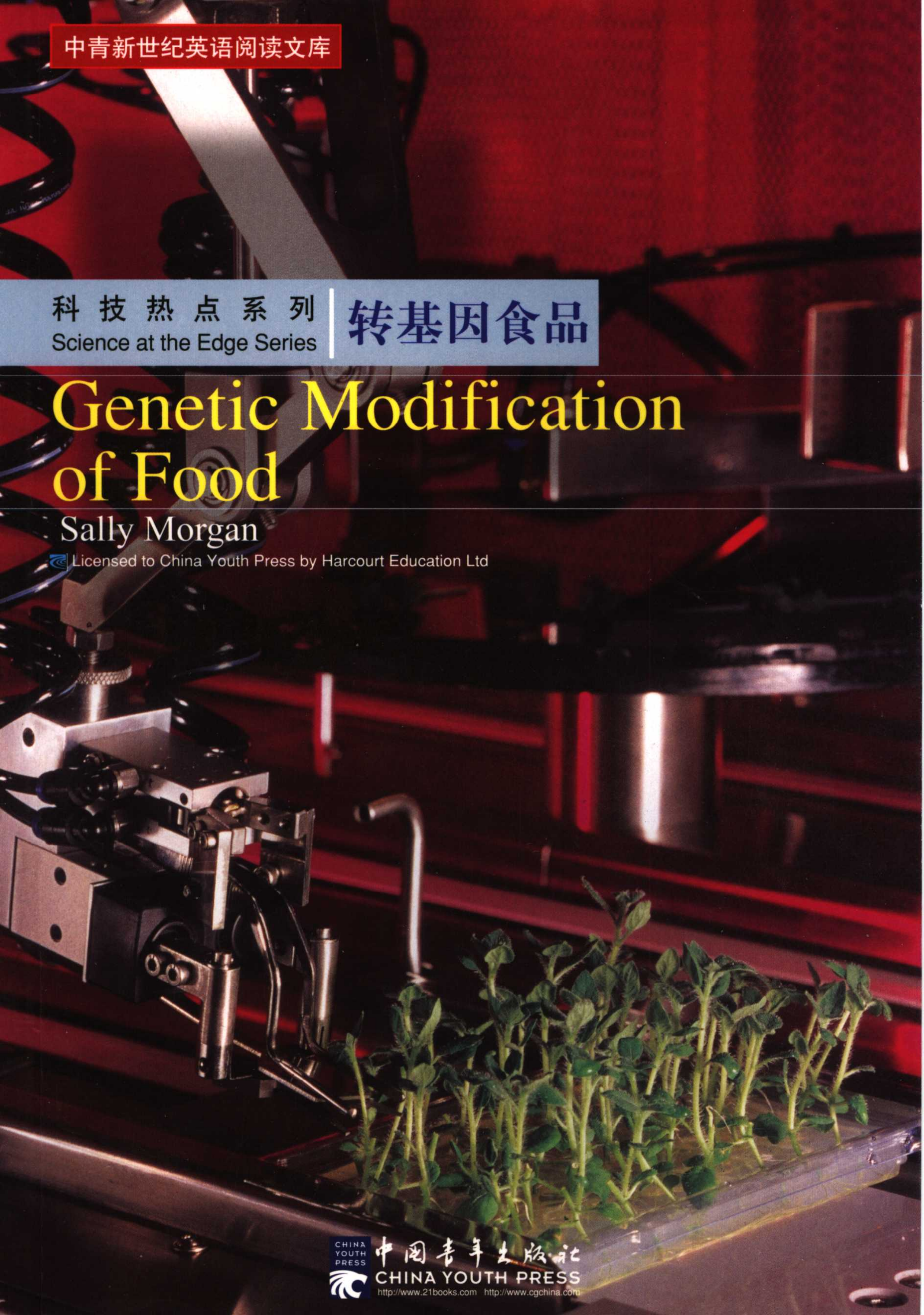

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Science at the Edge Series

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Genetic Modification of Food

