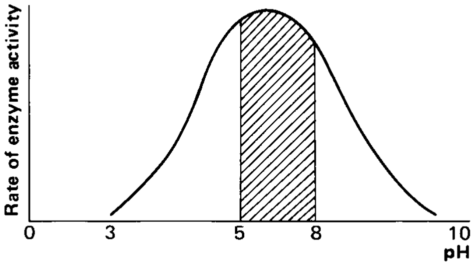


Figure 2.8
pH and enzyme activity.
The shaded region shows the optimum pH range for enzyme activity.

Digestion of proteins

Proteins, when digested, are hydrolyzed and break down into the various amino acids. A maximum of 21 amino acids is released on hydrolysis. Of all the amino acids obtained from proteins, only eight are essential to adults. The other thirteen amino acids can be synthesized by the body fast enough to meet its needs and are not required in the diet. A diet containing the eight essential amino acids will provide enough suitable material to manufacture all the amino acids required.

Proteins in the diet

Animal protein is generally more valuable nutritionally than vegetable protein, because animal protein contains the full complement of essential amino acids.

Food	beef	white fish	cheese (cheddar)	milk	bread	apples	nuts	potatoes	yeast
Protein / %	26	22	26	3	8.5	0.3	15	2	43

Figure 2.9 Average protein content of various foods.

Vegetable protein, in general, tends to lack one or more of the essential amino acids. Cereal protein, for example, lacks lysine, which is an essential amino acid. Bean protein, although lacking in other essential amino acids, contains a high proportion of lysine and can be used to complement cereal proteins.

2.3 Carbohydrates

Plants are the main source of dietary carbohydrates. Carbohydrates are produced from carbon dioxide and water by photosynthesis.

$$6CO_2 + 6H_2O \longrightarrow C_6H_{12}O_6 + 6O_2$$

Light supplies the energy needed for photosynthesis. Plants are able to synthesise a large number of different carbohydrates, including glucose, sucrose, starch and cellulose. Sugars are low molar mass carbohydrates. They are crystalline solids and dissolve in water to give sweet solutions.

The simplest sugars are **monosaccharides**. An example of a monosaccharide is glucose, which is found in many fruits and vegetables.

Disaccharides are formed by the condensation of two monosaccharides to form a dimer (see figure 2.10).

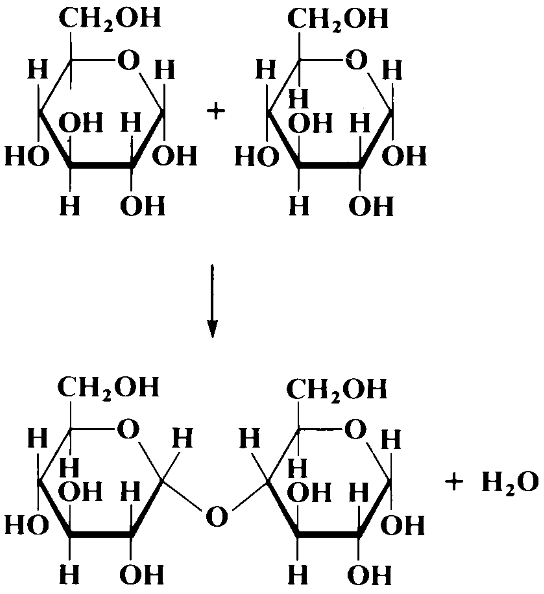


Figure 2.10 Condensation of two monosaccharides to form maltose

There are many disaccharides known, but those important to the food industry are maltose, lactose, and sucrose.

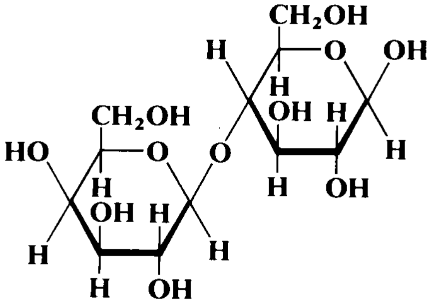


Figure 2.11 Lactose

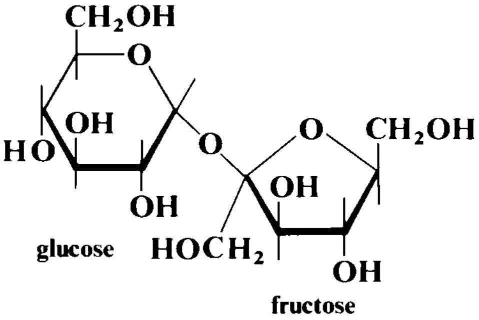


Figure 2.12 Sucrose

Polysaccharides are polymers formed by linking very large numbers of monosaccharide molecules. Glucose is the most important monomer of the naturally occurring polysaccharides.

Starch

Starch is the main food reserve of plants.
Under the microscope, we can see that it consists of irregularly shaped granules. The shape and size of the granules depend on the source and can be used to identify the origin of the starch.

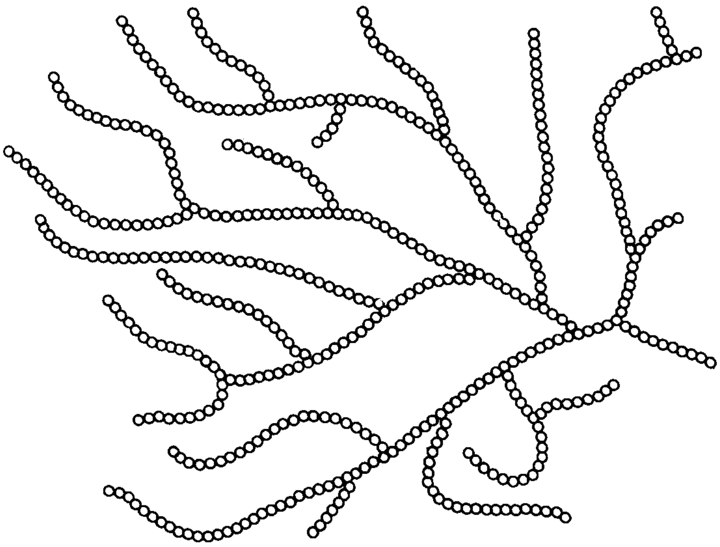


Figure 2.13 The general structure of amylopectin. Each circle represents a glucose residue.

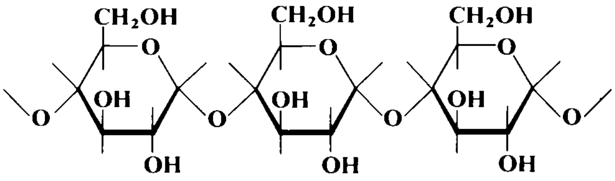


Figure 2.14 Amylose

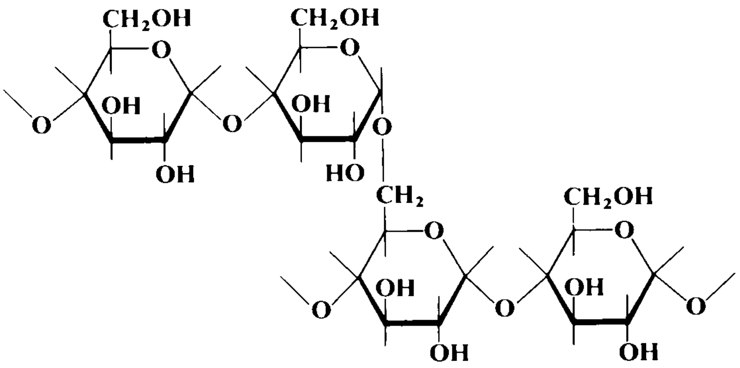


Figure 2.15 Amylopectin

Starch consists of two types of glucose polymer, amylose, which is linear, and amylopectin, which is branched (see figures 2.13, 2.14, and 2.15). Most starches are about 20–25% amylose, but there are exceptions. Pea starches are about 60% amylose. Some varieties of cereals have very little.

Cellulose

Cellulose is a structural carbohydrate and is widely distributed. It consists of about 10 000 glucose units. It cannot be digested by humans, and has no nutritional value for us. This is because humans do not have the enzymes necessary to break the links between the glucose units. Nevertheless it is valuable in the diet as roughage.

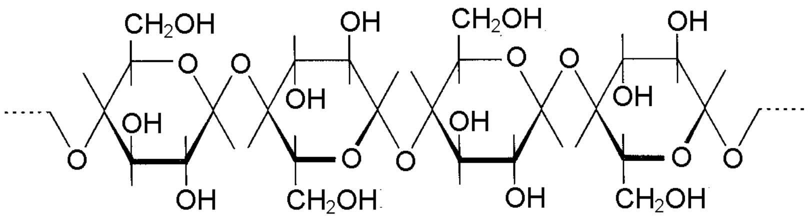


Figure 2.16 Cellulose

The structure of cellulose is in many ways quite similar to that of starch. But the differences are sufficient to make it impossible for the same enzymes to catalyse the hydrolysis of both starch and cellulose. Compare the starch (amylose) structure in figure 2.14 with the cellulose structure in figure 2.16 – see the previous page.

Carbohydrates in the diet

We obtain carbohydrates from plant foods such as cereals and root plants. In the developed countries, the consumption of carbohydrates from traditional sources has declined, while the consumption of sugar has greatly increased. In the UK over the last 100 years, sugar consumption has gone up from 2 kg to more than 50 kg per person per annum. The high level of sugar in our diet is considered to be undesirable by the medical profession. It contributes to obesity and dental decay.

Food	milk	meat	jam	potatoes	baked beans	bread	biscuits	orange	ice cream
Sugar /%	4.8	0	69	0.4	5.2	2	28	8.5	20
Starch /%	0	0	0	17.6	5.1	54	37	0	0

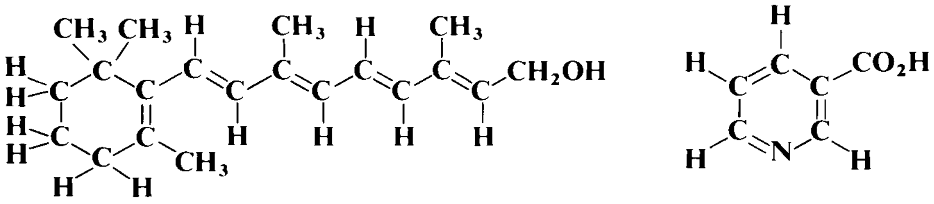
Figure 2.17 Average carbohydrate content of some foods.

2.4 Vitamins

Until about 90 years ago, it was thought that a diet containing proteins, carbohydrates, fats, minerals, and water was sufficient to maintain a healthy body. For example, Scott's expedition to the South Pole in 1910–1912 contrived diets which were carefully balanced for fat, carbohydrate, and protein. Unfortunately they were virtually vitamin-free. It was not the expedition's fault. Vitamins were not discovered until they were on their way back from the South Pole. They died of malnutrition, not from cold.

It was only after much research that scientists found that small quantities of certain vitamins were also necessary in a healthy diet. It was also found that, with a few exceptions, the body is unable to produce the vitamins it needs. Although most vitamins are quite complex molecules (see figure 2.18 below), most of them can be prepared synthetically. Before the chemical formulae and structures of vitamins were known, they were referred to, and identified, by using letters of the alphabet. See the table in figure 2.19 on the next page.

A lack or a shortage of any one of the necessary vitamins in the diet causes a deficiency disease.



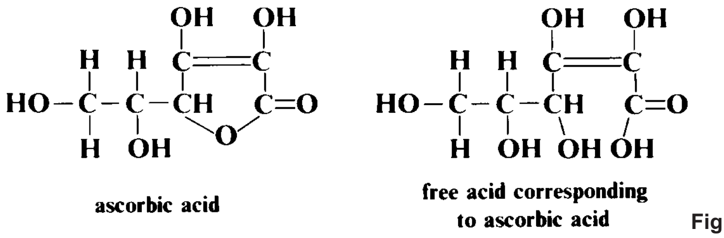
retinol (vitamin A)

nicotinic acid (vitamin B)

Figure 2.18
Vitamin A and Vitamin B.

Vitamin /mg	**Source**	**Function in the body**	**Recommended daily amount (RDA) /mg**
A **Retinol** **ß-carotene**	fish liver oils, butter, margarine, carrots	keeps eyes and skin moist and healthy lack of vitamin A can cause blindness	0.8
B_1 **Thiamin**	Whole grain, yeast nuts, some meats	growth, appetite, muscle function, liberation of energy, healthy nervous system; deficiency produces beri-beri	1.4
B_2 complex **Includes**: **riboflavin**	yeast, nuts, eggs, milk products, green leafy vegetables	B_2 functions similar to B_1; deficiency produces diseased eyes and cracks and sores at the corners of the mouth	1.6
B_3, niacin **nicotinic acid**	Nuts, meat, oily fish milk products	Maintains healthy skin and nervous system	18
B_5	Whole grains, nuts, vegetables, eggs	Aids the metabolic process by enabling the release of energy from foods	6
B_6	Whole grains, meat, nuts, oily fish, green leafy vegetables	Maintains health skin. Aids hormone balance	2
B_{12}	animal protein, eggs oily fish, milk products	regulates formation of healthy red blood cells	0.001
C **Ascorbic acid**	fruits, especially citrus; green leafy vegetables	Antioxidant, maintains healthy bones, skin, teeth, blood cells. Promotes resistance to infection. Deficiency results in scurvy, with symptoms including bleeding gums	60
D **Cholecalciferol** **Calciferol**	fish liver oils, egg yolk butter, margarine	necessary for healthy bones; deficiency produces rickets	0.005
E **Tocopherol**	wheatgerm oil, margarine, butter, eggs, nuts	healthy reproduction, muscle health	10
Folic acid	Breakfast cereal, sprouts, chick peas, liver	Helps maintain development of the neural tube during pregnancy (prevention of spina bifida)	0.2
K	cauliflower, yoghurt, tomatoes, potatoes, meat	helps resist blood clotting	1 mg per day max

Figure 2.19 The vitamins. RDA values are those for the EU. US values often differ from these.


ascorbic acid

free acid corresponding to ascorbic acid

Figure 20.20 Ascorbic acid

Ascorbic acid, although referred to as an acid, does not contain a free carboxylic acid group. The CO_2H group reacts with an –OH group in the molecule to eliminate a molecule of water and form a ring compound (see figure 2.20).

Ascorbic acid is readily oxidised and is therefore a good reducing agent. Ascorbic acid is more likely to be deficient in people's diet than some of the other vitamins. This is due to various properties of vitamin C. Vitamin C is present in significant amounts in a limited range of foods. It is relatively soluble in water and may be washed out of foods by cooking. It is thermally unstable and may be destroyed by cooking. It decomposes slowly when foods containing vitamin C are stored for any length of time. The amount of vitamin C in vegetables is at its greatest during the summer period of active growth.

COMMENT: Vitamin supplements

The British Nutrition Foundation is a charity funded by the British Government and by the Food Industry. According to the British Nutrition Foundation, most people are able to meet their requirements for vitamins by eating a varied diet. But there are certain groups of the population, including the sick, those taking certain drugs and pregnant women, with higher than average requirements.

The British Nutrition Foundation recommends that such people get their additional requirements by eating foods rich in particular vitamins.

Sometimes supplements are advised. Infants and young children are recommended to have supplements of vitamins A and D for at least 2 years.

A survey of adults' use of vitamin and mineral supplements in the UK undertaken in 2000/2001 found that 41% of women and 30% of men were taking dietary supplements, compared with 17% and 9% respectively in 1986/1987.

2.5 Minerals

The residue or ash left after food is heated at a high temperature for about an hour is called the mineral matter – sometimes called mineral salts or inorganic nutrients (see figure 2.21 on the next page). Although a large number of inorganic elements are found in the body, only about a dozen are known to be essential and must be included in the diet.

Inorganic nutrients have three main functions in the body.

i They form part of the body structure. Calcium, magnesium and phosphorus are mainly used to form the bones and teeth.

ii They form part of the fluids in the tissues, and assist in the control of pH and osmotic functions. The pH is controlled within narrow limits by the buffering actions of the ions present. For example, blood is buffered at pH 7.4 by the hydrogencarbonate ions and carbonates present.

iii They are an essential component of a large number of enzymes which are necessary for the release and utilisation of energy. Iron in haemoglobin is one example.

Element	Source	Function	Recommended daily amount (RDA) /g
Sodium and chlorine as sodium chloride	added salt, bread, bacon	regulates fluid balance and body temperature	4
Potassium	fruit, vegetables	regulates fluid balance	3.5
Calcium	milk products	maintains healthy bones, teeth, blood, muscle	0.8
Phosphorus	milk products	maintains healthy bones, teeth, blood, muscles, metabolism	8
Iron	Liver, eggs, spinach	Constituent of red blood cells. Lack of iron causes anaemia	0.014
Iodine	Water supply, seafood	Used in the production of several thyroid gland hormones. Lack of iodine results in goitre	0.0015
Fluorine	Tea, seafood, water supply	Teeth, bones	0.018
Selenium	Fish, meat, tomatoes, mushrooms, garlic	Helps to maintain healthy immune system. Antioxidant	0.2 mg maximum
Magnesium	Pasta, soya beans wholemeal bread seafood	Healthy bone development	0.3
Zinc	Meat, seafood, milk products	Supports healthy skin and immune system	0.015 g maximum

Figure 2.21 Mineral/inorganic elements in the diet (EU values; US values differ from these)

COMMENT Salt in the diet

The addition of salt, sodium chloride, to food has been common culinary practice for hundreds, if not thousands, of years. For at least the last hundred years doctors have recognised that there is a relationship between dietary salt and high blood pressure leading to increased risk of cardiovascular disease.

Despite the publication of over 20 000 studies on the subject, agreement about the source of the connection between salt and disease is lacking. The resulting controversy leads to confusion as conflicting advice to the public is given and received. This is a good example of the problems facing those who wish to promote or adopt ‘healthy eating’ habits.

There seems little doubt that salt enhances the flavour of many foods. Salt is the source of the hydrochloric acid which assists hydrolysis reactions in the stomach. Salt is a necessary stimulant to the action of the enzyme α-amylase in the saliva. There is an excretion mechanism for salt in perspiration.

Medical opinion, on the other hand, insists that it does not matter that we do not fully understand why salt increases the risk of high blood pressure; it is enough that it does so and therefore no more than a small daily consumption of salt should be allowed.

2.6 Water

Water is essential to all living things. Approximately 60% of the total mass of the human body consists of water. Water is continuously lost from the body as urine, as sweat and as water vapour in respiration. If the body is to function, the lost water must be replaced. One of the functions of food is to replace and to supply the water that the body needs.

The main functions of water in the body are to transport nutrients and to take part in chemical changes in the tissues and during digestion (such as the hydrolysis of proteins to amino acids, and polysaccharides to monosaccharides). Water is also important as an essential part of the structure of plant and animal tissues in maintaining tissue rigidity.

Food	milk	cheese (cheddar)	eggs	fish	beef	potatoes	apples	bread
Water content /%	87	37	75	82	64	80	84	39

Figure 2.22 Average water content of some foods.

CHAPTER 3 THE QUALITY OF FOOD

3.1 Eating qualities

If you were provided with bottles containing a range of isolated nutrients such as fats, essential amino acids, glucose, vitamins, necessary minerals, and water, you could make up a mixture which would enable you to live. But the mixture would not be very palatable, and you would soon get bored and lose your appetite. Food in the rich, developed countries is not necessarily eaten for its nutritional value, but for its eating qualities. People eat not just because they need the nutrients, but because they enjoy eating.