Sally Morgan

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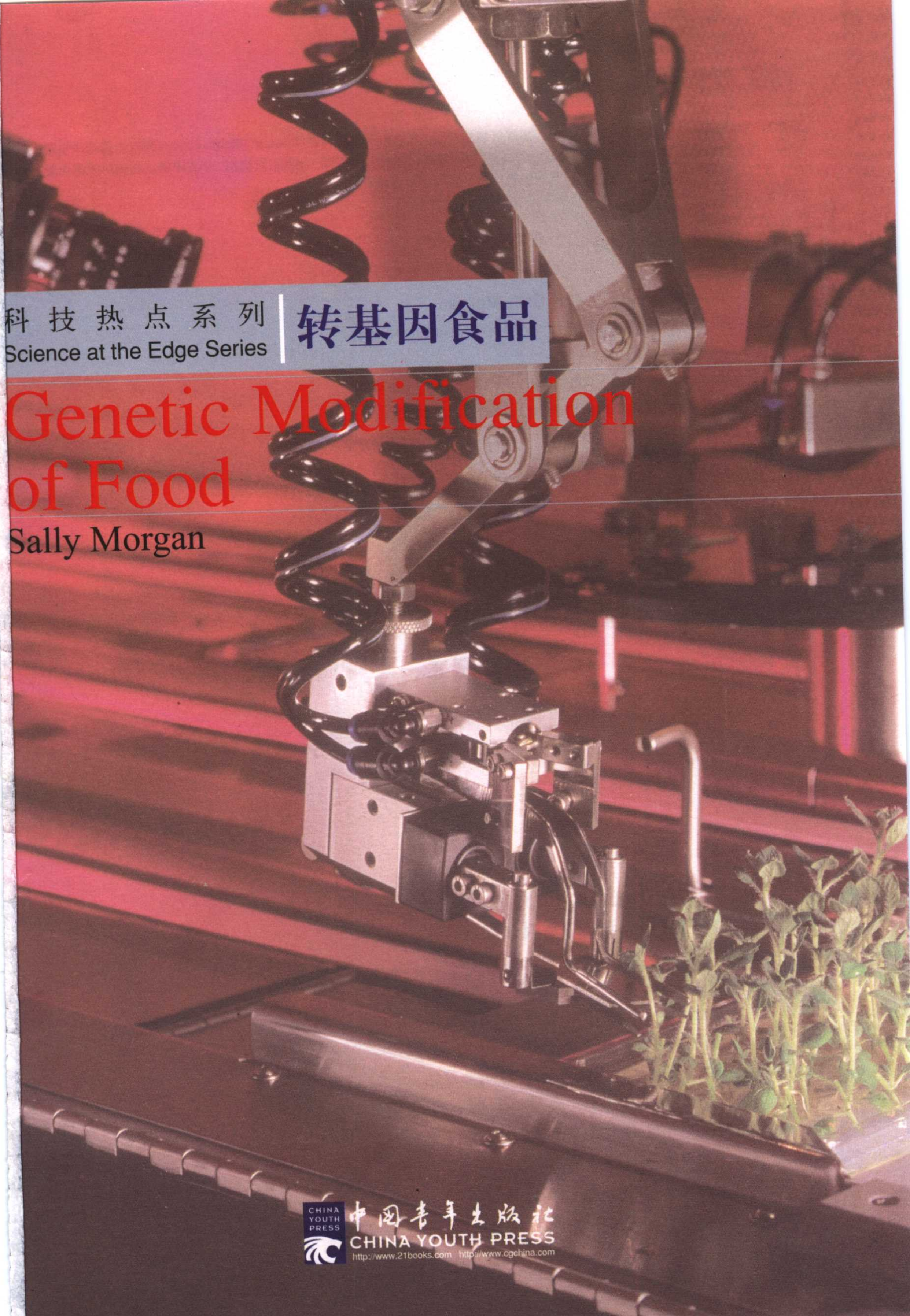

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Contents

Introduction

Each year around 600,000 children in the developing world go blind because they do not have enough vitamin A in their diet. Eating a couple of carrots a day would solve the problem, but there are no carrots grown in these countries. Within the next few years these children will be able to eat a special type of rice that has been genetically modified so that it contains enough vitamin A to stop them going blind.

Helping to feed the world

Malnutrition is just one of the challenges in feeding the world's population. At the turn of the Millennium, the human population stood at just over 6 billion. By 2030 there will be 8 billion people, a 30 per cent increase in just 30 years. This massive increase means that governments will have to solve huge problems of hunger and poverty, while also protecting the world's natural environment.

Meeting all of these challenges will require new knowledge gained by scientific advance, and the development of new technologies. Genetic modification or engineering is one of the most promising. It involves changing the genetic content of plants and animals in order to create foodstuffs with new characteristics.

A protest message from the environmental organization Greenpeace in a field of genetically modified soybeans in Iowa, USA.

New crops

Over the last ten years or so, scientists have created a range of new genetically modified (GM) crops. Now, commercial GM crops of soybean, cotton, tobacco, potato and maize are grown over millions of hectares in the USA, Canada, China, South Africa and Argentina. These crops are beginning to change the face of agriculture. But this change is not welcomed by everyone. During recent summers, protestors destroyed GM crop trials in both the UK and parts of Europe, and there were protests outside shops selling GM foods. The papers carried scary headlines such as 'Frankenstein foods' and 'Genetic nightmare'. This contributed to a widespread public rejection of genetic modification and the developments linked with it.

In this book you can read about DNA and discover how scientists can alter DNA through genetic engineering. You can find out how people can improve crops and livestock through a process called artificial selection, and how this process can be speeded up by using genetic engineering. Many types of genetically altered organisms and foods containing GM products are now sold to the public. Decide for yourself whether GM technology is a good or bad thing and if foods containing GM products are safe to eat.

> *'I have absolutely no anxiety. I am worried by a lot of things, but not about modified food.'*
>
> Dr James Watson, winner of the Nobel Prize for his work on DNA

A field of GM maize. Each year farmers in the USA plant thousands of hectares of GM crops.

Understanding genes

Every organism carries within it a set of instructions that control all the processes in its cells. The instructions are in the form of codes and they are stored in the genes. The genes themselves are made of DNA (deoxyribonucleic acid).

Genetic engineering or modification is the deliberate alteration of an organism's genes in order to give it new abilities. For example, bacteria have been given the gene to make the human **protein insulin**. Insulin is a substance that controls the level of **glucose** in the blood. The term 'genetically modified organism' (GMO) is used to describe a plant, animal or micro-organism that has had its DNA altered in some way by genetic engineering.

Early genetics

Our understanding of genetics dates back to the time of Gregor Mendel, who carried out experiments using peas during the 1860s. In one experiment he crossed tall peas with dwarf peas and found that all the **offspring** were tall. He concluded that the features of the two parents were not blended together to produce medium height peas. Instead the feature of one parent, in this case the tall parent, would appear in the offspring, while the other feature did not appear – it was masked.

Mendel's work forms the basis of modern genetics. It is important to remember that he discovered the laws of inheritance without any knowledge of cell structure or biochemistry. It was only at the beginning of the 20th century, when more powerful microscopes were invented, that biologists were able to study the genetic material found in the **nucleus** – the **chromosomes**. It wasn't until the 1920s that the substance that makes up the chromosomes – DNA – was discovered.

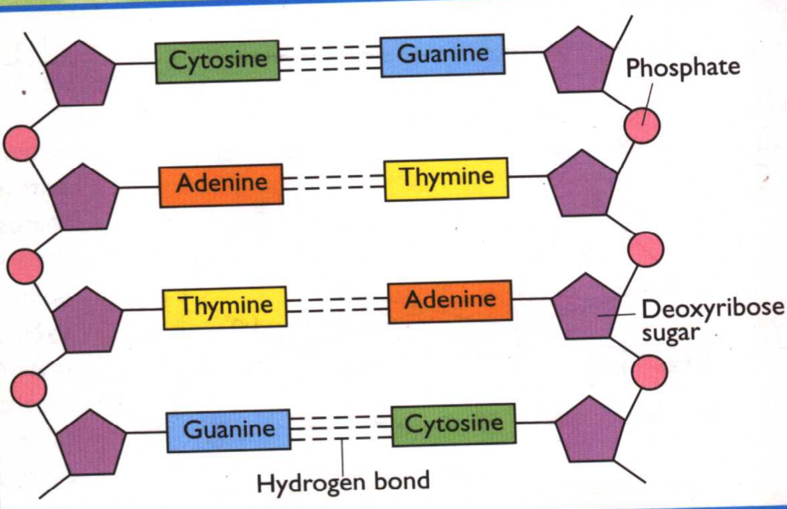
DNA structure

However, the major breakthrough in the understanding of genetics came in 1953, when Francis Crick and James Watson, with help from Rosalind Franklin, determined the structure of the DNA **molecule**. Since then, our knowledge of DNA and the genetic code has improved dramatically. This knowledge has enabled scientists to alter DNA and to transfer it between organisms.