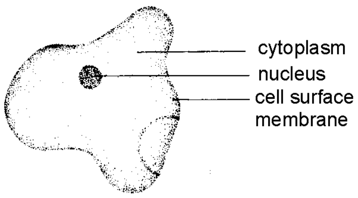
Food, in addition to providing nutrients, must be acceptable – have a pleasing texture, flavour, and colour. Wood, straw, and grass, which consist of lignin and cellulose, are carbohydrates. People would not eat them, not just because they are indigestible, but because they do not like the taste or texture. Some materials (such as chewing-gum) are just as indigestible and are chewed for hours on end, not for their nutritional value but for their taste and texture. Food, or materials which people are prepared to eat and find attractive as food, must have desirable eating qualities.

The eating qualities of food can be divided into two broad groups:

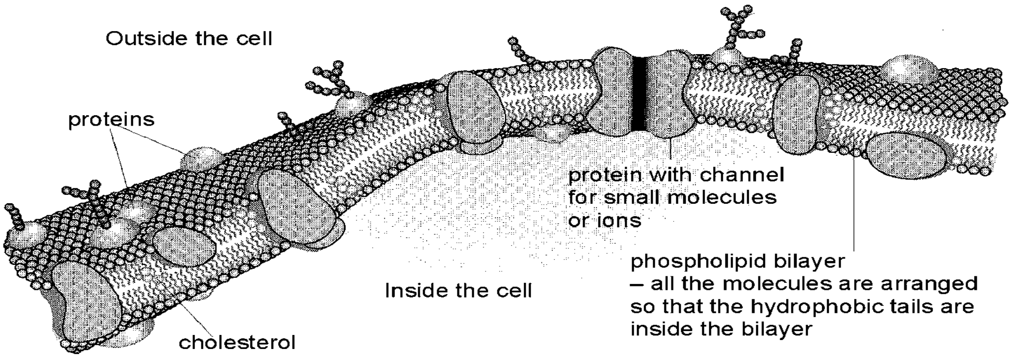
i Structural character	**ii Chemical character**
water-holding capacity	taste
texture	odour
tenderness	colour
juiciness	

Plant and animal tissues are composed of discrete units, or cells, and each cell is bounded by a cell membrane.

The **membrane** is a layered structure made up largely of lipids and proteins.



a cell (one of many types) as seen at low magnification



Cell wall at high magnification

Figure 3.1
Cell at low magnification (above).
Cell wall at higher magnification (right).
The cell membrane is not simply a phospholipid bilayer. It also contains proteins.
Right-hand diagram from Salters-Nuffield Advanced Biology "AS Student book" Heinemann 2005.

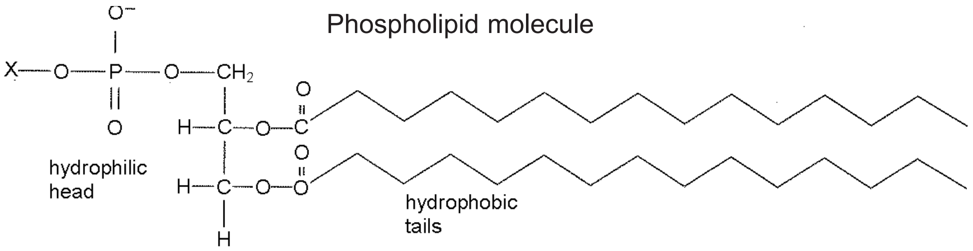


Figure 3.2
A phospholipid. Note the similarity to the structure of fats (see page 7)

Each lipid molecule is connected to a phosphate group to form a phospholipid. Each phospholipid molecule has a hydrophilic head and a hydrophobic tail. In a cell membrane the long, hydrophobic hydrocarbon tails of the lipids in one layer intermingle in an orderly way with the hydrocarbon tails of another layer, forming a double layer with the hydrocarbon portions of the lipids at the centre.

This arrangement creates a membrane that is selectively permeable to ions and molecules. Small molecules, such as water molecules, and some ions can diffuse through the membrane. Large molecules, such as protein molecules, cannot.

3.2 Water-holding capacity

Since water is the major component of living cells, it is also the principal constituent of foods. A substantial part of the texture, tenderness, and juiciness of foods is determined by the various ways in which water is arranged in relation to insoluble materials.

A small proportion of the total water is chemically bound to the polar groups of proteins and polysaccharides. This is achieved by hydrogen bonding between water molecules and the >N–H and >C=O groups in proteins, and the –O–H groups in the polysaccharides.

Some molecules of water are held by the hydration of free ions, or of ions such as Mg^{2+} and Ca^{2+}, which occur in some protein structures.

A much larger proportion of water is non-combined, or ‘free’, with properties the same as those of liquid water outside the living organism.

Since water does not pour out of plants or meats, it is clear that this non-combined water must be held immobile in some way. It is believed that the long chains of the proteins link with one another by means of hydrogen bonds and ionic bonds to form a meshwork which traps the water. Long chain polysaccharides also link up by means of hydrogen bonds to form an entrapping meshwork. Meshwork structures such as these, which have trapped large quantities of water, are known as gels.

Any factors which can alter the bonding forces holding the protein or polysaccharide chains together affect the extent to which water can be held by the system. One factor is pH, which affects the electrostatic charges on the protein molecules. Another is heating, which ruptures hydrogen bonds. In these ways the meshwork may break down.

Acids, alkalis, and high temperatures, may affect not only the meshwork structure but also the tertiary and secondary structures of the individual protein molecules. Such denaturation will usually lead to coagulation, solidification, and loss of water-holding capacity.

Strawberries and their water content

A fresh strawberry has a high total water content. However it is firm enough to offer immediate resistance to our teeth. This firm 'feel' and the sensation of the juice being released from the cells as the berry is bitten add greatly to the enjoyment of eating fresh strawberries.

A frozen strawberry is quite different. The cell structure has been disrupted by freezing and thawing, and much more water is in the intercellular regions. This drips out of the thawed berry and the berry has a soggy texture. It offers no resistance to the teeth until it has completely collapsed; the sensation in the mouth is quite different from a fresh strawberry, and you may be one of the people who dislike it.

3.3 Texture in foods of plant origin

Plant cells are surrounded by a semi-permeable membrane essentially as described in section 3.1. In addition, they are also surrounded by a freely permeable, rigid cell wall as shown in figure 3.2 at the bottom of the page.

Firmness of plant tissue is largely due to a combination of
- the force exerted by the water within the cell pressing on the wall, rather like air in a balloon
- the strength of the cell wall, and
- the efficiency with which adjacent cells are 'cemented' together.

The pressure of water inside a cell is the result of osmosis. Water can diffuse through cell membranes. It tends to diffuse into cells because of the high solute concentration in the sap of plant cells. This is osmosis.

Most fruit and vegetables contain high levels of water. For instance a tomato is often more than 95% water. This means that, in fresh produce, turgor pressure is high and the tissue firm and crisp. However, if water is lost during storage, the produce goes limp (as in lettuce) or spongy (as in apple). Indeed an apple need only lose about 6% of its water to become unacceptable. Many fruits become softer as they ripen; this is caused mainly by the degradation of their cell walls.

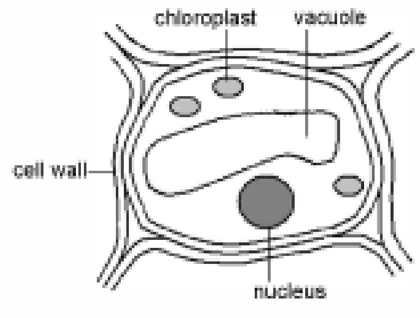


Figure 3.2
Simplified diagram of a plant cell and its main components.

See figure 3.3 for a diagram of part of the cell wall – to a much larger scale.

Structure of the plant cell wall

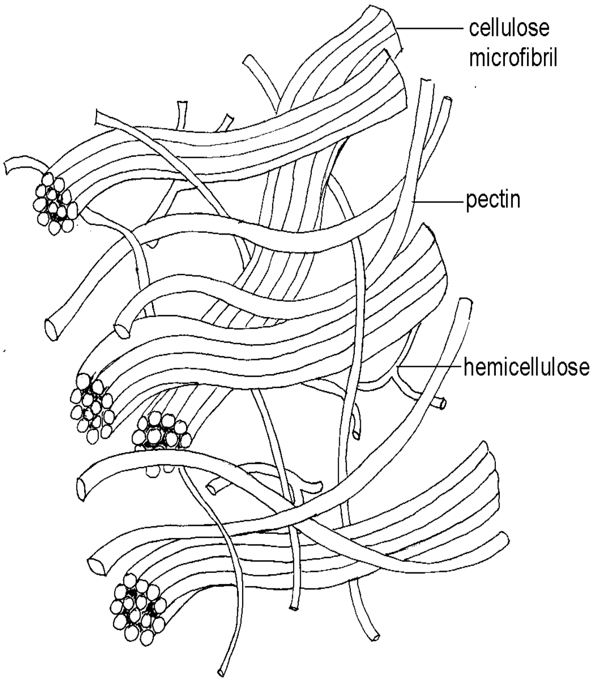


Figure 3.3
Hugely magnified close-up of part of the cell wall shown in figure 3.2 on the previous page.

Overlapping cellulose microfibrils form a mesh within a pectin and hemicellulose matrix in the cell wall.

The plant cell wall is a complex structure comprising 90% carbohydrate and 10% protein. A simplified diagram of the structure of a cell wall is shown in figure 3.3.

The cell wall consists of bundles of cellulose **microfibrils** which are laid down in layers and held together with a kind of glue. The glue consists of chains of sugar molecules called **hemicelluloses**. Hemicelluloses are mainly short polysaccharides with many fewer sugar units in the chain than cellulose itself. They are very hydrophilic and become hydrated to form a gel-like matrix.

The arrangement of cellulose in a matrix of hemicelluloses makes the cell wall very strong – like steel-reinforced rubber tyres. In this analogy, the hemicellulose matrix is the rubber and the cellulose microfibrils are the reinforcing steel cables.

Pectins

There are also pectins in the cell wall. **Pectin** consists mainly of long chains of galacturonic acid, interrupted occasionally by single residues of rhamnose. These polysaccharides contain many negatively charged groups: $–COO_2^-$. The negative groups associate with calcium ions to form calcium pectates. The calcium pectates are important components of the region between the walls of neighbouring cells. The region is called the middle lamella. The calcium pectates cement the cells together.

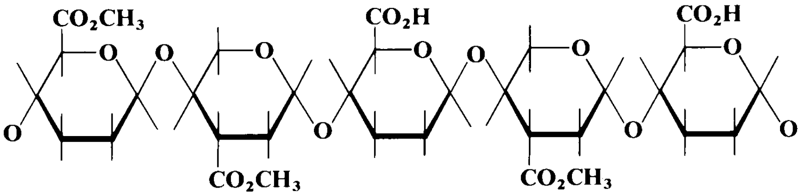


Figure 3.4 Part of a pectin molecule

The wall immediately adjacent to the cell membrane is relatively rich in cellulose. The intracellular 'cement' in the middle lamella is rich in pectin. During fruit ripening, it is the pectin in the middle lamella region which appears to be most heavily degraded. This results in the loosening of cell-to-cell adhesion and hence softening of the tissue.

The galacturonic acid residues can be either in the form of the free acid or the methyl ester.

It is the size of these pectin molecules, along with the amount of methyl esters, that determine their gel-forming properties. Demethylated polymers can form complex ions with calcium ions and hence form strong gels. The strength of these gels is also increased when the polymers involved are large.

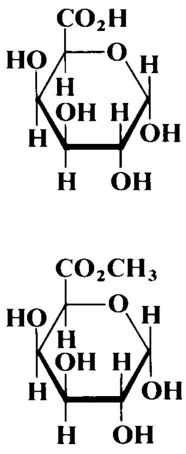


Figure 3.5 Galacturonic acid and its methyl ester

Pectin gels

Pectin is important in fresh fruit and vegetables. It is also responsible for the gelling of many processed products such as jam, and for the viscosity of others such as tomato ketchup. Changes in pectin are also important in contributing to the change in texture when fruit and vegetables are cooked. When vegetables are cooked in water, the pectin becomes more soluble and may be extracted. In some cases this is desirable, but over-cooking often results in mushy vegetables. This can be overcome to some extent by adding calcium compounds.

The degradation of pectin during ripening and processing of fruit is caused by enzymes. One of these is polygalacturonase. The enzyme catalyses the hydrolysis of pectin into shorter chains. This enzyme is often deliberately destroyed by heating during the production of jams and ketchup, as this gives a better product.

3.4 Texture in foods of animal origin

Animal cells do not possess a cell wall. They form tissues which are supported by connective tissues, cartilage and bone.

Skeletal muscle is the animal tissue most commonly eaten, at least in the western world. Skeletal muscle is comprised of many fibres, mostly made of protein, and usually running parallel to the long axis of the muscle as in a rope or skein of wool. It is largely this fibrous structure which imparts desirable texture to meat.

Much attention has been paid by meat scientists to the organisation of muscle and its component structural proteins. This is because the texture of cooked meat is what most consumers identify as the key to its quality.

Connective tissue

Connective tissue is found outside the muscle fibres. The proteins in connective tissue are mainly **collagen** and **elastin**. Collagen and elastin together generate the rubbery texture of connective tissue and cartilage, and contribute to meat texture. They are difficult to digest, except after cooking when they become converted to gelatin which is more soluble.

Many food products rely on the capacity of gelatin to form gels with desirable textures. Collagen tends to be more cross-linked in older animals, when meat is generally tougher.

Skeletal muscle

Despite this association between collagen and toughness, it is largely the properties of the hundreds of fibres comprising skeletal muscle which dictate meat texture. The major components of the fibre are the **myofibrils**

Under the microscope, the individual myofibrils are seen to have alternating light and dark bands. The bands of neighbouring myofibrils are exactly aligned, so that stripes or striations are observed across the whole width of the fibre. The repeating units of dark and light bands are organised in units called **sarcomeres**.

The banding pattern results from the precise arrangement of a number of key structural proteins. The dark band is largely composed of 'thick filaments' built out of polymers of the protein **myosin**. The light band is predominantly occupied by 'thin filaments' of polymerised **actin** which are anchored in the Z line.

When a muscle contracts, the sarcomeres shorten because the myosin filaments slide between the filaments of actin.

The contrast between the extended and contracted myofibrils is shown in figure 3.7 below.

In the other direction, it is not possible to stretch the sarcomeres beyond a certain point, since the myosin filaments are also attached to the Z line by an ultra-thin elastic thread built out of the giant protein **titin** – probably the largest protein found in nature.

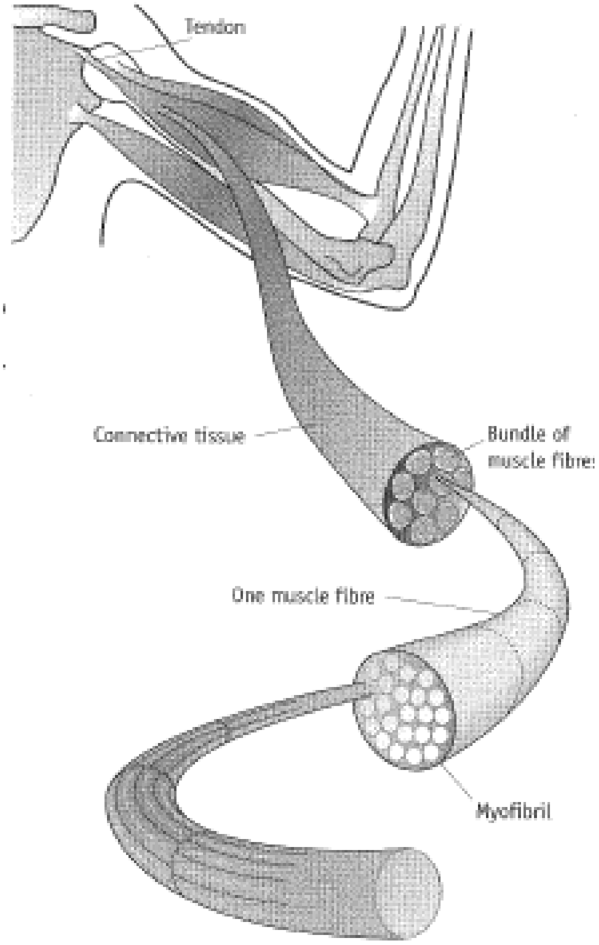


Figure 3.6 The relationship between muscles, muscle fibres, myofibrils, and a single fibre
From Salters-Nuffield Advanced Biology "A2 student book". Heinemann, 2006.

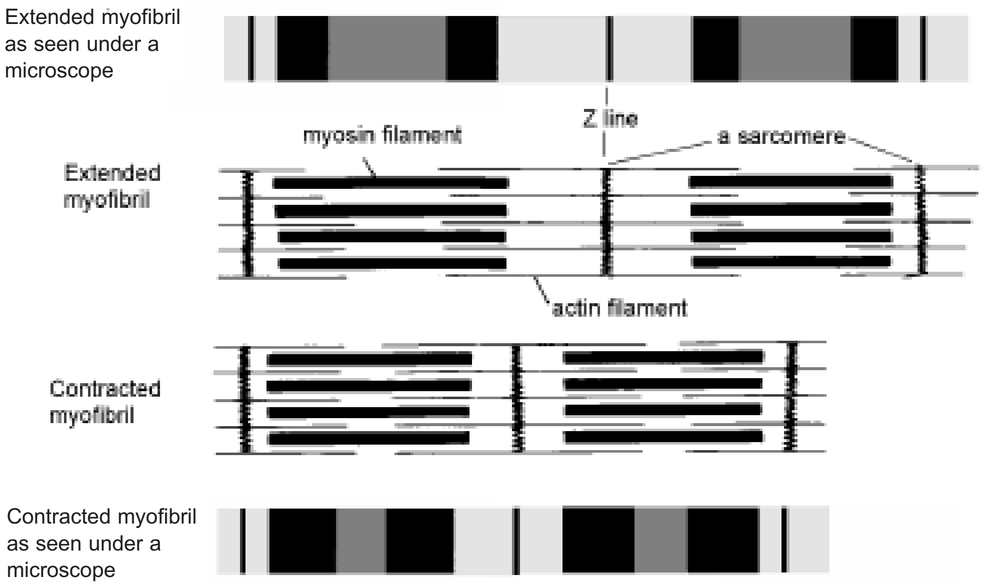


Figure 3.7
The arrangement of protein filaments during extension and contraction of muscle.

Above and below are the bands you would see down a good light microscope:
- the Z line
- dark bands where the myosin overlaps with the actin
- grey bands of myosin only
- light bands of actin only

Changes after death

After death of an animal, the sarcomeres naturally shorten. Actin and myosin become 'welded' together, leading to the phenomenon of **rigor mortis**.

The rate and extent at which this contraction occurs is influenced by many factors, including the amount of chemical energy stored in the muscle, the way the animal was handled, and circulating hormones resulting from stress.

If muscle were to be cooked or frozen for storage during this rigid phase, water-holding capacity (see section 3.2) would be lost and the texture of the meat would be unacceptably tough. A period of recovery from rigor mortis is usually allowed. This is **ageing**, and can take several days. As meat ages, subtle biochemical changes occur in unknown proteins in or close to the Z line, but surprisingly not involving actin and myosin themselves. It seems likely that one of the muscle's own intracellular proteolytic enzymes, **calpain**, is involved in this process of **tenderisation**. This process cleaves the Z line from the actin and myosin. The sarcomeres stretch, and the thick and thin filaments can loosen.

Faced with tough meat, tenderising proteolytic enzymes can sometimes be added before cooking to improve the texture. **Papain**, which occurs naturally in tropical fruits such as pineapple, is one example of an enzyme which can be used to mimic the muscle's own natural tenderizing agents.

Consumer preference

Consumer surveys seem to show that tenderness of meat is among its most desirable properties, although colour and flavour are also important.

The texture and especially flavour of meat are also greatly influenced by the fat content of the muscle. Consumers are demanding ever leaner meat products, and excessive superficial fat is unnecessary. But it is preferable that there is a small amount of 'marbling' fat, which is usually invisible between the individual fibres. This ensures that the meat is cooked properly and releases desirable flavours.

In animals, muscle is an important store of valuable nutrients, especially proteins and amino acids, as well as being used for movement. It is not surprising that meat is among the most concentrated sources of nutrients in the human diet.

3.5 Flavour and colour

Flavour (taste), smell. and appearance are all important aesthetic qualities of food. Our appreciation of the eating quality of food is heavily dependent on these key attributes.

There are **four primary tastes** – bitter, salt, sour (acid) and sweet. These are detected by different areas of the tongue but the ability to do this tends to vary between individuals. The odour of a food is also an important element in our perception of its flavour. Several chemical compounds, both natural and artificial, contribute to the flavour of food.

Sweetness

Sugars such as fructose and sucrose occur naturally in many fruit, and are responsible for their sweetness. Sweetness is a particularly important taste, and sweeteners are added to a wide range of food and beverages. Such sweeteners include sugars like sucrose, and also a range of chemically unrelated natural or artificial compounds. Saccharin, aspartame and cyclamate are about 300, 180 and 30 times sweeter, respectively, than sucrose.

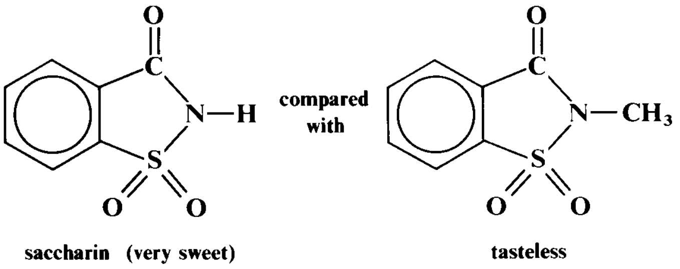


Figure 3.8 Sweetness and structure

Acidity

Many fruit, such as lemons and oranges, contain high levels of acids like malic and citric acid.

Bitterness

Bitterness is a property of a variety of unrelated compounds such as quinine, caffeine and calcium ions, Ca^{2+}.

Enhancing flavour

Other substances are often added to food to enhance flavour. One such compound, monosodium glutamate, is extensively added to canned and dried food. It is considered to have all four of the primary taste sensations.

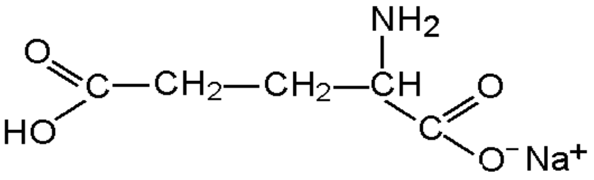


Figure 3.9 Formula of monosodium glutamate

Odour

The odour of a food is due to volatile compounds. These are detected by receptors in areas at the top of the two nasal cavities. The human nose is extraordinarily sensitive, and can detect certain substances at concentrations as low as 1 part in 50 000 million.

Why particular compounds have characteristic odours is unknown, but is probably related to size, shape and charge distribution on the molecules. The odour of most food seems to arise from the complex interaction of many ‘flavour volatiles’. For instance a fresh orange produces over 150 such compounds. However, it is possible to produce artificial flavours which closely mimic natural flavours. Examples are pentyl ethanoate (artificial banana flavour) and ethyl hexanoate (artificial pineapple flavour).

Colour

The main pigments responsible for the colours of fruit, vegetables and meat are:

- porphyrins
- carotenoids and
- anthocyanins.

Porphyrins are complex ring-shaped molecules with a metal atom in the centre, for example, magnesium in chlorophyll and iron in haemoglobin. Chlorophyll is the green pigment responsible for the colour of vegetables (see figure 3.10) whilst haemoglobin is a red pigment important for meat colour (see figure 3.11).

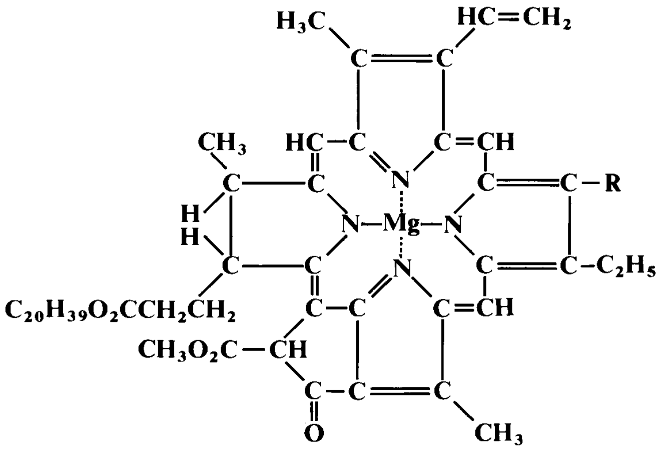


Figure 3.10 The structure of chlorophyll

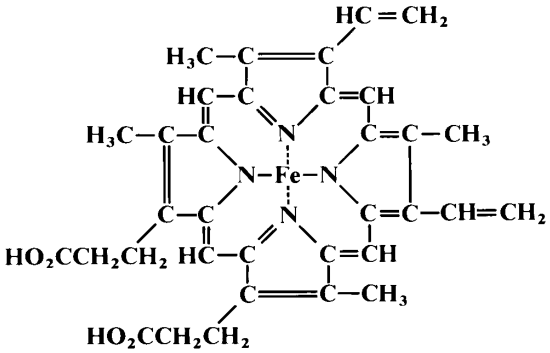


Figure 3.11 The structure of haem

Carotenoids are fat-soluble, long-chain hydrocarbon molecules which range in colour from yellow to red. Anthocyanins are responsible for a range of colours including yellow, red and blue. Carotenoids and anthocyanins are widely distributed in vegetables and fruit.

In addition to providing colour in fresh food, carotenoid pigments are also important in processed foods. However, processing and, in particular, cooking can effect the pigments. Many of the pigments are thermally unstable and can also be effected by extremes of pH. As green vegetables are cooked, the brightness of the green colour fades, changing to olive green, then yellow green and finally becoming brownish. This colour change is due to the thermal instability of chlorophyll, and loss of the magnesium atom and/or the phytol, $C_{20}H_{39}OH$, group.

To preserve the green colour of vegetables, sodium hydrogencarbonate is sometimes added to the cooking water, with a disastrous effect on the vitamin C content.

Discolouration of fruit and vegetables can also occur following cutting, a process called enzymic browning. A sliced banana will rapidly turn brown. This is due to the action of the enzyme polyphenoloxidase. This enzyme reacts with phenols released in damaged cells to give brown products.

3.6 Genetic Modification

A potentially important contribution to improving the quality of foods is the application of genetic engineering, either directly to the source of the food by developing transgenic plants and animals, or indirectly by producing food ingredients and enzymes for food processing using genetically modified micro-organisms.

Genetic engineering involves changing the genetic information of a cell or organism so that the processes of cell division and growth are altered. Genetic engineering is used to transfer genetic information (DNA) across species barriers that cannot be crossed by conventional techniques. The objective is to

- add a gene to a cell to change the behaviour of the cell
- inactivate a gene in a cell to remove undesired behaviour
- modify a gene so that higher yields of products are obtained.

GM tomatoes

Long-lasting, genetically modified (GM) tomatoes came on to the market in 1994 and were the first genetically modified food available to the public. The tomato plants had been engineered to produce much less polygalacturonase. Because the GM tomatoes could remain fresh longer they were allowed to ripen in the sun before picking. The producers also had the advantage that all the tomatoes can be harvested simultaneously. The new variety softened more slowly and produced thicker tomato paste and tastier ketchup. Very strong public opposition to genetic modification meant that the new products were soon removed from supermarket shelves. GM tomatoes are no longer grown.

Genetic modification of micro-organisms

Genetic modification is being used commercially to produce food ingredients and enzymes for food processing. Products obtained from GM sources include ascorbic acid (vitamin C), aspartame (the sweetener) and caffeine-free coffee.

Genetic modification means that cheese-makers no longer have to rely on rennet from the stomachs of calves. Rennet contains enzymes that make the protein in milk coagulate to produce a curd that can be turned into cheese (see page 38). Modern cheeses-making relies more and more upon microbial sources of the most important enzyme, the protease chymosin. This is now produced by micro-organisms that have been genetically modified.

COMMENT
Genetic modification of plants and animals

Plants can be modified genetically so that they are resistant to herbicides, or contain more vitamins, or can grow on poor soils or in harsh conditions. At the moment (2005), public resistance to genetic modification is keeping foods from GM crops out of shops in Europe.

The UK Government authorised a series of GM crop trials which ran for four years ending in 2004. The crops had been modified to be resistant to herbicides. This allows a farmer to spray herbicide on a field to kill weeds without harming the crop. The aim of the trials was to explore the environmental impact of growing the crops.

After the trials the Government allowed manufacturers to apply to grow one GM variety of maize in the UK, but the manufacturers decided not to go ahead. This was partly because of public opposition and partly because the selected variety was already out of date.

Genetic modification of animals is mainly carried out for medical and biological research. Most of the experiments involve mice. Some work on ‘pharming’ is under way. This involves modifying the genetics of animals so that they produce pharmaceutical products in milk, urine or eggs. Other possibilities include ‘super fish’ that grow much faster than wild fish when farmed, and animals grown to provide organs for tissue transplants. So far as the food industry is concerned, GM animals are not significant at the moment (in 2005).

CHAPTER 4 MICROBIAL AND BIOCHEMICAL CHANGES IN FOOD

4.1 Types of change

So far we have been largely concerned with the 'statics' of food science: the ingredients of food, how these are assembled in natural products, and how they contribute to the perceived quality of food. The next three chapters introduce some aspects of 'dynamics', covering the range of food preservation, domestic cooking, and industrial processing.

This chapter concentrates on changes resulting from microbial and biochemical action. Chapters 5 and 6 introduce changes due to cooking and food processing.

We can summarise the various types of food changes as follows.

i Due to microbial activity

- Undesirable, and sometimes dangerous to health
- Beneficial

ii Due to biochemical reactions

- Undesirable
- Beneficial

iii Due to cooking or food processing

- Undesirable
- Beneficial

The chemical and biological reactions underlying changes in food are not just of theoretical interest. The aims of food preservation and processing are to prevent undesirable changes and bring about desirable ones. A knowledge of chemistry can suggest ways of controlling change.

Knowledge of the reactions in food is very important in food technology. There can be unexpected and undesirable changes if a different raw material or process is used for a new product. It is often easier to suggest a solution if the chemical reactions are understood. Otherwise it may need a trial-and-error approach.

Demand for food is constant throughout the year, but most agricultural production is seasonal. Food must be stored or preserved without noticeable deterioration in quality. Raw foods deteriorate in quality and nutritional value at varying rates after harvesting or slaughter. The storage life of raw foods may be defined as the length of time they will store in dry conditions at 10–15 °C without showing significant signs of deterioration in quality. Storage life depends on the type of food. Here are some examples.

Storage life of various foods

- Wheat grain – several years
- Potatoes – 6 to 9 months
- Raw meat – 2 days
- Strawberries – 1 to 2 days
- Green peas – 4 to 6 hours

Most of the spoilage in food results from the activities of **micro-organisms**. Some deterioration results from the action of enzymes naturally present in the food, and from chemical reaction between constituents in food and oxygen. Most changes brought about by micro-organisms make food less acceptable. However, some changes result in a product as desirable or even more desirable than the original food. An example is the microbial changes involved in producing cheese and yogurt from milk.

4.2 Microbial changes

Micro-organisms are found everywhere: in water, in air, in the soil, and on all plants and animals, including us. Unless a surface has been sterilized, it must be assumed to be covered in micro-organisms. There are between 1000 and 10000 bacteria on each square centimetre of the surface of our hands. Even higher populations are to be found in the mouth, throat, lungs, and intestines. Most of these bacteria are harmless to their host.

Animals and plants can normally cope adequately with their resident bacteria. Moreover, any bacteria which invade the tissues are dealt with by the natural defence mechanisms. After death, these defence mechanisms cease to function and, in time, bacteria invade the tissues of the plant or animal.

Types of micro-organisms

The main types of micro-organisms found in foods are

- moulds
- yeasts and
- bacteria.

Moulds

Moulds are the most common type of food-spoilage organisms. Moulds are microscopic fungi, and consist of filaments of cells joined together to form a network, which is visible as moulds on food. Moulds develop rapidly on foods stored in humid conditions, and are nearly always considered to be undesirable, although they contribute to the flavour of blue cheeses.

Yeasts

These are another group of fungi. Yeasts are oval-shaped and about 7000 nm long. Although they cause spoilage in some foods, they are generally of considerable importance to the food industry. Many yeasts can ferment sugars such as glucose, in the absence of oxygen, into ethanol and carbon dioxide. Fermentation is used to make alcoholic drinks. Bakers depend on the production of carbon dioxide in this way to leaven the dough in bread-making.

$$C_6H_{12}O_6 \longrightarrow 2C_2H_5OH + 2CO_2$$

Bacterial cells

Bacteria are smaller than yeasts, measuring about 2000 nm. The two common types of bacterial cells are **cocci**, which are spherical, and **bacilli**, which are rod-shaped.

Undesirable bacteria

Undesirable bacteria can be divided into two groups

- spoilage organisms and
- pathogens

Spoilage organisms make food unpalatable and reduce its nutritional value. They may bring about changes which lead to the food looking, smelling and tasting unpleasant. Nevertheless, these changes do not usually present a danger to health.

Typical examples are *Lactobacillus* and *Lactococcus* (lactic acid bacteria) which produce lactic acid and cause souring in foods.

Pathogens are disease-causing organisms. These can be divided into two groups according to their mode of action.

i Some pathogens (*Staphylococcus aureus* and *Clostridium botulinum*) form toxins while growing in the food. It is the toxin rather than the bacterial cells which leads to illness (**food poisoning**).

ii Other pathogens (*Salmonella*, *Campylobacter jejuni* and *Listeria monocytogenes*) give rise to illness by growing in the body. The first two infect the intestine where they invade the cells and cause fluid to accumulate leading to diarrhoea. *Listeria* invades via the intestine but its site of action depends on the host (see page 35).

Reproduction of micro-organisms

Micro-organisms reproduce by cell division. When a cell is fully mature, it divides into two daughter cells. These, on maturing, further divide, giving four cells, which further divide to form eight cells, and so on. As the number of mature cells increases, the rate of growth increases. Micro-organisms grow very rapidly. It takes them only about twenty minutes to reach maturity, at which point they can divide. They are counted by spreading samples on Petri dishes containing a solid nutrient medium, and the population is quoted per gram of food. Under favourable conditions it is only a matter of seven hours before the micro-organism population reaches 1×10^6 per gram of food.

When food is first contaminated, the organisms begin by adapting to the new environmental conditions and there is no growth – the population remains constant. This is called the **lag phase**.

This is followed by a period of very rapid growth, when the organism population, under favourable conditions, is doubling its population about every twenty minutes. This is called the **exponential phase**.

The rate of growth then begins to decline and the population may remain constant for several hours. During the so-called **stationary phase**, cells may still be dividing, but the rate of death approximately equals the rate of cell reproduction.

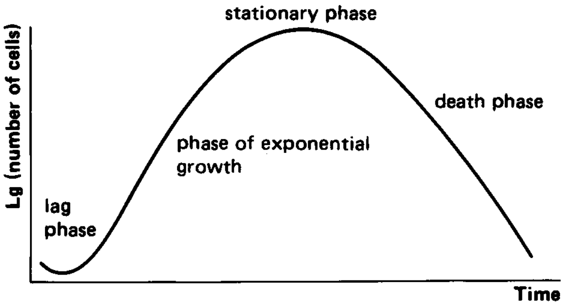


Figure 4.1 Generalised growth curve for a colony of bacteria. Note the logarithmic scale on the y-axis.

The stationary phase may be caused by nutrients being used up. The organisms may be inhibited by the production of toxins, or there may be change in the pH of the environment. In the souring of milk, for example, *Lactococcus lactis* grows very rapidly and soon reaches a population of 1 x 10^8 per gram of milk. However, the lactic acid produced inhibits further growth, but allows acid-tolerant *Lactobacillus* to grow. This then become the dominant organism. When nutrients have been exhausted, eventually the organisms die.

In practice, contaminated food would be considered unpalatable before the stationary phase was reached. In meat, when the population of the micro-organisms reaches 1 x 10^7 per gram, odours begin to evolve and, at about 1 x 10^8 per gram, slime begins to appear.

Temperature

Food-borne micro-organisms may be divided into three classes, according to the optimum temperature at which they grow.

Micro-organism	Optimum temperature range/ °C	Example
Thermophilic	55 - 65	Spore-forming *Bacillus* sp.
Mesophilic	20 - 40	*Salmonella* and *Staphylococcus*
Psychrophilic	10 - 15	Water-borne organisms, *Vibrio* sp

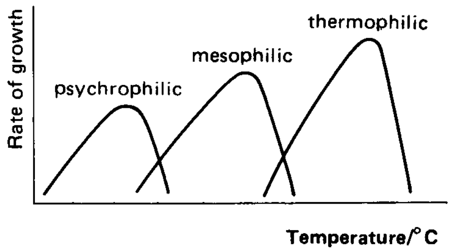


Figure 4.2 The three classes of micro-organisms, and their groiwth rates relative to temperature

Oxygen: presence or absence

Micro-organisms may also be classified by their need for oxygen. **Aerobic organisms** will grow only in the presence of oxygen. Moulds and many of the acid-forming organisms, such as *Lactobacillus*, are in this class. **Anaerobes** such as *Clostridium botulinum* will only grow in the absence or oxygen.

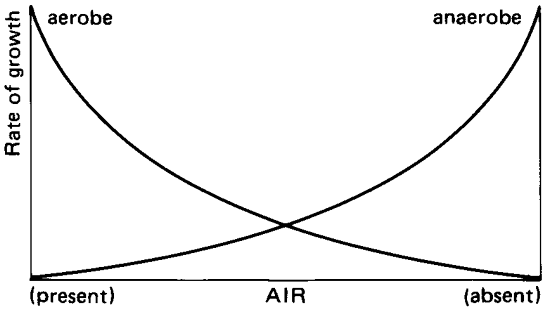


Figure 4.3 Effect of air on the rate of growth of different types of bacteria.

Humidity

The rate of growth of micro-organisms also depends on the humidity. Bacteria require a moisture content of 20 to 40% and a relative humidity of greater than 95%. Moulds and yeasts can grow at a lower moisture content and relative humidity.