DNA is a long molecule that consists of two strands twisted around each other to form a spiral called a **helix**. It can be likened to a twisted ladder: the sides of the ladder are made from alternating sugar and **phosphate** molecules, and the rungs are formed by molecules called bases. There are four different bases in DNA – **adenine** (A), **guanine** (G), **cytosine** (C) and **thymine** (T). A and G are large molecules, while C and T molecules are smaller ones. Each rung consists of one large molecule joined to a small one so that the width is always the same. In addition, A always pairs with T, and C with G. It is the order of bases along a strand of DNA that forms the genetic code.

Discovering the double helix

Probably the most exciting and significant biological discovery of the 20th century was solving the structure of DNA. In 1953, Francis Crick and James Watson published the details of their proposed structure of DNA. It had been known for some time that DNA was made up of sugar, phosphate and the four bases – adenine, guanine, cytosine and thymine – but nobody knew how these components were joined together. One of the vital parts of the puzzle was provided by Edwin Chargaff. During the late 1940s his research had found that the number of guanine bases equalled the number of cytosine bases and, similarly, the number of adenine bases equalled the number of thymine bases. Then, Maurice Wilkins and Rosalind Franklin took an 'X-ray' of the DNA, which showed that it formed a helix. Finally, Crick and Watson studied all the evidence and decided that DNA in fact formed a double helix.



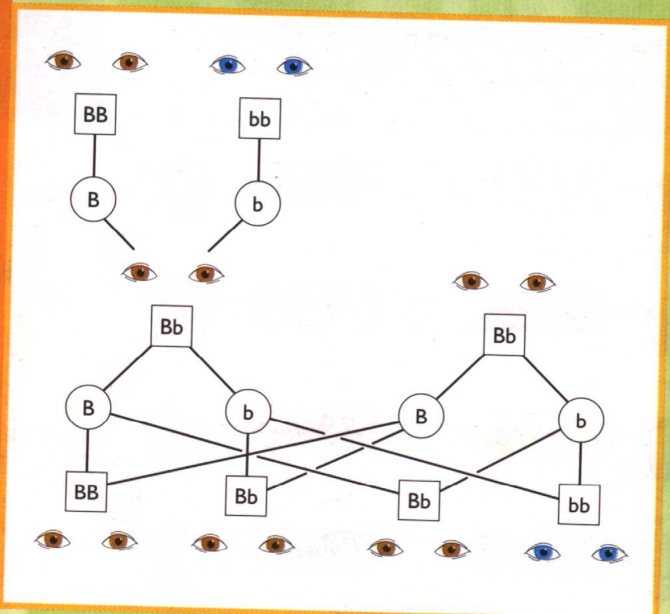
DNA is made up of sugar and phosphate molecules together with four different types of bases. The two strands of the DNA are held together by weak bonds called **hydrogen** bonds.

Genes and simple genetics

Genes control the manufacture of proteins in the cell. There are thousands of different genes, each responsible for making a specific protein. In a human cell there are two copies of each gene, one inherited from the father and the other from the mother. Genes can exist in two forms. One form is described as being **dominant** and the other as being **recessive**. The dominant form of the gene will usually mask the appearance of the recessive form. A person can have two dominant genes, one dominant and one recessive, or two recessive.

For example, humans can have brown eyes or blue eyes. The dominant gene codes for brown **pigment** in eyes and the recessive form codes for blue eyes. To have brown eyes, a person must inherit at least one gene for brown eyes. This means that both of the genes could be brown or just one. The outward appearance is always the same – brown eyes. To have blue eyes a person must have two blue-eye genes – in other words, they have to have inherited a blue-eye gene from each parent. This is a very simplified explanation of inheritance. In reality, most characteristics are controlled by several genes working together.

Inheriting genes



In this diagram, the letter B represents the gene for brown eyes and b represents the gene for blue eyes. (Remember a person inherits one gene from each parent.) If a brown-eyed person (BB) with two brown-eye genes mates with a person with blue eyes (bb), all the children will have brown eyes. They have one brown-eye gene and one blue-eye gene (Bb). The blue-eye gene is masked by the brown-eye gene. If one of these children mates with a person with the same genes, there are three possible outcomes. Three out of four children will have brown eyes (BB and Bb). One out of four will have blue eyes.