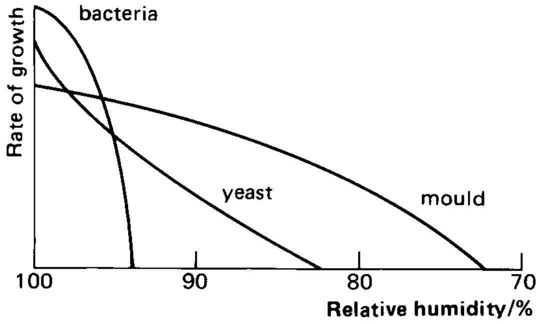


Figure 4.4 Effect of humidity on the rate of growth of different organisms

pH

Bacteria require suitable nutrients and minerals, and most prefer a neutral or slightly alkaline medium. Acid tolerance varies considerably among organisms, but most will grow at pH values ranging from 4.5 to 10.

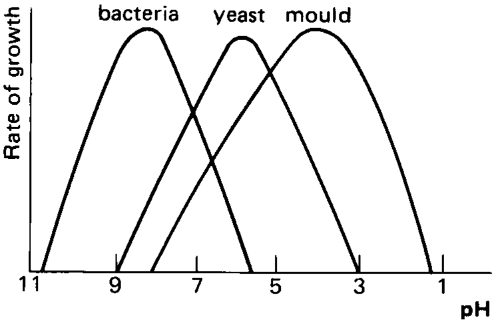


Figure 4.5 Effect of pH of the medium on the growth rate of different organisms

4.3 Micro-organisms and food poisoning

Food-borne disease refers to illness caused by the presence of either harmful bacteria in food or toxins produced by bacteria. Typical symptoms may include abdominal pain, diarrhoea and vomiting, but *Clostridium botulinum* and *Listeria monocytogenes* cause much more serious diseases which can be fatal.

Salmonella

There are around two thousand species of *Salmonella*, but it is *Salmonella enteritidis* which is a common cause of food poisoning in the UK. *Salmonella* are infectious and cause salmonellosis, a form of gastroenteritis.

To be a health risk, the organisms must be consumed live and in high numbers. They travel through the gastrointestinal system to the small intestine where they invade the cells, grow and release toxins. This results in fluid loss, causing diarrhoea. Live cells are shed in the faeces for some time after illness. Around 2.5% of people in the UK are carriers of the organism.

Foods usually causing the disease are meat, poultry and eggs. *Salmonella* grow rapidly if the infected food is kept warm, but growth almost stops after refrigeration below 4 °C. The organisms have a low resistance to heat, and may be destroyed by heating at 60 °C for 2 minutes.

Campylobacter jejuni

This organism is the commonest cause of food-borne illness in the UK. It produces disease in a similar way to *Salmonella*, but the effects are more acute with severe abdominal cramps and explosive diarrhoea. However, this is rarely fatal.

Illness can result from eating under-cooked chicken (barbecues are well known for this) and raw (unpasteurized) milk. The organism is carried by many animals, such as birds, dogs and cats, and is transferred to humans by contact with animal faeces.

Listeria monocytogenes

An unusual characteristic of this organism is that it affects only certain groups of people: very young children, the elderly, pregnant women, and people with certain diseases. Less vulnerable people are usually not affected by it.

The disease it causes, listeriosis, can result in a serious brain infection (meningitis), except in pregnant women where either it causes abortion of the baby or the baby can be born with the disease. The mortality rate is about 30% of infected individuals.

Foods which may carry the organism are soft cheeses containing moulds, like Brie and Stilton, some patés and raw meat, poultry and milk. Again this organism is heat-sensitive, being readily killed by heating at 70 °C for 2 minutes.

Staphylococcus aureus

This organism is carried on the skin and in the nose of most animals, including humans. It causes food poisoning by the production of a toxin in the food which, when eaten, induces vomiting and diarrhoea within a few hours. The bacteria are killed relatively easily by heat, but the toxin is heat-stable and so although heating the food thoroughly will kill the bacteria, the toxin will remain.

Food poisoning often results from cold food which has been handled and then left to stand in a warm room before it is eaten. Sometimes a spectacular number of people may be victims after a cold buffet at a banquet or wedding reception – and if the speeches go on too long the toxin is so fast-acting that people can start to be ill before the end of the dinner! In a classic case the origin of the food poisoning was identified because members of a choir who had entertained the guests ate only one of the courses.

Comment: MRSA

The treatment of infections due to *Staphylococcus aureus* was revolutionised in the 1940s by the introduction of the antibiotic penicillin.

Unfortunately most strains of *Staphylococcus aureus* are now resistant to penicillin. This is because *Staphylococcus aureus* has undergone a modification which produces an enzyme called β-lactamase able to degrade penicillin. Some related antibiotics, such as methicillin are not affected by β-lactamase, and could be substituted for penicillin. But, some strains of *Staphylococcus aureus* have also become resistant to methicillin. Hence the term Methicillin-Resistant Staphylococcus Aureus, MRSA.

This is not strictly to do with the deterioration of food, but it does illustrate a worrying feature of the use of antibiotics.

Clostridium botulinum

There are about six types of *Clostridium botulinum* which can produce toxins in food. Some are found in the soil and others are found in water, including sea water. All the types form spores when conditions are hostile. In the spore state, the organism is more resistant to heat and extremes of pH than most organisms.

Unlike the *Staphylococcus aureus* toxin, the botulinum toxin is not very resistant to heat. The toxin can be inactivated by boiling at 100 °C for a few minutes, but the spores may take up to six hours to be destroyed. The botulinum toxins are some of the most toxic substances known. The mortality rate of its victims is 50% but this is improving with good hospital treatment. Most incidents of botulism have been associated with canned or bottled vegetables, fruits and fish. *Clostridium botulinum* is inhibited by oxygen and an acidic environment ($pH < 4.5$) so low pH foods do not require the extensive heat treatment administered to foods having a pH above 4.5.

Escherichia coli (E.coli)

Escherichia coli bacteria occur in human faeces. For the most part this is normal and causes no problems. If the bacteria are transferred to food or drink, illness in the form of acute diarrhoea can result. People are at most risk from water, raw vegetables and some prepared meats. Transfer into these foodstuffs is usually the result of failing to wash hands after using the toilet. The *E.coli* strain 0157:H7 causes the most serious outbreaks.

Safety

Food poisoning can be avoided by ensuring that the storage conditions are such that harmful bacteria cannot grow. There must be an understanding of the times and temperatures of storage in relation to bacterial growth. It is important to realize that the safety of refrigerated foods depends on the extent of bacterial contamination before refrigeration, as well as the temperature of refrigeration. Remember that low temperature merely reduces or delays the growth and multiplication of bacteria. They immediately renew their activity when the food is transferred to a warm room.

Fresh foods cooked and eaten while hot should never be responsible for food poisoning due to micro-organisms.

Nevertheless, heat-resistant bacterial spores frequently survive cooking. They can give rise to large numbers of bacterial cells when cooking is slow, and the storage time of the cooked foods in the kitchen is too long. Short, high-temperature cooking is best for the safety of the foodstuff. Frozen foods allowed to thaw should be cooked thoroughly and eaten within a short time.

Comment: Norwalk Virus

Food poisoning can also be caused by virus infection. From time to time it has been necessary to close hospital wards because of outbreaks of Norwalk Virus infections. This is so called because it was first identified as a cause of gastroenteritis at a school in Norwalk, Ohio, USA.

Like some other forms of gastroenteritis, the symptoms include diarrhoea, vomiting and sometimes fever and headache. The virus is contagious and is transferred from faeces to food through inadequate hand-washing. It may be destroyed by cooking.

4.4 Microbial changes in milk

Milk is usually treated in one or more ways before it is consumed as a liquid or milk product. To understand how milk is processed, a knowledge of the composition of fresh milk and possible microbial changes is needed. Milk provides good examples of both undesirable and of beneficial changes.

Undesirable microbial changes in milk

The spoilage reactions brought about in milk by micro-organisms provide examples of many types of microbial reactions. Fresh milk, as it leaves the udder of a healthy cow, contains few bacteria and these do not grow well in milk.

As soon as milk leaves the udder it is contaminated from the exterior of the udder. Bacteria from soil and water may enter in this way. Other sources of contamination are the hands of the milker, milking machines, and dairy equipment. By the time bulk milk reaches a factory it often has a bacterial count of 1×10^7 organisms per centimetre cube.

Milk is an excellent culture medium for many kinds of micro-organisms because it is high in moisture, nearly neutral in pH, and rich in microbial nutrients, such as milk sugar (lactose), butterfat, citrate, proteins, amino acids, and minerals.

Carbohydrate changes (souring)

A large proportion of the bacteria present in milk under normal conditions produce lactic acid. The first major change is the conversion of lactose to lactic acid, 2-hydroxypropanoic acid, a process involving eleven steps and nine enzymes:

$$\begin{array}{lcl} CH_3CHOHCO_2H & \xrightarrow{+2H} & CH_3CHOHCO_2H \\ \text{pyruvic} & \text{lactic} & \text{lactic acid} \\ \text{acid} & \text{dehydrogenase} & \text{2-hydroxypropanoic acid} \end{array}$$

The pH of milk drops as lactic acid forms, and this affects the milk proteins. Fresh milk contains three main classes of soluble milk proteins: casein, globulins, and albumins. Casein exists in a globular form with calcium, inorganic phosphate, magnesium, and citrate. As the pH drops, the bonds with calcium and phosphate are broken and casein becomes less soluble. At about pH 5.2 it coagulates and separates out. The phenomenon is known as curdling. Albumins and globulins remain in the liquid phase as serum or whey.

After a time, the decreasing pH inactivates the lactic acid-producing bacteria. No further lactic acid is produced, and the product left is known as ‘curds and whey’.

Although milk souring is nowadays generally regarded as undesirable in Britain, this has not always been the case. When the contaminating organisms in milk are predominantly lactic acid producers, sour milk is a very stable product, and was regarded in the past as a useful form in which to store milk. It is still used quite widely in some countries.

Today the same reactions are also used to produce yoghurt, but here the change in pH is controlled by the addition of desirable lactic bacteria which determine the flavour and texture of natural yoghurt.

When a high proportion of organisms other than lactobacilli is present, the spoilage does not stop at this point, and there may be a lot of end products besides lactic acid – for instance, ethanol, ethanal, ethanoic acid, propanone, carbon dioxide, and some higher alcohols, acids, and carbonyl compounds. For example, pasteurized milk, if stored at too high a temperature, spoils in a different manner from the souring of raw milk. The mild heat treatment of pasteurisation kills most of the normal lactic acid-producing organisms, and although spoilage of pasteurized milk takes longer to develop, it is much more unpleasant than souring, as it involves protein breakdown and fat breakdown.

Protein and fat changes

The enzymes in bacteria can catalyse reactions resulting in the breakdown of both proteins and fats. Not only do the proteins degrade into amino acids and the fats into fatty acids, but both these groups of compounds react further, giving a variety of undesirable organic and, sometimes inorganic compounds.

The situation may be summarised as follows:

- **Breakdown of proteins** (proteolysis) gives peptides and amino acids, followed by the reaction of amino acids to give ammonia, hydrogen sulphide, carbon dioxide, amines, mercaptans, and aldehydes.
- **Breakdown of fats** (lipolysis) gives fatty acids, which may be oxidized to long chain carbonyl compounds, particularly aldehydes which give very intense odours and rancid flavours.

Milk is used as the example here. Bacteria spoil other foods such as fruits, vegetables, and meat by the same or very similar mechanisms.

Beneficial microbial changes in milk

Cheese-making provides a good example of the beneficial effects of bacteria.

Cheese manufacture

The first step is to encourage acids to be produced in milk. On farms and in small dairies, fresh milk can be used, and the natural population of micro-organisms in the milk can be allowed to act on the lactose.

On a large industrial scale the bulk milk supplies contain a higher and more varied bacterial population. The milk is pasteurised to get rid of harmful micro-organisms, and a culture of a desirable strain of lactic acid-producing bacteria is added. After some acid has formed rennet is added. **Rennet** is a digestive enzyme obtained from the lining of the fourth stomach of calves. It reduces the solubility of casein so that the souring milk sets to a soft curd. The slightly acid pH produced by the bacteria is necessary for rennet to act, and its optimum temperature is about 35 to 40 °Celsius. Alternatively, other enzymes may be made, such as chymosin from a genetically-modified yeast, and a microbial protease from a fungus.

The curd is cut up and heated (scalding). This destroys most of the micro-organisms and stops the souring. It also causes the curd to separate from the whey. The curd is filtered off, pressed into blocks, and allowed to mature. During the maturing process the cheese becomes firm and the flavour develops. The flavour is characteristic of the type of cheese, the method of manufacture, the type of organism present in the original milk, and organisms such as moulds which inhabit the storage rooms. Different microbial populations create the very different but extremely characteristic flavours of the various types of cheese, such as Cheddar, Stilton, and Camembert.

Although the reactions which produce flavour, and indeed the actual compounds responsible for the flavours, have not been fully identified, the general reactions proceed according to the following scheme:

Proteins ⟶ peptide ⟶ amino acids

Fats ⟶ fatty acids ⟶ ketones, aldehydes, alcohols, and esters

Proteolysis and lipolysis are essential for cheese production, but are regarded as undesirable in most foods.

4.5 Non-microbial changes

Even in the absence of micro-organisms, food undergoes changes during storage. These changes are due to biochemical reactions.

Biochemical reactions

The time taken for food to spoil in the absence of micro-organisms depends on the activity of its biochemical system at the time of slaughter or harvesting.

Foods from plants

For example wheat is harvested and stored at a stage in the life cycle of the plant when the activity of the cells is very low. The bio-systems of wheat grain can exist without damage when removed from the parent plant. Peas, however, are harvested at an unnatural stage, when the cells are very active and not equipped to exist apart from the parent plant.

One undesirable change is pectin breakdown in fruit and vegetables, which makes them ‘mushy’. Pectins play an important part in giving structure and texture to fruit and vegetables. In developing fruit and vegetables, a polymer called protopectin forms, which is insoluble in water.

During ripening, enzymes degrade the protopectin to more soluble compounds. In a fruit such as an apple, this corresponds to the ripening process: the apple starts off by being too hard for eating, reaches a desirable texture for eating, then becomes over-ripe and over-soft, until finally the tissues collapse.

All these processes are part of the life-cycle of the plant and are essential for the propagation of the species. The enzymes become active in a particular order and at a particular stage of development. However, when the plant is used as food, all the changes beyond the best condition for eating are highly undesirable and must be prevented when the food is to be stored.

The same series of reactions can be achieved, often more quickly, by pectic enzymes in some micro-organisms such as the moulds and rotting fungi found on damaged fruit.

Foods from animals

The maturation of meat is an example of a desirable change. Maturation is the sequence of reactions which converts living muscle into hung meat. Freshly killed meat tends to be tough and has very little flavour. In normal practice carcasses are hung in cool stores for a few days, until the meat becomes tender and flavour develops. This improvement in quality is due to alterations in the system of enzymic reactions when no more oxygen is supplied to the muscle.

4.6 Investigating browning reactions in fruit and vegetables

When apples or potatoes are peeled and sliced for eating or cooking, a relatively rapid change (depending on the time of year) takes place, and the tissues brown. The purpose of the series of experiments associated with this section is to determine the conditions which affect the rate of this reaction and to determine whether it is microbial or biochemical. Then you can try to devise methods of avoiding or controlling the spoilage without harming the texture and flavour of the food and introducing toxic additives.

Fruit-browning reactions are studied because they are relatively simple (and safe) when compared with more complicated types of food spoilage, such as fat oxidation, maturation of meat, and pectin changes in vegetables. But the same principles apply in all these cases.

All experiments, and in particular those involving biological materials, should contain a control sample. This helps to differentiate between changes which are due to the treatment and changes which would have taken place anyway. The treated and control samples should come from the same specimen, because wide variations in composition may occur between different varieties of fruit or vegetables.

See Experiments 4 to 7.

CHAPTER 5 FOOD PRESERVATION

5.1 Methods of preservation

Raw foods are not stable and, unless some positive action is taken, they deteriorate. Food spoilage is mainly due to micro-organisms (bacteria, moulds, and yeasts) and, to a lesser extent, to biochemical reactions which are often catalyzed by enzymes. The eating quality of food may also deteriorate because of physical damage, such as bruising and dehydration. For example, fresh vegetables wilt, fruits dehydrate and shrink.

Food preservation techniques are designed to reduce the deterioration in quality which inevitably occurs in unprocessed foods, and to increase the food's shelf-life beyond that of the raw material. These techniques are based on two broad principles.

The first principle involves destroying or inactivating some or all of the micro-organisms and/or enzymes. This includes:

- heat processing
- irradiation
- chemical techniques
- high pressure.

The second principle involves creating conditions which limit deterioration. This can mean either controlling the conditions within the food or in the environment in which the food is stored. This includes:

- freezing
- dehydration
- packaging.

As well as reducing deterioration in quality, an effective, practical method of food preservation must retain, as far as possible, the original characteristics of the food, or give the food characteristics which are just as acceptable. Moreover, the preservation technique must not have a detrimental effect on the nutritional value of the food nor be potentially harmful, either immediately or cumulatively, to health.

5.2 Methods which destroy or inactivate micro-organisms and enzymes

Heat treatment

There are two methods of preserving foods by heat treatment.

i Sterilisation
Sterilisation is designed to kill all micro-organisms capable of growing on the food while it is being stored.

ii Pasteurisation
Pasteurisation is designed to kill most pathogenic organisms, and some of the spoilage organisms, which are capable of growing in the food while it is being stored. Botulism spores, for example, are not killed.

Sterilisation

Two general methods of sterilisation are used:

- in-pack sterilisation
- ultra-high temperature sterilisation, followed by aseptic packaging.

With vegetables the food is first blanched by immersion in hot water at 70–100 °C for 1–5 minutes, or exposed to steam for as little as 25 seconds. This inactivates the enzymes and removes much of the air in the tissues.

In a typical **in-pack sterilisation** process, the food is then put in clean containers such as metal cans. The air in the container is replaced by steam, which condenses and forms a vacuum in the sealed can. The cans are then put in pressure-tight heating chambers and heated by steam. After sterilization the cans are cooled by immersion in sterile cold water. Sterile water is used to prevent infection which otherwise might result when water is drawn into an occasional leaky can, as a result of the vacuum caused by cooling.

A disadvantage of in-pack sterilisation is that the heat penetrates slowly into large cans, making it necessary to give the cans a long heat treatment. For an A2 size can of vegetable soup the process will need 70 minutes at 121 °C followed by 50 minutes cooling. This may result in over-processing of the outer layers and a deterioration in nutritional value. This could be avoided by heating with microwaves. However, since microwaves cannot pass through metals, the packaging would have to be changed to a material which is transparent to microwaves, such as paper or plastic.

The over-cooking can also be avoided by heating the food before packaging. This procedure, known as **ultra-high temperature processing (UHT)** can at present only be used for liquid or semi-liquid foods. Food in a liquid or slurry form is passed in thin layers through heat exchangers, operating at about 140 °C, where sterilisation takes place in a relatively short time. The sterile food is then rapidly cooled and sealed in aseptic containers. Vegetable soup needs only 5 seconds heating at 140 °C for sterilisation to be effective. The disadvantages are the limited range of foods that can be treated and the relatively costly equipment needed.

Pasteurisation

Pasteurisation is the term used for a relatively mild heat treatment of food, which kills or inactivates the heat-sensitive pathogens. As in the case of sterilisation, pasteurisation may be carried out in-pack or before packaging. It is suitable for liquids such as fruit juices and beer and is particularly applied to milk processing.

There are various methods of pasteurising milk. In the high temperature short time (HTST) process, the milk is heated rapidly to 72 °C, held at that temperature for 15 seconds, cooled rapidly, and then aseptically transferred into pre-sterilised containers. The higher the temperature the shorter the treatment time: 1 second at 84 °C, 0.1 second at 94 °C. The methods using high temperatures for short times avoid the cooked flavours which occur in sterilisation where the temperatures are maintained for longer periods.

The effectiveness of a heat process depends on a number of factors, the main consideration being the acidity of the food. For the purposes of heat processing, foods are classified into three groups, based on their pH.

Low-acid foods, pH more than 4.5

Low-acid foods (see figure 5.2) support the growth of most organisms, including the lethal *Clostridium botulinum*. Its destruction is the minimum requirement for heat treatment. Such foods need to be heated at 100 °C for at least five hours to ensure full sterilisation (see figure 5.1).

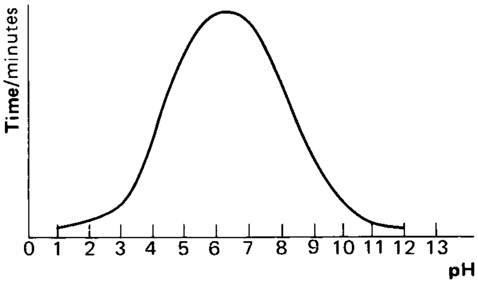


Figure 5.1
Heat-resistance of spores of *Clostridium botulinum* at 100 °C in buffers.

Acid foods, between 4.5 and pH 3.7

Foods having a pH between 3.7 and 4.5 do not support the growth of heat resistant micro-organisms and only require a short heat treatment like pasteurisation.

High-acid foods, pH less than 3.7

High-acid foods do not support micro-organisms, and only require a very short heat treatment to inactivate enzymes present.

Food	apples	rhubarb	plums	peaches	peas	tomatoes	carrots	potatoes	peas	meat
pH	3.0	3.1	3.4	3.7	4.2	4.3	5.2	5.5	6.0	6.2

Figure 5.2 The pH of some foods.

Irradiation

Since the discovery that radioactivity and X-radiation produce biological effects and can kill micro-organisms, there has been continued interest in their application to reduce harvest losses and to reduce the incidence of food-borne disease. About 30% of the World's food supply is lost after harvesting as a result of spoilage or too rapid ripening, so any method which might reduce the scale of the losses needs to be examined seriously.

The two types of radiation used are high-energy electrons and γ-radiation. Both are just as effective in destroying micro-organisms and can delay ripening, but electrons are less penetrating than γ-rays so they are less useful.

Radiation for food preservation

The preservative value of irradiation is due to its property of inhibiting processes leading to deterioration, and destroying micro-organisms and insects which may cause spoilage. Unfortunately, irradiation is not selective and may destroy vitamins and denature proteins, reducing nutritional value. It may also produce undesirable changes and affect eating qualities. An international research effort, going back 60 years, has established the doses of radiation needed to kill particular micro-organisms without producing off-flavours in the food. More recent research has been directed at establishing that irradiated food remains wholesome and is safe to eat.

Regulations in the UK allow for the irradiation of several categories of food: fruit, vegetables, cereals, bulbs and tubers, spices, fish and shellfish. Producers have to label foods that have been irradiated or contain irradiated ingredients. Caterers also have to indicate on menus and other notices if they are using irradiated ingredients.

Producers have to obtain a licence to offer irradiated food for sale but, as there is considerable consumer resistance to irradiated foods, it is not surprising that only one UK licence has been granted so far (2005). This licence permits irradiation of herbs and spices.

High pressure

Food can also be processed by the application of high pressure, greater than the pressure at the bottom of the deepest ocean. Pressure in the range 1000–10 000 atmospheres applied to foods in a single application, or as a series of pulses, will kill a range of micro-organisms, change enzyme activity, and alter physical characteristics such as emulsifying behaviour.

The technique is useful for acidic foods where the range of micro-organisms is more limited. In contrast to heat treatment, the effect of high pressure is felt immediately throughout the food. So fruit juices and jams can be treated by high pressure and have an exceptionally fresh flavour compared with heat-treated products.

The application of pressure inactivates the enzyme polyphenoloxidase which is involved in the browing reaction of freshly cut fruit and vegetables. And pressure treatment of milk partially unfolds the micelles, so a more viscous yoghurt can be prepared with a reduction in whey separation.

Chemical techniques

The addition of chemicals to inhibit spoilage and prolong the shelf-life of foods is strictly controlled by legislation in Britain. Only certain chemicals are permitted under the Food Safety Act (1990) and European Union legislation. Additives permitted throughout Europe have numbers with the prefix 'E-'. Their amounts are very strictly controlled. When correctly used, chemical preservatives are very effective.

Acid

Reducing the pH to a level which inhibits microbial and enzymic activity is widely practised, and has been for many years. There are two ways in which acids are used.

- The acid may be produced in the food by the actions of micro-organisms. Usually a selective starter organism is added to the food, which is then matured until the pH is low enough to inhibit further deterioration. The production of cheese is an example of this process – lactic acid bacteria (*lactobacilli*) are added as a starter to convert the lactose into lactic acid. This results in a decrease in the pH to about 5.5.
- Alternatively, acid (usually ethanoic acid) may be added to vegetables such as onions and gherkins – preservation by pickling. In practice the vegetable is first soaked in salt solution for several days. During this time acid is produced by the action of bacteria on the carbohydrate. The vegetables are then washed with warm water and stored in vinegar (4–6% ethanoic acid).

A large number of acid preservatives are weak acids, such as ethanoic, sorbic and benzoic acids. Although a given concentration of a strong acid is more effective in lowering the pH than a weak acid, weakly-dissociated acids are better preservatives. The concentration of the undissociated acid, rather than the hydrogen ion concentration, is the inhibitor.

Salt (curing)

In the curing process, the meat is soaked in a solution containing 25% sodium chloride, 0.001% sodium nitrite, and 1% potassium nitrate for about twelve days. The mixture, which is known as the pickle, may be injected into the meat. This shortens the soaking time.

The salt and the potassium nitrate inhibit the growth of micro-organisms. Originally very small amounts of sodium nitrite were added to produce nitrosomyoglobin, to give the cured meat its characteristic red colour. It has been shown that nitrites, under suitable conditions, also inhibit spoilage bacteria.

Some cured products (herrings, cod and bacon) are first soaked in a concentrated salt solution and then exposed to the smoke from a wood fire for about 20 hours. Smoking coats the surface with condensed tar (phenol and aldehydes) which inhibits microbial growth. This is a slow process and may be speeded up by spraying the surface of the material with condensed tar.

Antibiotics

Antibiotics are chemical substances, produced by micro-organisms, which destroy or inhibit the growth of other micro-organisms. They are widely used therapeutically and some can be used as food preservatives. However, there is a danger that the bacteria the antibiotics are meant to destroy may develop a permanent resistance to the antibiotic. This could make the therapeutic use of antibiotics ineffective. For this reason, the general use of antibiotics as preservatives is not permitted in the UK.

Nisin, however, is permitted. This is because, firstly, there are no medical uses for nisin, and bacteria which may develop resistance to it can be treated with other antibiotics. Secondly, nisin is produced naturally in milk and certain cheeses by lactic acid bacteria, and has been consumed by us for hundreds of years with no apparent ill effects. For this reason it is assumed to be safe, and no maximum permitted level is specified.

Very small amounts (2–3 ppm) of nisin are added to cheese, cream and canned foods. Nisin does not destroy bacterial spores; it inhibits their formation. The only other antibiotic permitted in the UK is thiabendazole, which is used to control rot on the skins of bananas and citrus fruits.

Antioxidants

Antioxidants reduce the oxidation of fatty acids in processed foods. Unsaturated fatty acids, such as linoleic and linolenic acids, absorb atmospheric oxygen to produce unpleasant-smelling substances (aldehydes). Antioxidants are added to foods such as oils, fats and butter. Vitamin E, which is a fat-soluble vitamin, is a very effective antioxidant.

Unfortunately, for economic reasons, it is not always possible to use natural preservatives. The Food Safety Act (1990) allows the controlled use of a small number of specified antioxidants – propyl, octyl and dodecyl gallates; butylated hydroxyanisole (BHA), butylated hydroxytoluene (BHT), naturally occurring lecithins and ascorbic acid (vitamin C).

The action of antioxidants has been found to be improved by the use of synergists. Synergists (citric acid and ascorbic acid) function by forming complexes (metal chelates) with metals such as copper, which otherwise catalyse oxidation.

5.3 Methods which create conditions that limit deterioration

Freezing

Freezing affects enzymic and microbial activity in two ways. First, by reducing considerably the rate of growth of micro-organisms and the activity of enzymes. Then, by converting the water into ice, so making it unavailable to micro-organisms and enzymes and thus further reducing deterioration.

Chilling to about 5 °C enables food to be stored for short periods, but for long-term storage the temperature must be reduced to at least –18 °C. At this temperature most microbial and enzymic activity is inhibited. However, some micro-organisms are active at this temperature, and some enzymes remain active. For this reason food cannot be stored at low temperature indefinitely, and vegetables should be blanched before freezing to destroy the enzymes.

The rate at which freezing takes place is an important factor in determining the quality of the thawed product. A food must be chilled to below its freezing point, always below 0 °C, before ice crystals form, and the freezing point drops progressively as the concentration of dissolved solutes increases. The crystallisation of solutes can cause temporary temperature rises. Even when chilled to –20 °C not all the water will be frozen: about 10% liquid water remains in foods such as fish and lamb.

When the freezing is carried out correctly there is very little loss of nutritional value. In fact, most of the loss occurs during the preliminary preparation of the fruit and vegetables. Industrial loss of nutritional value is minimised by reducing the time between harvesting and freezing. In the case of peas the time delay is less than $1^1/_2$ hours.

Fast freezing destroys between 50 and 80% of the micro-organisms and tends to produce very small ice crystals within the cells. This produces very little cellular damage. Slow freezing, although destroying more micro-organisms, tends to form large crystals between the cells and draws the water from within them (see figure 5.3). This has the effect of dehydrating the cells and causing considerable damage to the cell walls, which may result in a mushy product on thawing.

Commercially, foods may be frozen in three ways.

Blast freezing

In blast freezing, refrigerated air at –30 to –40 °C is passed over the food to be cooled. This technique is used to freeze peas and similar small particle foods and produces fast, uniform freezing.

Fluidised bed freezers are modified blast freezers in which the cold air is passed up through a layer of the food, which is carried on a perforated tray. Freezing is rapid and uniform.

Immersion freezing

Cold solutions of salt or glycerol are used. The food is immersed in the solution, or the solution is sprayed on to the food. In cryogenic immersion freezing, liquid nitrogen or carbon dioxide are used: cold gas from evaporation first chills the food and then the liquid is sprayed onto the food. The use of liquid nitrogen produces almost instantaneous freezing which results in very little cellular damage, and is used for fruit such as strawberries and raspberries. The main disadvantage is the high cost of the refrigerant.

Freezing by contact (plate freezer)

The food is put on hollow plates through which refrigerant at –40 °C is pumped. The food is cooled by contact. The disadvantage of this method is the high cost of the equipment and the restriction to foods that are thin and flat, like fish fingers, fish fillets and beefburgers.

Method	**Time** / minutes
Plate (cartons of peas)	25
Blast	20–15
Fluidised bed	4–3
Cryogenic (liquid nitrogen)	$^1/_2$

Figure 5.3 Freezing loose peas to –18 °C .

Dehydration

Dehydration is the removal of about 90% of the water content normally present in food. Sun drying is the most widely practised process in the world: more than 250 million tons of fruit and grain are dried by this process every year. Other drying techniques fall into two main classes, heat drying and freeze drying.

Heat drying

This is achieved by heating to temperatures between 40–100 °C.
Drying peas at 85 °C may take an hour.

Heat drying produces irreversible effects such as cellular damage and denaturation of protein, with the result that less water is reabsorbed on reconstitution. Heat drying, however, has the advantage that oxygen cannot readily penetrate. Also it does not require the expensive packaging which freeze-dried foods need.

Freeze drying

This is carried out by freezing the water in the food and then removing it by sublimation of the ice under reduced pressure. This avoids heat damage and also the cooked flavour characteristic of heat-dried foods. However, freezing damage may take place.

Freeze-dried products have an expanded porous structure which rehydrates much more easily than heat-dried foods. Freeze-dried foods, however, are fragile and may powder during handling and packaging. This is seen with coffee granules. Moreover, the open structure exposes a large surface area to oxidation, and, if fats are present, rapid deterioration may take place.

Dehydration of foods may result in the reduction of nutritional value, for example, the loss of 30% of the vitamin C content of peas. Nevertheless, the advantages of reduced mass, which results in lower handling costs and reduced microbial and enzymic activity, can outweigh the disadvantages.

Packaging

Packaging is not regarded by most people as a preservative technique. Nevertheless, appropriate packaging extends the shelf-life of processed and unprocessed food, and may be considered as a way of preserving foods.

Appropriate packaging increases the shelf-life of food in the following ways:

- by providing protection against damage during handling; this is necessary for biscuits, cakes and eggs
- by reducing physical changes which may shorten the shelf-life, for example, the dehydration of frozen foods and of processed foods such as ham
- by reducing the uptake of moisture by dried foods
- by preventing oxidation of fats in processed foods, such as crisps, and unprocessed foods.

Packaging materials can be impermeable or allow a slow rate of gaseous exchange. Fruit and vegetables usually continue to respire. Therefore their packaging film must allow an appropriate rate of exchange for carbon dioxide, oxygen and water vapour, in order to maintain an optimum atmosphere inside the pack. Meat has to be packed in an impermeable film, either vacuum-packed or in a modified atmosphere (MA). A concentration of 75% oxygen maintains the bright red colour favoured by shoppers, and 25% of carbon dioxide inhibits the growth of micro-organisms. Meat in MA packaging still looks ‘fresh’ 5–6 days after being packed.

CHAPTER 6 CEREAL SCIENCE

6.1 Wheat grain

Cereals, such as rice and wheat, have been used as food for years. Wheat was grown and used as food in the Middle East over 9000 years ago. There is also evidence that wheat was grown for food in Britain around 2000 BC. On a worldwide scale, wheat is the major cereal crop. However, much is used for animal feed and rice is probably the major cereal crop for human consumption. Wheat grows best in temperate climates so it is mainly grown in the northern hemisphere, where there is a far greater land area in the temperate zone than in the southern hemisphere.

The wheat grain is the fruit of the plant and is a valuable food source. It contains cellulose starch, protein, some fat, and small but valuable amounts of vitamins and minerals. In general, common cereals such as wheat, oats, barley, rye, maize and rice vary in their composition according to variety, climate and agronomic conditions. It is therefore not possible to give precise figures for their composition. The values given below represent a typical range for wheat.

Moisture	Carbohydrate	Protein	Fat	Vitamins and minerals
8–20%	65–75%	7–16%	1–3%	1–2%

A grain of wheat is about 6 mm long and 3 mm broad. It has a crease running along one side and a number of hairs called the ‘beard’ at one end. It is enclosed in a tough skin, collectively called the **bran**, which consists of the aleurone and pericarp layers.

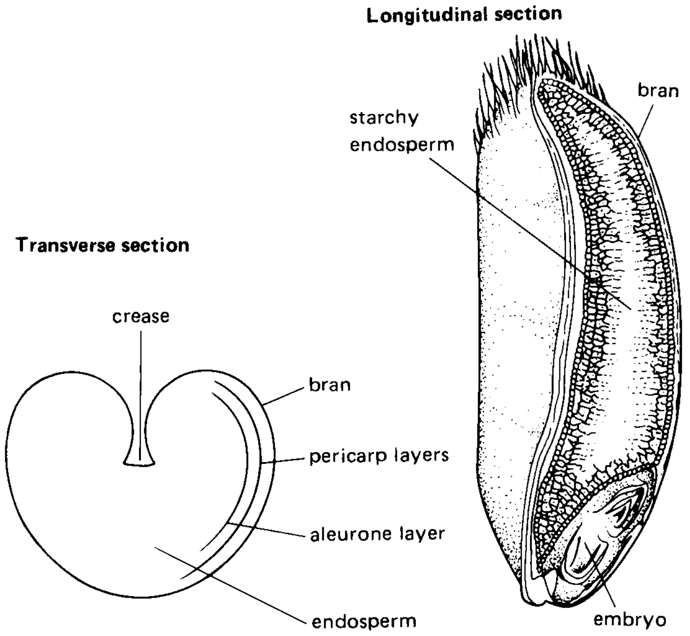


Figure 6.1 Sections of wheat grains

The pigment which gives the wheat its golden brown colour is in the **pericarp** layer. This is mainly cellulose. The aleurone layer separates the pericarp layer from the endosperm, and consists of a single layer of fat and protein-rich cells. However, this layer is removed with the bran during the milling process.

The **endosperm** is the largest part of the wheat grain (80–90%) and is mainly starch. The spaces between the starch grains are packed with a mixture of proteins.

6.2 Moisture content

Grain moisture content is important for three reasons.

i The market value of the grain is partly determined by the moisture content. High moisture content means proportionately lower protein and carbohydrate content. A higher price is paid for grain with a higher protein content.

ii Moisture content affects the safe storage of wheat. Grain with a moisture content of about 18% is liable to germinate and develop moulds when stored at 20 °C. Most mills store grain for a period of time, so millers prefer a moisture content of about 10–15%.

iii Moisture content is important in the milling process. Before wheat can be milled it is necessary to **condition** it to produce a moisture content of about 15–16%. This moisture content limits the break-up of the bran and improves its separation from the endosperm.

The moisture content is affected by the climate on the day the crop is harvested. Farmers try to harvest so that the moisture content is below 18%. This then drops to about 14% by the time it reaches the miller. In the EU the moisture content is defined as the loss of mass expressed as a percentage of a 10 g sample of ground wheat heated at 130 °C for 2 hours.

6.3 Protein content

Protein content and quality are important because they determine the suitability of the wheat for a particular purpose. In baking, the term **protein quality** refers to the physical characteristics of **gluten**, including its elasticity, and strength. Gluten is the viscoelastic complex formed when the proteins in the flour are mixed with water.

In general, flours good for bread-making tend to have a protein content of about 12–14%. Protein content is usually expressed on a 14% moisture-content basis. A good bread-making flour is described as ‘strong’, and tends to be more elastic and more resistant to stretching than a ‘weak’ flour.

The gluten retains the gas bubbles as they form during the baking process and gives the baked product its characteristic texture. A high level of protein, giving a good yield of gluten, is required for the production of bread-making flour. A low protein level, giving an extensible gluten, is required for biscuit and cake production.

Gluten proteins consist mainly of gliadins (about 30%) and glutenins (about 60%). A single variety of wheat may have over 40 different gliadin proteins. The gliadin proteins tend to have very little ionic character. They are relatively insoluble compared with other proteins of similar molecular size. The glutenin proteins are even less soluble than the gliadins. The glutenins appear to consist of coiled, protein sub-units linked together by disulphide bridges.