Recombinant DNA

In 1970, researchers discovered **enzymes** that could cut the DNA at specific points. These enzymes were essential to the process of cutting out a length of DNA and pasting it into the DNA of another organism. This created **recombinant DNA** – DNA made up of one or more lengths from different organisms. The first successful transfer of DNA took place in 1973. During the 1980s, the first transgenic animals and plants appeared. These were organisms that contained genetic material that had been artificially inserted from another species.

During the 1990s a wide range of genetically modified animals and plants were produced, followed by the appearance of GM foods in shops. It was at this stage that the first concerns about the genetic modification of foods started to appear in the media.

Key players

Genetically modified plants and animals are produced by a wide range of international biotechnology companies and research institutes. Before a GMO may be used commercially, it has to be approved by the food agencies of the various governments, for example the Advisory Committee on Novel Foods and Processes in the UK. In addition, international organizations such as the Food and Agriculture Organization (FAO) and the Codex Alimentarius Commission provide advice and guidance to governments and help to draw up internationally agreed standards.

Food and Agriculture Organization (FAO)

The FAO was established in 1945 as an independent organization of the United Nations. Its role is to promote agricultural development and to improve the nutritional standards of rural populations. It aims to provide all people with access at all times to the food they require for an active and healthy life. It offers direct development assistance; collects, analyses and distributes information; provides policy and planning advice to governments; and acts as an international forum for debate on food and agricultural issues. In 1999, a task force was set up to investigate the safety of GM food, and in 2001 it published a draft document called 'General principles for risk analysis of foods derived from biotechnology'. Risk analysis is the system by which governments consider the safety of foods and the measures that need to be taken to protect the public from any health risk.

Improving plants and animals

Plant and animal breeding has produced higher yield crops, plants with better pest and disease resistance, larger meat animals and dairy cows that produce thousands of litres of milk per year.

First farmers

Twenty thousand years ago or more, people were hunter-gatherers. They moved from place to place, hunting animals and collecting fruits and nuts from the wild. Then people settled down and started to grow their own crops. They sowed seed collected from wild grasses and at the end of the growing season they harvested the seeds. They soon learnt to save the seed from the plants that gave the best yield as this would produce a better crop. As a result of this selection process, the yield of the first cereal crops increased greatly.

The story of wheat

Wheat can be traced back to wild grasses that were growing thousands of years ago. These grasses had cells that contained 14 chromosomes. The different types of wild grasses were grown together and, by chance, a **hybrid** plant was produced. This grass had 28 chromosomes, double the original number. It was a far more vigorous plant and had larger seeds. Thousands of years later another lucky crossing produced the modern wheat plant, which has 42 chromosomes. Recently, a new cereal called Triticale has been produced by cross-breeding durum wheat (*Triticum*) with rye (*Secale*). Triticale is a versatile cereal with good yield and hardiness so it can be grown in harsh climates.

Natural selection vs artificial selection

Natural selection is one of the processes by which evolution occurs. In any group of individuals of the same species there will be a few that are better suited to the environment than others. The best adapted individuals survive and breed, passing on their genes to their offspring. This is often called 'survival of the fittest'.

Imagine several plants, from the same species, that have **prickly** leaves. The individual plants that have more prickly leaves are less likely to be eaten by grazing animals than those which have just a few prickles. So more prickly plants survive and produce seeds that grow into plants that also have more prickles. Over time, the less prickly plants disappear and the more prickly ones increase.

Farmers have replaced natural selection with artificial selection, that is selection based on a human decision. If this species of plant was good to eat, it is easy to imagine that the farmer would have chosen to grow the less prickly plants. It wouldn't matter that the plants were more vulnerable to grazing animals because the animals would have been kept out by fences. Gradually, the plants become less prickly. In effect, the farmer has selected certain genes.

A similar process has occurred with animals. The first animals to be domesticated were herd animals, that could be rounded up and kept in corrals (fenced-off areas). The early farmers bred from the smaller animals that were easier to handle and did not eat as much as the larger ones. Today, domesticated animals are bred for size, muscle and milk production.

Most calves are raised for beef, so farmers often cross a beef-type bull, such as the Hereford (right), with more **docile** dairy Friesians (left) to produce a calf that is good for beef and easy to handle.

Characteristics of artificial selection

Speed and success rates

The process of artificial selection is slow, especially with animals. Larger animals take several years to mature and only produce one offspring at a time. The process is also pretty hit and miss. Farmers choose the parents with care, trying to bring together animals with desirable features, for example a ewe and a ram that both have good quality wool. But there is no guarantee that two sheep with quality wool will produce offspring with even better quality wool. Sometimes the new combination of features in the offspring can actually make it worse, rather than better.

Changes can be seen more quickly in plants. First, the parent plants with the desirable characteristics are identified. **Pollen** is removed from the flowers of one plant and used to **pollinate** the flowers on another. Since plants generally produce many seeds, all the seeds are **germinated** and the new plants examined to see if there has been any improvement.

Mutations

Sometimes, a completely new variation appears in the genetic material of the offspring. These sudden changes are called **mutations**. Many mutations are harmful to the organism and it does not survive, but occasionally they are useful and the animal or plant passes on the mutation to their offspring. Some mutations have been known to greatly improve a crop plant or an animal.

A high yielding variety of wheat has a short stalk that is less **susceptible** to lodging (bending over after wind and rain). It also produces an 'ear' or seed head with many seeds that swell in size and ripen ready for harvest at the same time.

For example, in wild grasses the seed stalk shatters easily in order to disperse the seeds. Early in the history of wheat, a **mutant** appeared that had a strong seed stalk. This was a real bonus to farmers, as the seeds stayed attached to the plant and could be collected. This mutation would have been disastrous in a wild grass as the plant would have been unable to spread its seeds.

Recent developments

Breeders continue to use selective breeding programmes to improve crops and livestock. Recently, researchers crossed a commercial Chinese variety of rice with a bizarre-looking wild rice and boosted the rice yield by a staggering 10 to 20 per cent. Similarly, there is a new variety of **oil-seed rape** (an oil-producing crop that has yellow flowers) called smart canola, that has natural resistance to two **herbicides**. It was created by crossing plants that each had resistance to a different herbicide. Now the farmer can spray the crop with two different herbicides, killing a greater range of weeds without harming the crop.

'If you do it [crop breeding] by natural methods, we have no problem with that. This could be extremely effective, and you don't need to get genes from daffodils or micro-organisms.'

Benedikt Haerlin, spokesperson on genetic engineering for the environmental organization Greenpeace

It is important to maintain as many different varieties of rice as possible in case they are useful in plant breeding programmes. Research at this centre in Hyderabad, India, is studying the resistance of different rice varieties to the white backed plant hopper, a major insect pest.

Genetic changes

Traditional selective breeding methods are based on the transfer of genetic material between individuals of the same species. Some genetic engineering is not that different to selective breeding, but it is a far more rapid and precise process. However, genetic engineering also makes it possible to move genes between species that would not normally interbreed – something that cannot usually be achieved using selective breeding.

Transgenic organisms

Plants and animals that contain foreign DNA are called **transgenics**. For example, sheep that have been given an extra gene to make a substance that is normally made by humans are transgenic because they contain human DNA. The change in the sheep's DNA means that it is different from other animals of the same type – it is a new strain.

Organisms that receive a new gene have new abilities. They may be able to make a new protein or enzyme, or produce a substance such as an **antibiotic**. It is this feature that makes the technique of genetic engineering revolutionary, in terms of the potential benefits it can bring.

Genetic engineering has the following advantages over traditional selective breeding:

- the desired change can be achieved in very few generations
- it is faster and lower in cost
- it allows greater precision in selecting characteristics
- it allows a much wider selection of traits for improvement. In plants, for example, it can introduce pest, disease, drought and herbicide resistance as well as improved nutritional content.

Making proteins

Proteins are essential building blocks and have many functions in the body. Haemoglobin, for example, is the oxygen-carrying substance in the blood. Keratin in the skin, nails and hair is a structural protein.