When water is added to flour, a dough is formed as the gluten proteins hydrate. The viscoelastic properties of the dough depend on the glutenin fraction – this is able to form an extended three-dimensional network. The relative proportions of glutenin and gliadins determine the bread-making character of a flour. A higher proportion of glutenins results in doughs which are ‘stronger’, require more mixing, and produce loaves of greater volume.

The amount of protein in the grain is largely determined by the amount of nitrogen fertilisers available to the crop during its growing period, and also by the climate. Above average rainfall ensures a readily available nitrogen supply to the plant, and produces high protein levels. Extremely dry conditions also produce high protein levels due to the reduction of starch going into the grain. This also creates a high percentage protein content.

The test for gluten content often carried out at mills is the **SDS sedimentation test** (see Experiment 11). The grain is ground to flour and shaken with a solution containing lactic acid and a detergent, sodium dodecyl sulphate (SDS). The gluten proteins form a sediment, the volume of which is measured.

6.4 Starch

Starch is the largest component of wheat. It is an α-glucose polymer. The polymer chains are arranged to give spherical crystallites which make up the starch grain. Uncooked starch is indigestible and all the starch foods must be heated with water to enable the digestive enzymes to break the starch down to sugars. Heating starch with water breaks the hydrogen bonds which hold the polymers together and allows the water to penetrate the grain. The grain swells into a roundish ball of a suspension of starch. The process is referred to as **gelatinisation** (see Experiment 12).

6.5 Processing wheat to make flour

Conditioning

Before wheat can be milled it has to be **conditioned** to produce a uniform moisture content of about 15%. Wheat is conditioned by adding water and allowing it to stand for about 24 hours. After conditioning, the different wheats are blended together (**gristed**) to produce flour with the required quality, that is, protein content. The protein content of the grist is important because the finished flour usually has a protein content about 1.5 % lower than the initial blend. This is because the protein-rich aleurone and germ components are removed in the milling process.

Milling

The object of milling is to produce the maximum quantity of flour at a given level of colour. This is done by a sequence of breaking, grinding, and separating operations.

Flour colour refers to the whiteness and brightness of milled white flour. It depends on the inherent whiteness of the grain endosperm, the particle size of the flour, and the amount of bran in the flour. It is the bran contamination which imposes limits on the amount of white flour that can be extracted from wheat (65–68%). The finer the mill is set to scrape the last few particles of endosperm from the bran, the greater is the risk of bran particles breaking off and contaminating the flour, with the resulting loss of flour whiteness.

The conditioned and gristed wheat is initially passed through break rollers which roll the wheat open and break it up into:

- bran (removed)
- bran with endosperm attached
- bran-free endosperm chunks
- flour (small amount).

After each break roll, the ground material is sieved to separate it according to particle size. Material of the same particle size is then separated, according to density, in a purifier. This separates pure bran from pure endosperm, and from particles that consist of both bran and endosperm. The particles containing both bran and endosperm go to further break rollers. Those of pure endosperm go to reduction rolls and sieves to reduce their size to that of fine white flour (0.15 mm).

In a typical mill there may be as many as four break rolls and twelve reduction rolls. This will produce sixteen flour streams.The whitest flours are produced at the early stages in the milling process. As the stages increase, the flour gets progressively darker as the bran fragments contaminate the flour. By blending together different streams the miller can produce many types of flour.

Storage

The bread-making properties of a flour improve with prolonged storage. Auto-oxidation of the polyunsaturated fatty acids results in the formation of hydroperoxides which are powerful oxidising agents. These bleach the carotenoids in the flour, giving the bread a more ‘attractive’ whiter crumb. Prolonged storage also results in the oxidation of some of the free –SH groups of the gliadins to $–SO_3H$. This enhances the viscoelastic properties of the dough. Flour which was imported in large quantities in the beginning of the twentieth century had enough time during its journey to mature. Rather than storing the flour for a time to achieve these effects, nowadays it is sometimes bleached with chlorine or chlorine dioxide.

Mixing dough

A satisfactory dough is one which will hold a large quantity of gas and retain it as the protein sets during baking. A good dough is made by mixing the ingredients and by kneading. During the mixing process, the large glutenin molecules are stretched into linear chains which interact to form sheets around the gas bubbles. The stretching of the glutenin involves a number of chemical reactions.

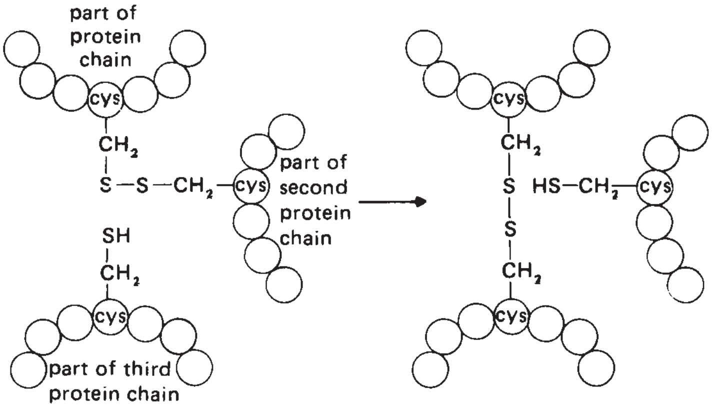


Figure 6.2 The possibility of disulphide exchange reactions in dough.

Chemical reactions when dough is mixed

Firstly, the mechanical stresses set up within the dough temporarily break the bonds which bind the different gluten proteins together in bundles in dry flour.

Secondly, the various cysteine residues take part in disulphide exchange reactions. Under mechanical stress these reactions allow the glutenin subunits to take up more extended configurations, and form the sheets characteristic of developed gluten. (See figure 6.2.)

Flour improvers become active when water is added to flour, and are used to control these reactions. The most important improving agent is ascorbic acid. The enzyme in the flour, ascorbic acid oxidase, catalyses the oxidation of ascorbic acid by oxygen to dehydroascorbic acid, which is an oxidising agent and oxidises –SH. (See figure 6.3.)

This further inhibits disulphide bridge formation, and allows the dough to expand further than it normally would.

Fortification of flour

Products made from flour are important in the British diet. Flour is fortified with calcium, iron, thiamin and niacin in order to increase intake of these minerals and vitamins.

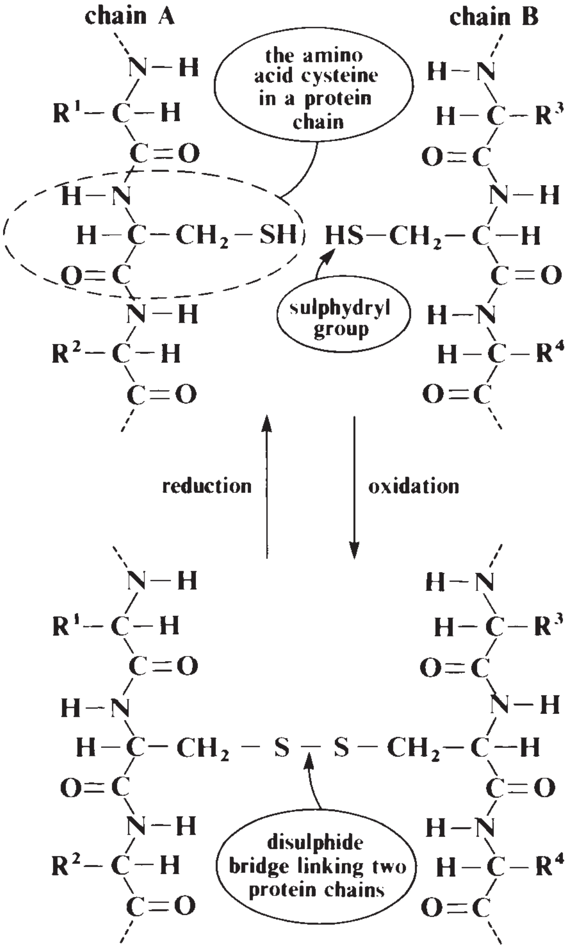


Figure 6.3 Two protein chains can be joined by an S–S covalent bond formed between cysteine residues.

6.6 Bread-making

Ingredients of dough

Bread-making provides an excellent example of deliberate control of chemical reactions in food. The starting point of baking is dough, a mixture of flour and water. Wheat flour contains amylases which are capable of hydrolysing the amylose and amylopectin of starch. The hydrolysis does not occur to any significant extent in dry flour, but begins immediately a dough is made. The product of the hydrolysis by α-amylase is maltose, a disaccharide.

When a dough is heated, the physical form of the starch is greatly changed. The starch in flour is contained in granules which form a suspension in water but do not dissolve. The starch granules take up 25 to 30% of water, but this has little effect on the structure of the granule, and is reversible if the granules are dried again. On heating to a temperature which varies according to the type of starch, the granules suddenly swell and take up a large amount of water. The granules change in appearance, and soluble starch molecules begin to leak out of the granules. On further heating, the suspension becomes more translucent and more viscous, and the granules become enormous and rupture, releasing more free starch. The viscosity decreases on further cooking, but increases again on cooling. Gelatinised starch is much more readily hydrolysed by the starch-splitting enzymes in the human digestive system.

A type of bread, known as unleavened bread, can be made by baking the simple flour-water mixture. This is the forerunner of modern bread, and lacks the honeycomb structure which gives modern bread its lightness. This honeycomb structure is obtained by generating a multitude of small pockets of carbon dioxide throughout its bulk. The carbon dioxide is produced before the bread is baked and while it is still an elastic dough.

The oldest and most important method of aeration of the dough is fermentation. Yeast is added to the dough. This converts both the sugars naturally present in the flour, and the maltose made available by the action of amylases, into glucose. Then, by the fermentation systems we have already discussed, the glucose is changed into alcohol and carbon dioxide. The carbon dioxide aerates the dough, and the alcohol is driven off during baking.

When the flour is kneaded with water, two proteins called gliadin and glutenin form an elastic complex called gluten. Gluten forms an interconnected network which holds the carbon dioxide within the loaf. When the bread is baked, the carbon dioxide expands, the starch gelatinises, and the gluten coagulates to produce a more or less rigid loaf.

Salt is also added to the dough for making bread. It influences the rate at which fermentation takes place, and enables the baker to control the development of the dough. In addition, salt has a strengthening action on the gluten. This is possibly due to its inhibiting action on protein-splitting enzymes which, in the absence of salt, would cause a certain amount of degradation of the gluten.

Fermentation

All the ingredients are mixed thoroughly until a homogeneous dough is obtained. This is allowed to ferment for about one hour at about 25 °C. The dough is then thoroughly kneaded to create many small bubbles of the carbon dioxide, and to bring the yeast cells into contact with more nutrient. The dough is then allowed to ferment for a further period, during which the kneading process may be repeated. After fermentation the dough is divided and moulded into loaves. Much of the gas is expelled during this moulding process. After being placed in baking tins or on baking sheets, the dough is allowed a further short period of fermentation. This is so that it may once again become inflated with carbon dioxide.

Baking

Bread is baked at 120 °C for 30 to 50 minutes, depending on the size of the loaf. During baking the dough first expands rapidly. This is because the pockets of carbon dioxide in the loaf expand as temperature increases. At first there may also be some slight increase in the activity of the yeast resulting in increased gas production. This diminishes as the temperature increases, until at a temperature of about 55 °C the yeast is killed and fermentation ceases.

As the temperature increases, the water present causes the starch grains to swell and gelatinise. During this period the starch extracts some water from the gluten. Hot gluten is soft and devoid of its characteristic elasticity, and gelatinised starch now supports the structure of the loaf. The gluten begins to coagulate at about 75 °C, and the coagulation continues slowly to the end of the baking period.

The temperature of the interior of the loaf never exceeds the boiling point of water, in spite of the high temperature of the oven. Water and much of the carbon dioxide and alcohol formed during fermentation escape during baking.

Most of the bread produced in the UK is produced by the Chorleywood Bread Process. In this process, the traditional 3-hour fermentation and kneading is replaced by high-speed mixing in a partial vacuum to develop the dough and create its bubble structure. The energy imparted to the dough is regulated to be 3500 J per kg of flour. Flour for bread-making using the Chorleywood Bread Process can have about 1% less protein than is needed for long fermentation, and it can tolerate greater starch damage. High starch damage leads to greater water-holding capacity, and gives a loaf with a characteristically soft crumb which stales slowly.

CHAPTER 7 FOOD LEGISLATION

7.1 The need for food legislation

There has been regulation of the content of specific foods in England and Wales since the thirteenth century, but the early regulation was primarily concerned with financial matters. Before the eighteenth century, the need for food safety legislation did not exist. Most food was produced within the local community; buyers of food knew where it had come from and could safely make up their own minds whether to buy it or not. The Industrial Revolution meant that more people lived in towns and cities. The relationships between food supplier and consumer became less personal and, in the absence of proper control of food quality, the increased opportunities for contamination, fraud and deception were exploited. As a response, Parliament brought in the Adulteration of Food or Drink Act 1860, which prohibited the sale of food that was impure or contained ingredients injurious to health, and provided for the prosecution of the offenders.

An Act of Parliament in 1872 created the appointment of public analysts and allowed enforcement officers to confiscate samples of food, so that offenders could be prosecuted if the food was not of high enough quality. There was a further Act in 1875 to strengthen the earlier Acts, and give even greater powers to enforcement officers.

These various elements of food legislation were brought together in the Food Act 1938, which also introduced offences relating to the misleading labelling of food and gave powers to the government minister responsible for food to introduce further regulations when necessary. There were further Acts of Parliament in 1955 and 1984.

Social and technological changes

It soon became clear that these Acts did not take into account the social and technological changes which radically altered food production in the second half of the twentieth century. Much more food was sold in supermarkets rather than in smaller shops. Consumers were buying more and more prepared foods which were easier and quicker to prepare and in many cases pre-cooked. Consumers expected to find foods available throughout the year which had previously been regarded as seasonal and, above all, food was no longer produced locally.

Food legislation needed substantial modernisation to reflect these and other changes, and also to ensure that the United Kingdom was able to comply with the requirements of European Union Law – this was playing an increasing role in food safety and regulation. Parliament brought in the Food Safety Act 1990. Building on the existing law, the Act was intended to control all aspects of food safety throughout the production and distribution processes, starting with the animal feed and agricultural chemical industries.

7.2 Food Safety Act 1990

What the Food Safety Act 1990 was all about

The Act creates four principal criminal offences, two relating to food safety and two relating to consumer protection:

- rendering food injurious to health
- selling food which fails to comply with food safety requirements
- selling food not of the nature, quality or substance demanded by the purchaser
- falsely describing or presenting food.

The 1990 Act only provides the framework for food safety and consumer protection. Much of the detail is contained in regulations made by the appropriate government departments such as the Department of Environment, Food and Rural Affairs (DEFRA), and the Department of Health and Social Services (DHSS). These regulations deal with such matters as the composition of foods, processes in the preparation of food, food hygiene, labelling and advertising of food, food sources, contact materials, novel foods, registration and licensing of food premises, and compliance with the requirements of European Union Law.

The Act also provides for the government departments to issue codes of practice on the administration and enforcement of the Act and regulations made under it. Responsibility for the administration and enforcement of the Food Safety Act is divided between central and local government. Certain powers, notably the power to make regulations and to issue codes of practice, are retained by the government ministers. Otherwise, enforcement is the responsibility of food authorities (district and county councils), who generally act through environmental health officers and trading standards officers as their 'authorised officers'. Food authorities are required to appoint public analysts and are empowered to appoint food examiners. Authorised officers are empowered to enter premises and procure samples for analysis or examination.

Food safety

The Act allows authorised officers to inspect and seize unsafe food. They can compel food outlets to comply with regulations and they can ban processes, equipment, premises or individual people from participating in any business to do with food.

Offences relating to food safety

Rendering food injurious to health (section 7 of the 1990 Act)
The offence can only be committed in four specified ways:

- adding any article or substance to the food
- using any article or substance as an ingredient in the preparation of the food
- abstracting any constituent from the food
- subjecting the food to any other process or treatment.

This appears to leave outside the scope of the offence, food that is injurious to health because it has *not* been subjected to a necessary process.

Selling food that fails to comply with food safety requirements (section 8)
Food can fail to comply with food safety requirements in three situations:

- it has been rendered injurious to health
- it is unfit for human consumption
- it is so contaminated (whether by extraneous matter or otherwise) that it would not be reasonable to expect it to be used for human consumption in that state.

Offences relating to consumer protection

Selling food not of the nature, quality or substance demanded by the purchaser
This section covers such things as the sale of soya where the purchaser demanded meat, and the sale of beef where the purchaser demanded lamb. However, the offence most commonly charged is the sale of food not of the quality demanded by the purchaser. An example of this is where the consumer might reasonably expect a certain maximum or minimum fat content but the food contains less or more than is expected.

Falsely describing or presenting food
Food must not be labelled in such a way that the reasonable consumer might be mislead about what it contains or about its quality. An example of this would be if the labelling stated ‘pure orange juice’ when in fact the product contained juice from some other fruit.

7.3 Continuing regulation: the Food Standards Act, 1999

The legal regulation of the food industry is not a once-and-for-all exercise; it requires constant review. In 1999 the Government introduced the Food Standards Act which allowed the setting up of a body called the Food Standards Agency. The UK Food Standards Agency (FSA) is an independent organisation established by the Government on 1 April 2000 to protect the public’s health and consumer interests in relation to food.

The Food Standards Agency

The Food Standards Agency aims to:

- reduce food-borne illness by improving food safety all along the food chain,
- encourage healthy eating,
- promote informative food labelling,
- promote best practice in the food industry,
- improve the enforcement of food law.

The FSA website provides information for consumers on food law, the food industry right through the food chain, food labelling, healthy eating, advice on how to store, handle and cook food safely, and information on its independent scientific research and survey work, to ensure that its advice is based upon the most up-to-date food science. Research projects include research into novel foods, meat hygiene, nutrition, food allergies, and food additives. The site also provides access to press releases, an 'ask an expert' service for healthy eating advice, information on the food hygiene campaign, and information about FSA centres in Scotland, Northern Ireland and Wales.

The other main impetus for legislative change comes from the European Union. As a result of its membership of the Union, the United Kingdom is required to ensure that its food laws are compatible with those of the European Union.

Additives

The use of additives is closely controlled. There is an exhaustive list of permissible additives (which term includes colouring, preservatives, antioxidants, emulsifiers, thickeners, stabilisers, flavourings and sweeteners); and the use of particular additives can only be approved subject to strict conditions.

- The additive must satisfy specified purity criteria. It must be demonstrated that the additive would be used to fulfil a reasonable technological need that cannot be achieved by other practicable means.
- The additive (at the proposed level of use) must present no risk to the health of the consumer (on the basis of evidence from initial and on-going scientific testing)
- There must be evidence that the use of the additive would have demonstrable advantages for the consumer.

Irradiation of food

Irradiation is permitted only under licence and must be clearly indicated by labelling.

Claims

Claims that food has certain properties or is suitable for particular needs (for example, energy claims or slimming claims) are strictly controlled.

Labelling

Labelling has become a central element in consumer protection. Subject to certain product-specific regulation, all foods are required to be labelled with:

- the name of the food;
- a list of ingredients;
- the quantity of certain ingredients or categories of ingredients;
- the appropriate durability indication ('sell by' date for perishable foods, 'best before' date for other foods);

- any special storage conditions or conditions of use;
- the name and address of the manufacturer or packer, or a seller established with the EC;
- particulars of the place of origin if necessary to avoid misleading the purchaser to a material degree;
- instructions for use if necessary.

Nutrition labelling

Nutrition labelling (information relating to energy, protein, carbohydrate, fat, fibre, vitamin content) is compulsory only where nutrition claims are made for the food in question. However, although otherwise voluntary, the practice is widespread.

Contact materials

Contact materials (notably plastics) which are intended to come into contact with food must be so manufactured that they do not transfer their constituents to the food in quantities that would endanger human health or cause a deterioration in the food, or an unacceptable change in its nature, substance or quality.

CHAPTER 8 THE HUNGRY WORLD

The world is not short of food, but many people are severely undernourished, and every year millions of people die of hunger. The problem is that, while the world produces more than enough food to feed everyone many countries do not. The food that is produced is not shared equally between everyone, so that many of the poorest people receive less than their daily needs.

'The Hungry World' does not imply that there is a single food problem which affects the whole world, nor that we should be searching for a single solution. There are many problems, each requiring its own solution. In any situation, the problems are usually many and interlocking. So single solutions on their own are often ineffective.

Nevertheless, a shortage of food has been attributed to a number of factors, which contribute to the problem to different extents in different countries. Amongst these factors are the following.

- Population growth. This factor is arguably more apparent than real. Many countries, even European countries, have had very large population increases without there being any problem at all with food supplies. Where other factors have already created a food problem, population growth makes matters worse.
- Some regions produce less food than their potential would suggest. There are many reasons for this: drought, flood and plagues of insects are just a few. In some cases improvements in farming practice might be beneficial.
- Unequal distribution of food within and between countries.

We shall consider each of these factors in turn, with examples from different parts of the World.

We shall concentrate primarily on issues connected with science, though these often overlap with matters of economics and politics.

8.1 Population growth

A report from the Food and Agriculture Organisation of the United Nations at the end of the twentieth century pointed out that the previous fifty years had seen unprecedented growth in the population of our planet. In 1950 the world population was only 2.5 thousand million. By 2000 it had risen to 6 thousand million.

During 2000-2050 the population of developing regions is expected to grow by another 59%. There are likely to be marked differences between regions. The added percentage could range from 16% for developing Eastern Asia to 100% for Western Asia and 137% for sub-Saharan Africa.

On average, there was more food per person in 2000 than had ever been available on the globe. In the second half of the twentieth century, food production more than kept up with population growth. In 1995, world supplies of food for direct human consumption were 18% greater per person than in 1965. This was in a period when the world population had increased by 70%. These figures are global averages, however; the extra food and the extra population have too often happened in quite different places.

In any case there is no guarantee that food supplies will keep up with population growth in future. From 1997 to 1998 food production worldwide only increased by 0.5 %. This was the lowest figure since 1993.

The most productive agricultural systems are in industrialized countries where there is usually little or no population growth. In many developing countries, agricultural production keeps falling behind the rapidly growing population. Most of the countries concerned lack alternative economic resources to import increasing quantities of food. Some of the reasons for this are mentioned in the comment box at the end of this chapter.

Few countries with high rates of population growth (above 3%) have succeeded in keeping annual growth in line with the growth of their populations.

Access to food within countries can be very uneven. About 1300 million persons throughout the developing regions live on the equivalent of less than one US dollar a day. Even where there is enough food, poor people go hungry. More than 800 million people, most of them in developing countries, do not have enough food to meet their basic nutritional needs.

COMMENT: Age and health issues

There is a gradual increase in the proportion of adults and elderly people in human societies. In developing countries the proportion of population over 60 is now about 8% but is expected to rise to 21% by 2050. At the same time the percentage of dependent young people under age 15 is expected to decline to 20% from 33% during the same period. This has implications for agriculture and food production as the needs of society change.

The AIDS pandemic makes it hard to increase agricultural production in many countries. This can increase malnutrition. The sickness and death of working adults affects labour supply and its division between adults and children.

8.2 Producing more food

Water

Over 70% of the Earth's surface is covered by water but less than 3% is fresh water upon which plants and animals depend. Even 3% is more than enough to grow all the food needed if the water available were well distributed and well used. However rain does not fall where it is most needed.

For instance, Iceland is water-rich and has over half a million cubic metres of rain per person per year. Egypt has only 20 cubic metres per person. It depends on the River Nile to irrigate its cropland, so agreement has to be reached with the eight countries the Nile flows through before it gets to Egypt on how to share the water.

Only about 15% of the world's cropland is irrigated, but it produces more than a third of the total harvest. Irrigation increased five-fold during the twentieth century and perhaps holds the key to producing more food in the developing countries.

Irrigation

There have been major irrigation projects in many parts of the World, but the degree of success has been variable.

Lake Chad in Africa was the scene of one project, but no land has been irrigated because completion of the project coincided with reduced rainfall in the region.

Another project diverted water from the Rivers Syr and Amu, which normally flow into the land-locked Aral Sea in Central Asia. The area of irrigated land was nearly trebled, and for a time large crops of cotton were produced. But the environmental impact of diverting so much water had not been properly considered. The Aral Sea has shrunk by 60% and its salinity has trebled. Fishing has ceased. Windblown salts from the dried-up sea bed are being deposited on previously fertile land, and on glaciers in the region causing them to melt. Even the irrigated land is losing its fertility because salts build up in the soil as large volumes of irrigation water evaporate.

Improving irrigation

However, much could be done by improving existing irrigation systems. Irrigation techniques in many parts of the World are no different from the methods that archaeologists find were in use 5000 years ago. Water runs in channels from reservoirs to the fields where it is allowed to flood across the surface. It is estimated that this method wastes 60% of the water drawn from rivers for irrigation. Water is lost by evaporation before it reaches the fields, and the land nearest the irrigation channels can become waterlogged before land further away receives enough water.

New technologies can reduce wastage to 5%. For example, 'drip irrigation' delivers water directly to the plants through a network of perforated pipes laid on or just below the surface of the field. But this is an expensive method only normally suitable for high value fruit crops. A simpler improvement is to supply water to fields in a series of 'surges' rather than continuously. Even putting rows of stones across the slope in a field so the water does not run downhill so quickly is a useful improvement. And many irrigation systems could be improved by regular maintenance.

Small systems which can be managed by the local farmers seem to have advantages over large systems that need to be managed by governments and their officials.

Extending the use of irrigation can bring great benefits, but only if the systems use appropriate technology and the water supply is sustainable.

Farming methods

Traditional farming methods may not be the most productive, but deliberate experimentation with alternative methods and different varieties is not really an option when the failure of the crop means that the family may starve. Patient observation of natural events has led to some very sensible methods of farming.

For instance, Andean farmers plant ten or more varieties of potato to ensure they get a reasonable crop every year: one variety is resistant to frost, another survives drought well, a third is resistant to fungus and so on.

New methods

Bringing knowledge to farmers, partly through education making them more literate, can help them to improve farming methods. For example, oil seed production is being improved in India by showing farmers how to grow two crops of groundnuts each year. And the farmers are told about the sunflower which is a useful alternative because it is deep rooted, whereas the shallow rooted groundnut is susceptible to any failure of the monsoon rains.

Vegetable oil is traditionally produced by an animal-powered version of a pestle and mortar but 10% more oil can be obtained by the use of powered compression to expel the oil followed by solvent extraction. This, however, provides a good example of the influence of economics and, to some extent, politics. Animal power is under the direct control of the user and is cheap whereas the more modern use of engines is expensive and may put the user at the mercy of big commercial interests.

Farm chemicals

The use of fertilizers and pesticides (herbicides, insecticides and fungicides) has brought significant increases in food production by increasing yields and preventing losses. The use of pesticides increased greatly after World War II when the use of DDT appeared to offer an easy solution to pest control and the improvements in food production and health were dramatic. Then pests developed resistance to DDT. DDT was also found to damage animal life far from the original sites of application by passing up the food chain.

Nowadays people are learning to be more careful. The use of pesticides is better controlled and more varied methods are considered: the Food and Agriculture Organization of the United Nations, the FAO, introduced a Pesticide Code to control the export from industrial countries to developing countries of banned or severely restricted pesticides.

The FAO also advocates **integrated pest management**, IPM, to control pests in an ecosystem. For instance, after many years of laboratory and field work, the best integrated set of solutions to an invasion of coconut palms by the rhinoceros beetle in the South Pacific has been:

- introducing a virus lethal to the beetle;
- growing cover-crops over the beetle’s breeding sites;
- limited spraying.

Integrated Pest Management solutions are likely to be complex. Their successful implementation depends on well-educated farming communities who can appreciate the principles behind the methods advocated.

Biodiversity

The development of large-scale farming, with its emphasis on mechanization and high yields per acre, has often resulted in the planting of far fewer traditional varieties, The use of a single variety, however high yielding in successful years, is not without risks.

Rice

Rice, the staple food of many people, provides some cautionary case studies.

From one wild rice species, *Oryza sativa*, farmers have created over 50 000 distinct varieties, and without the help of professional plant breeders.

In recent years the International Rice Institute has developed rice varieties with one-third higher yields which can mature in 100 days – 33% faster than traditional varieties. Three-quarters of the new rice varieties being grown world-wide are related to just one dwarfing variety, *Cina*. When grown on a large scale some of the varieties have succumbed to virus diseases and pests. The response has been essentially technical, aimed at producing another variety. But to do this, plant scientists have had to seek out traditional varieties for cross-breeding, only to find they have been abandoned in favour of the new high-yielding variety that had failed. 'Miracle rice has lead to miracle locusts' as the farmers say in Pakistan.

Security through diversity

The FAO recognizes the value of diversity, especially in developing regions. For instance, in one village of Sierra Leone, before war devastated the country in the eleven years up to 2002, farmers planted 49 different varieties of rice. Each variety was matched to its soil and water supply. The farmers planted quick-growing varieties to feed themselves early in the season. They planted other varieties in the waterlogged fields in the valleys, and yet others on the much drier hillsides. The intention was that, when disease came, it would probably attack only a few of the varieties planted. In countries like India, which have concentrated on a few high-yielding varieties, disease may attack a whole nation's food supply.

8.3 Feeding everyone

Apart from knowledge of effective farming methods, the other essential requirements are land and water. Both of these may be in short supply.

Land degradation may be a problem – land that is losing its productivity and turning into waste land. This can ultimately result in desert-like conditions.

Land degradation

The contrast is between sustainable farming, farming that has continued in many parts of the World for generations without loss of soil productivity, and farming practices that degrade the soil so that it is lost by erosion or lacks necessary nutrients. In Britain, East Anglia is becoming an example of this. Deforestation is one way of freeing more land for farming, and poor farmers have traditionally used 'slash-and-burn' for clearing forest. The land made available is usually of poor quality for growing crops and the farmer has to move on. If the forest is left to regenerate, this is a form of sustainable farming. But large-scale deforestation, for logging to supply the demand from industrial countries or for ranching by wealthy landowners, can lead to permanent land degradation. What is happening in Brazil is an example of this.

Cash crops

Much of the land that is available for farming is used by wealthy landowners to grow cash crops: the number of landless rural households in India is rising much faster than the population as a whole. Small farms are also being used for cash crops, even though the use of machinery and the crops' heavy demand for nutrients can result in non-sustainable farming. In Chad small farms have changed to growing cotton. In Senegal and The Gambia they grow groundnuts. As a result, some farmers have moved from the poverty and drudgery of subsistence farming to the relative affluence of a market economy.

Politics and economics have been shown to have a bearing even on this apparently hopeful development. For example, in Kenya, the manufacture of cotton clothing has benefited the population in industrial areas, but the removal of import tariff barriers to encourage this development has meant that Kenyan cotton growers cannot compete financially with heavily subsidised imports of cotton from the USA.

Rather than switching to cash crops, there would seem to be a need to make the growing of food crops economically more attractive.

Remember that it is not only in the developing countries that poor people have a poorer diet than the better off. In the UK the long-term unemployed and people on the lowest incomes have poorer health and poorer physical development because of their diet.

8.4 Perspectives

Although there is enough food in the World to feed everyone, about 500 people are likely to have died of the effects of starvation while you have been reading this chapter.

It not enough to say that the situation is 'not fair' or that no one should be poor. Until we convert our emotional distress into action at the personal and national level the problems of the people of the developing world are only likely to gain attention at times of crisis. There has to be a thoughtful study of each problem and the setting of rational and precise goals to meet the basic needs identified.

One of the ways that we can help developing countries is through direct aid. This can take the form of money, food, technological know-how or trained helpers. Supplying free food is one of the easiest options, but except at times of crisis, can disrupt the local market. A more useful form of aid is in vocational programmes to help people to improve basic farming skills and make farming and life in rural communities a more attractive proposition. Providing the expertise and materials for digging wells to supply villages with clean water is one example. Another example is the building of dams and hydroelectric schemes to help the development of local industries, based on appropriate technologies. Unbiased analysis of needs and benefits is needed for all aid programmes. A technological investment programme can be run for five years on the money needed for one year of a food relief programme.

The Brandt Commission reported in 1979 that they saw 'no more important task before the World community than the elimination of hunger and malnutrition in all countries'. In March 2005 British Prime Minister Tony Blair said at the launch of the UK-led Commission for Africa 'There can be no excuse, no defence, no justification for the plight of millions of our fellow beings in Africa today.'

We have not made much progress in the last 35 years. We need to do better if there is not to be a catastrophe in the next 35 years. As humans we have been described as essentially altruistic, but it is all to easy to appeal to the selfish side of our natures. What might your contribution be?

Comment

It must be clear from reading this chapter that the world food problem is not a simple one to solve and that science alone cannot be the only means by which beneficial change can be brought about. If you want to think about this further you might research issues such as:

- Debt. It has been claimed that some countries have to pay more in interest on the money they have borrowed than they receive in direct aid. There is little chance of their repaying the actual loans but the interest alone is crippling enough. The G8 'Summit' in Edinburgh in 2005 seemed to hold out hope for a way forward on this issue.
- Civil war. Except when there is a sudden escalation of hostilities, news media tend to ignore long military disputes which convert meagre resources into materials for waging war.
- Trade barriers. Governments of industrialised countries have been accused of protecting their own industries by denying access to goods from developing countries.

You may be able to think of other factors which have a bearing on this.

Remember that the contents of this and other 'Comment' boxes are not examinable material.

Glossary

ACTIN Thin filament in a muscle structure

ALEURONE Part of the bran of a wheat grain

AMYLOPECTIN Branched-chain polymer of glucose, constituent of starch

AMYLOSE Linear polymer of glucose, constituent of starch

BACILLUS Rod-shaped bacterial cell

BASAL METABOLISM, ENERGY OF Minimum energy required to maintain essential bodily functions

BIODIVERSITY (in food production) Agricultural practice of planting a number of varieties of the same crop

BRAN Outer layers of wheat grain

BRITISH MEDICAL ASSOCIATION Professional organisation representing members of the medical profession

CALPAIN Proteolytic enzyme present in muscle

CAMPYLOBACTER JEJUNI Pathogenic food spoilage organism

CARBOHYDRATE Compound of carbon, hydrogen and oxygen where the ratio of H to O is 2:1

CASEIN Protein found in milk

CELLULOSE Polymer of glucose, indigestible by humans

CHORLEYWOOD BREAD PROCESS Commercial bread-making process involving mixing under reduced pressure

CLOSTRIDIUM BOTULINUM Pathogenic food spoilage organism

COCCUS Spherical bacterial cell

CURDLING Coagulation and separation of casein from milk

DEFRA Government department: Department of Environment, Food and Rural Affairs

ENDOSPERM Starchy inner part of a wheat grain

ESSENTIAL FATTY ACID Fatty acid, the absence of which causes disorder of some kind

EXPONENTIAL PHASE Time of very rapid reproduction of bacteria

FATTY ACID Long-chain carboxylic acid present in lipids

FIBRE, DIETARY Indigestible material, principally cellulose; assists passage of material through the bowel

FOOD A substance containing nutrients which is accepted as food by the community

FOOD AND AGRICULTURE ORGANISATION United Nations initiative dedicated to the relief of World hunger

FOOD SAFETY ACT 1990 Government Act regulating safety in the making, marketing and advertising of food

GENE A section of the DNA of an organism, responsible for an inherited characteristic

GLUTEN Protein constituent of wheat flour

HARDENING (OF OILS) Hydrogenation of an oily lipid to produce one which is a solid at room temperature

LAG PHASE Initial time during which a bacterium reproduces very slowly

LIPASE Type of enzyme which catalyses the hydrolysis of lipids

LIPIDS Esters of propane-1,2,3-triol with long-chain carboxylic acids

LIPOPROTEIN Combination of lipid and protein making up, e.g. cell membrane

LISTERIA Pathogenic food spoilage organism

MESOPHILIC (BACTERIA) Bacteria which function best at moderate temperatures, e.g 20–40 °C

MICROFIBRIL Cellulose rod-like structure in plant cell walls

MOULD A microscopic fungus, responsible for some food spoilage but also for beneficial change

MYOSIN Thick filament in a muscle structure

NUTRIENT One of six types of substance which must be present in a healthy diet

PASTEURISATION Mild heat treatment which kills or inactivates heat-sensitive pathogens

PATHOGEN Bacterium which causes disease

PECTIN Constituent of walls of plant cells

PERICARP Part of the bran of a wheat grain

PRIMARY STRUCTURE (OF PROTEIN) Sequence of amino acids in a protein molecule

PROTEASE Type of enzyme which catalyses the hydrolysis of proteins

PSYCHROPHILIC (BACTERIA) Bacteria which function best at relatively low temperatures, e.g 10–15 °C

SALMONELLA Pathogenic food spoilage organism

SARCOMERE Region between two Z lines in a muscle structure

SDS Sodium dodecylsulphate; used in sedimentation testing for gluten in flour

SECONDARY STRUCTURE (OF PROTEIN) Helical sections of a protein structure

SEDIMENTATION TEST Method of assessing the gluten content of flour

SPOILAGE ORGANISM Bacterium which makes food unpalatable and/or reduces nutritional value

STAPHYLOCOCCUS AUREUS Pathogenic food spoilage organism

STARCH Polymer of glucose, composed of amylose and amylopectin

STATIONARY PHASE Time during which reproduction rate of bacteria equals death rate

TERTIARY STRUCTURE (OF PROTEIN) Folded overall shape of a protein molecule

THERMOPHILIC (BACTERIA) Bacteria which function best at relatively high temperatures, e.g 55–65 °C

TRANSGENIC Describes an organism which has been genetically altered by adding or removing a gene

TURGOR PRESSURE Pressure exerted on the cell wall by water within a plant cell

UHT Ultra-high temperature processing; method of preserving some liquid foods

VITAMIN A dietary constituent, the lack of which causes a deficiency disease

WHEY Liquid derivative of milk from which the casein has been precipitated

YEAST Generally beneficial fungus often responsible for fermentation

Nuffield Advanced Chemistry

FOOD SCIENCE

Experiments

Contents

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Health and Safety

It is contrary to COSHH regulations to eat or drink in any laboratory which could be contaminated with hazardous chemicals. Nothing should be eaten in the laboratory during this Special Study. The tasting experiments must be specially organized and take place in rooms suitable for food tasting.

When food is being used in experiments, there is a great temptation to sample it, or to finish off unused portions. The dangers of eating in a laboratory should be obvious to you. An additional hazard in food experiments is for a treated sample to be mistaken for a fresh one.

No food should be removed from the laboratory. All materials used for experiments must be gathered up when finished with, and disposed of safely to avoid the possibility of the food being eaten by students from other classes.

See the safety notes given with each experiment.

Health and safety in school and college science affects all concerned: teachers and technicians, their employers, students, their parents or guardians, as well as authors and publishers.

As part of the reviewing process, these publications have been checked for health and safety. In particular, we have attempted to ensure that:
- all recognized hazards have been identified,
- suitable precautions are suggested,
- where possible, the procedures are in accordance with commonly adopted model (general) risk assessments,
- if a special risk assessment is likely to be necessary this has been pointed out
- where model (general) risk assessments are not available, we have done our best to judge the procedures to be satisfactory and of an equivalent standard.

It is assumed that:
- practical work is conducted in a properly equipped and maintained laboratory,
- rules for student behaviour are strictly enforced,
- mains-operated equipment is regularly inspected, properly maintained and appropriate records are kept,
- care is taken with normal laboratory operations such as heating substances and handling heavy objects,
- good laboratory practice is observed when chemicals are handled,
- eye protection is worn when risk assessments require it,
- any fume cupboard required operates at least to the standard of Building Bulletin 88,
- students are taught safe techniques for such activities as heating chemicals, smelling them, or pouring from bottles,
- hand-washing facilities are readily available in the lab.

Under the COSSH and the Management of Health and Safety at Work regulations, employers are responsible for carrying out risk assessments before hazardous procedures are undertaken or hazardous chemicals used or made. Teachers are required to co-operate with their employers by complying with such risk assessments.

However, teachers should be aware that mistakes can be made and, in any case, different employers adopt different standards. Therefore, before carrying out any practical activity, teachers should always check that what they are proposing is compatible with their employer's risk assessments and does not need modification for their particular circumstances. Any local rules issued by the employer must always be followed, whatever is recommended here.

Model (general) risk assessments have been taken from, or are compatible with:
CLEAPSS Hazcards (see annually updated CD-ROM)
CLEAPSS Lab handbook (see annually updated CD-ROM)
CLEAPSS Recipe cards (see annually updated CD-ROM)
ASE Safeguards in the school laboratory 10th edition 1996
ASE Topics in Safety 3rd edition, 2001
ASE Safety reprints, 2000 or later

Clearly, teachers must follow whatever procedures for risk assessment their employers have laid down. As far as we know, all the practical work and demonstrations in this course are covered by the model (general) risk assessments detailed in the above publications, and so, in most schools and colleges, you will not need to take further action.

If teachers or students decide to try some procedure with hazardous substances beyond what is in this course, and you cannot find it in these or other model (general) assessments, then the teachers' employer will have to make a special risk assessment. If the employer is a member, then CLEAPSS will act for them. Otherwise the ASE may be able to help.

Only the teacher can know when the school or college needs a special risk assessment. But thereafter, the responsibility for taking all the steps demanded by the regulations lies with the employer.

Investigations will involve independent action by the student. Our notes on investigations warn students to carry out a risk assessment; students should be responsible for safety in the first instance and credited in any assessment for making safe plans. Nevertheless, proposals must be seen by the teacher and who must make an appropriate check, particularly with respect to safety, on what will go on. The teacher will need to take particular care if students consult library books published before modern safety standards came into force or get ideas from the internet.

Experiment 1 Investigating the glucose content of drinks

See Chapter 2 Nutrients in foods

/!\ SAFETY
Drink nothing in the lab

The glucose content of liquids can be measured by titrating boiling Benedict's solution with a sample of the liquid.

Quantitative Benedict's solution contains potassium thiocyanate as well as copper(II) sulphate so white copper(I) thiocyanate is precipitated instead of red copper(I) oxide.

Procedure

a Fill a burette with a glucose solution of known concentration, about 0.5% glucose.

b Using a safety pipette, measure 25.0 cm^3 of quantitative Benedict's solution into a wide mouth conical flask, add 10 g of anhydrous sodium carbonate (IRRITANT) and a boiling stone.

c Heat until the sodium carbonate has mostly dissolved and then titrate with the glucose solution, rapidly at first and then dropwise at intervals of 20–30 seconds until the blue colour has disappeared.

d **Keep the solution boiling** (*Care!*) during the titration and add pure water if necessary to compensate for losses due to evaporation.

1% aqueous methylene blue may be used as an indicator.

e Repeat the titration, filling the burette with the liquid being investigated. The end-point should lie between 15 and 30 cm^3. Dilute or concentrate the liquid if the end-point lies outside these limits.

Questions

1 Describe the chemistry of the reactions involved in the titration.

2 Calculate the concentration of sugars in your liquid, measured as glucose.

3 What additional procedure would be necessary to measure the concentration of any sucrose present?

Experiment 2 Investigating the effect of cooking on the vitamin C content of cabbage

See Chapter 2 Nutrients in foods

Standardization of indicator solution

Before the indicator is used to determine the vitamin C content of cabbage, it must be standardised – to find the number of mg of vitamin C equivalent to 1 cm^3 of dye solution. The indicator has been made up by dissolving 0.4 g of the dye 2,6-dichlorophenolindophenol in 200 cm^3 of warm water, filtering the solution, and making up the filtrate to 1 dm^3 with pure water, to give approximately 0.04 % solution (400 mg dm^{-3}).

a Use a pipette, with safety filler, to transfer 25.0 cm^3 of standard vitamin C solution (200 mg dm^{-3}) to a conical flask and titrate rapidly with the dye solution from a burette.

b As the dye is run in, the deep blue colour of the dye is discharged to give a colourless solution. The end-point is taken to be when the pink coloration, due to the dye, persists for 10 seconds.

c A blank titration using 25.0 cm^3 of 5% phosphoric(v) acid solution must be carried out to the same end-point.

Calculation

The number of mg of vitamin C equivalent to 1 cm^3 of dye (**dye factor**) may be calculated by deducting the blank titre from the standardisation titre and using the concentration of vitamin C.

Dye factor $= F$ mg cm^{-3}

$= $ mg of vitamin C equivalent to 1 cm^3 of dye solution

So dye factor (F)

$$= \frac{\text{volume of standardised vitamin C/cm}^3 \times \text{concentration of vitamin C/mg dm}^{-3}}{(\text{standardisation titre/cm}^3 - \text{blank titre/cm}^3) \times 1000}$$

Continued on next sheet

Experiment 2 Investigating the effect of cooking on the vitamin C content of cabbage *continued*

Estimation of vitamin C in uncooked cabbage

a Weigh out 50 g of cabbage and put it in a liquidiser with 250 cm^3 of 5.0% phosphoric(V) acid. Liquidise at high speed. Filter off the liquid into a 500-cm^3 measuring cylinder, using a muslin filter.

b Make up the volume of extract plus washings to 300 cm^3.

c Titrate 25.0 cm^3 of the extract with indicator solution as before. All titrations should be carried out in duplicate.

Calculation

Mass of sample = 50 g

Volume of extract solution = 300 cm^3

Volume of dye titre = V cm^3

Work out for yourself that:
100 g of sample contain $V \times F \times 300 \times 2/25$ mg of vitamin C

Estimation of vitamin C in cooked cabbage

a Simmer 50 g of cabbage in 100 cm^3 of water for 10 minutes, allowing some of the water to evaporate. Repeat the above experiment on the cooked cabbage.

b Determine the loss in vitamin C on cooking cabbage for 10 minutes.

c If time allows, repeat the titration on the residual water and determine the amount of vitamin C present in solution.

Other suggestions

You could also try using cabbage leaves from different sources:

- outside leaves
- inner leaves
- freshly picked cabbage
- an old cabbage

Experiment 3a Taste

See Chapter 3 Quality of food

Solutions of sodium chloride, citric acid, caffeine, and sugar have been put in four separate cups labelled A, B, C and D, not necessarily in that order.

- Taste the four solutions and identify their tastes. If you cannot detect the flavours, ask your teacher for more concentrated solutions.

/!\ SAFETY

It is contrary to COSHH regulations to carry out these experiments in a chemistry laboratory.

Solid caffeine is HARMFUL.

Experiment 3b
The tongue and the primary taste sensations

a Use the same four solutions as in Experiment 3a.

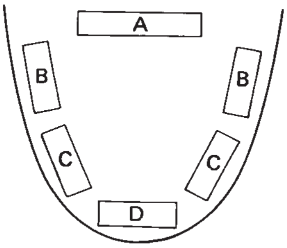
Draw up a small volume of sodium chloride solution into a drinking straw.

Put a small quantity of the solution on to area A of your partner's tongue.

b Make a note if your partner finds the solution salty.

c Repeat this on each of the areas of the tongue, and determine the areas sensitive to the sensation of saltiness. Rinse your mouth with fresh drinking water between samples.

d Repeat the experiment using the other solutions: citric acid, caffeine, and sucrose.



Areas of the tongue

Experiment 4 Which substances are involved in the browning reaction?

See Chapter 4 Microbial and biochemical changes in food

To find the substances involved in the browning reaction, we would first have to identify the various constituents in the apple or potato. Next it must be experimentally determined which constituent compounds increase the rate at which darkening takes place when added to an apple or potato segment. This is a long and complex process and outside the scope of this course.

We can, however, make use of information available in similar browning reactions. For example, conversion of green tea leaves to black tea leaves is known to be due to the presence of phenolic compounds. By treating samples of apple or potato with a variety of phenolic compounds we can determine which ones increase the rate of browning.

/!\ SAFETY
The apple samples should be held with tongs or tweezers. Wear eye protection as usual. Protective gloves should also be used when handling phenol solution because it can be absorbed through the skin.

Do not eat any of the apple samples; dispose of them safely when the experiments are finished.

a Cut six segments from an apple or potato, and put them separately in beakers or dishes, or watch-glasses.

b Wash the upper surface of the first with two portions of about 1cm^3 of solution A.

c Wash the second with solution B, and so on, until the sixth segment has been washed with pure water (control).

A 1% benzene-1,2-diol (catechol) solution

B 1% benzene-1,2,3-triol (pyrogallol) solution

C 1% benzene-1,3-diol (resorcinol) solution

D 1% benzene-1,4-diol (hydroquinone) solution

E 1% phenol solution HARMFUL

F pure water (control)

Questions

1 What is the order of the rate of browning of the treated surfaces?

2 Is there a structural feature common to compounds whose aqueous solutions speed up browning?

Experiment 5 When does the browning reaction take place?

See Chapter 4 Microbial and biochemical changes in food

a Cut an apple or potato in four. Take one quarter and macerate it (crush it), and put it on a watch-glass next to another quarter segment.

b To both samples add enough 1% benzene-1,2-diol solution (3–4 drops) to wash the surface. Compare the rate at which both samples brown.

c When the quarter segment is brown, cut a small piece and also *break* a small piece from the segment. Note the colour of the freshly exposed surfaces.

d To both fresh surfaces add 1% benzene-1,2-diol solution and note which surface browns more rapidly – the cut or the broken surface.

Experiment 6 Is the reaction due to micro-organisms?

The spoilage can be due either to micro-organisms or to enzyme action.

Questions

1 Which type of spoilage would be faster: micro-organism or enzyme action?

2 Which is more likely to be found in the interior of fruits and vegetables, micro-organisms or enzymes?

Instructions

a Soak one slice of apple or potato in a 1% solution of phenol for 1 minute – *Care!* (This should kill any micro-organisms present, but will not inactivate enzymes.) Soak a similar slice in pure water as a control.

/!\ Safety
Phenol is HARMFUL – wear gloves

b Use tongs to remove the slices, shake off excess liquid, and wash the upper surfaces of both slices with 3–4 drops of 1% benzene-1,2-diol solution.

Questions

3 Is there any significant difference in the rates at which the two segments brown?

4 Is the reaction due to micro-organisms?

5 What is the effect of temperature on the rate of a non-enzymic reaction?

6 How would you expect the rate of an enzyme-catalysed reaction to change with temperature?

Instructions

a Cut four apple or potato slices and treat as described below.
Sample A: Immerse in a water bath at 100 °C for 1 minute.
Sample B: Immerse in a water bath at 60 °C for 1 minute.
Sample C: Immerse in a water bath at 40 °C for 1 minute.
Sample D: Immerse in pure water at room temperature for 1 minute.

b Remove the slices, using tongs, shake off excess liquid, and wash the surfaces with 3–4 drops of 1% benzene-1,2-diol solution.

c Compare the rates at which the four samples brown.

Q7 Do these experiments suggest that the browning reaction in the apple or potato is enzymic?

Experiment 7 Does the reaction require air or some part of the air?

See Chapter 4 Microbial and biochemical changes in food

a Put three slices of apple or potato in three separate boiling-tubes.

b Wash the upper surfaces with 3–4 drops of 1% benzene-1,2-diol solution, flush, and hold:

A in an atmosphere of nitrogen
B in an atmosphere of carbon dioxide
C under reduced pressure.

c Wash the fourth slice similarly with 1% benzene-1,2-diol solution and leave exposed to air, as a control. Note the rate at which various slices brown.

Q1 Which component in air is responsible for the browning in apple or potato?

You should now be able to suggest methods of controlling the browning reaction. You can obtain further hints by re-reading sections 4.1 to 4.5 in the *Food science* students' text.

Experiment 8 Can ascorbic acid be used to control the browning reaction?

a Look up the structure and properties of ascorbic acid.

b Take six slices of apple or potato, and soak one in each of the following solutions for 2 minutes.

A 5% ascorbic acid solution
B 3.5% ascorbic acid solution
C 2.5% ascorbic acid solution
D 2% ascorbic acid solution
E 1% ascorbic acid solution
F pure water (control)

c Remove the segments, shake off excess solution, and wash the upper surfaces with 3–4 drops of 1% benzene-1,2-diol solution.

d Note the rate at which each slice browns.

Questions

1 Does ascorbic acid stop browning?

2 Does ascorbic acid retard browning in proportion to its concentration?

3 From the structure and properties of ascorbic acid, can you suggest how it may be acting?

4 Can ascorbic acid be used to restore the fresh colour of slices which have started to brown?

5 From the safety point of view, is ascorbic acid a suitable substance to add to fruit and vegetables?

Experiment 9 Controlling browning by inactivating the enzyme

See Chapter 4 Microbial and biochemical changes in food

a Take 7 slices of apple or potato and soak one in each of the following solutions for 2 minutes.

A 2% hydrochloric acid

B 2% citric acid

C 2% sodium hydrogensulphite (gives TOXIC gas with acids)

D 2% sodium chloride

E 2% sucrose

F boiling water

G cold pure water (control)

b Remove the slices, shake off excess solution, and wash the upper surfaces with 3–4 drops of 1% benzene-1,2-diol solution. Note the time taken in each case for browning to take place.

/!\ SAFETY
Do not to eat any of the apple samples. Dispose of them safely when the experiments are finished.

Q1 Which methods of control are less desirable as methods of controlling browning, and why?

Experiment 10 Making curd from milk

a Measure 10-cm^3 portions of whole pasteurized milk into 4 boiling tubes, and warm in a water bath to 37 °C.

b Add 1 cm^3 of rennet solution to one of the tubes. Repeat the process for the other enzyme solutions available, keeping the fourth tube as a control.

c Record the times for a 'partial set' when particles cling to the sides of the boiling tubes, and also for a 'full set' when a solid curd has formed.

Q1 Which enzyme produces the fastest 'set'? What other factors would a cheese maker have to consider before adopting that enzyme?

d If time is available, investigate the effect of pH by repeating the experiment with the addition of 1 cm^3 of 1M acids or bases to the milk.

Q2 What pH values did you achieve, and what interpretation can you suggest for your results?

e You could also investigate the effect of other factors on setting time.

Q3 What factors are worth investigating? What results would you predict?

Experiment 11 The SDS sedimentation test for gluten

See Chapter 6 Cereal science

When ground flour is suspended in an acidified solution of sodium dodecyl sulphate (SDS), a detergent, the insoluble protein fraction swells and affects the rate of sedimentation. The higher the sedimentation volume after 30 minutes, the higher the protein content and the better the protein quality.

a Measure out 6.0-g samples of well-ground flour.

b Measure 50 cm^3 of pure water into a *stoppered* 100-cm^3 measuring cylinder and, cautiously, so as to avoid a head of foam, measure 50 cm^3 of the standard SDS-lactic acid solution into a 50-cm^3 measuring cylinder.

c Add the weighed sample of flour to the water in the stoppered cylinder so that it all falls into the water. Start timing, and shake the cylinder in the horizontal plane for 15 seconds.

d When 2 minutes have elapsed, shake the flour-water mixture again for 15 seconds.

e When 4 minutes have elapsed, shake the flour-water mixture again for 15 seconds; after shaking immediately add 50 cm^3 of the standard SDS-lactic acid solution and mix by inverting 4 times.

f After 6, 8, and 10 minutes, repeat the mixing by inverting 4 times at each time interval. After 10 minutes you must not move the cylinder again, so place it where the scale can easily be read.

g Conclude the experiment by reading the sedimentation volume when 30 minutes have elapsed from when timing started.

Question

What is the sedimentation volume of your flour after 30 minutes?

The higher the sedimentation volume the greater the protein content, provided your samples have been ground to the same degree of fineness. For a flour ground to a standard specification, a sedimentation volume of above 60 cm^3 means the flour is a ‘strong’ flour suitable for bread making; below 60 cm^3 the flour is more suitable for general baking.

Experiment 12 Gelatinisation temperature of starch

See Chapter 6 Cereal science

Method 1

During gelatinisation, the starch grains swell. This property can be used to determine the gelatinisation temperature. This swelling can be seen when you heat small samples of starch in water.

a Mix 10 cm^3 of water and about 0.5 g of starch in a test-tube. Heat the suspension in a beaker of water at 50 °C, stirring occasionally. Cool the tube under a tap.

b Remove one drop of the suspension and put it on a microscope slide. Cover with a coverslip and examine the grains for swelling and bursting. Repeat at 55, 60, 65, 70, 75 and 80 °C.

c Note the gelatinisation temperature of the starch which you have used.

Method 2

The thickening of the suspension during gelatinisation can also be used to determine the gelatinisation temperature.

d Mix 10 cm^3 of water with 2.0 g of starch in a test-tube. Put a thermometer in the suspension, put the test-tube in a beaker of water, and slowly heat the water until the starch gelatinises and the suspension thickens.

e Note the temperature at this point.

Experiment 13 Comparison of flour colour, and qualitative tests for flour improvers

See Chapter 6 Cereal science

Experiment 13A Comparison of flour colour

a Pour flour into a Petri dish. Press down gently and, using the edges of the dish as a guide, produce a flat surface using a spatula.

b Compare standard baker's flour and biscuit flour. Distinguish between background colour and bran specks.

c To emphasise the difference, immerse the dishes carefully in water for one minute, sliding them quickly in at an angle of about 45°. Slide them out of the water at the same angle, drain, and dry at room temperature.

d Note the colour difference when still damp and when dry.

Questions

1 To what is the colour difference due?

2 Darkening of the wet flour is speeded up by keeping the dish warm. Why?

Experiment 13B Qualitative test for ascorbic acid

e Pour a little 2% aqueous iodine solution over the wet flour in a Petri dish.

Question

3 What do you see? What explanation can you offer?

Experiment 13C Qualitative test for added iron

f Immediately before use, prepare thiocyanate reagent by mixing equal parts by volume of 1M aqueous potassium thiocyanate and 2M hydrochloric acid *(Care!)*

g Add about 1 cm^3 of the thiocyanate reagent to the dry flour in a Petri dish and leave for about ten minutes. Use untreated flour as a control.

Question

4 What do you observe, and why does it happen?