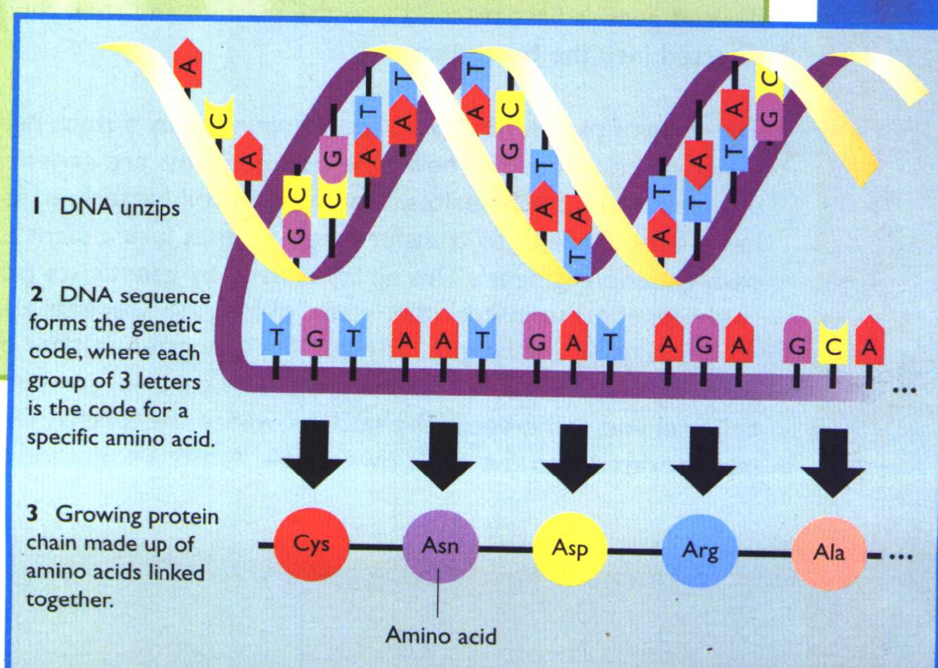
Each gene is responsible for the manufacture of a specific protein. For example, one gene carries the instructions for a specific type of blood protein, while another is responsible for making the brown pigment found in skin, hair and eyes. All proteins are made from **amino acids**. There are 20 different amino acids, and it is the composition of these and the order in which they occur within the protein that determines the type of protein.

If a gene mutates in some way, the genetic code may be changed. This means that cells may not be able to make a particular protein and the body suffers from a malfunction. A single faulty gene, for example, causes the disease cystic fibrosis, which affects the lungs and digestive system.

Protein synthesis

Part of a DNA **molecule** in the nucleus unwinds to expose the bases. The genetic code is formed from groups of three bases. Each group of three bases identifies a specific amino acid. There are 64 possible combinations of the four bases – A, T, G and C. As there are only 20 amino acids, some amino acids have more than one code while others are used to indicate the start and finish of the message.

A messenger molecule (RNA) is used to carry the information from the DNA in the nucleus to the **cytoplasm**. Here, the RNA attaches to a tiny structure called a ribosome and the code is read, one group of three bases at a time. The corresponding amino acids are picked up from the cytoplasm and joined together in the correct order. This forms a strand of amino acids that makes up new protein.



Genetic engineering – the process

The first stage in genetic engineering is to identify the desired gene on the DNA of the donor organism. Once located, the gene has to be 'cut out' and then 'pasted' into another piece of DNA which will be inserted into the recipient organism. DNA that contains foreign DNA is referred to as recombinant DNA.

Molecular scissors

Scientists use special enzymes to chop up DNA into many small pieces. These enzymes act like molecular scissors. There are thousands of different special enzymes, each of which cuts at a specific point on the DNA. These enzymes make it easier to find and remove individual genes. Now it is possible to remove a specific length of DNA from one organism and insert it into the DNA of another. Before the selected length of DNA can be pasted into the new DNA, it has to be copied billions of times to produce enough material to work with. This takes place in a solution containing a specific mix of chemicals.

Inserting the DNA

Once the length of DNA has been copied it has to be inserted into the host cell. Some animal cells can be persuaded to take up new DNA by simply injecting it into their nucleus. First, the new DNA is attached to a length of DNA that has been taken from the animal cell, so the cell will recognize it. Then the new DNA and the bit to which it is attached get **stitched** into the host cell's own DNA.

In bacteria, a circular piece of DNA called a plasmid, found in the cytoplasm, is used to get the DNA into the host bacterium. The desired gene is first stitched into the plasmid and then the plasmid is inserted into the bacterium.

The cells of plants, however, are surrounded by a thick cell wall. In order to introduce the new DNA, some plants are genetically modified using natural plant parasites. One type of soil bacterium, for example, has a natural ability to transfer its own genes into a plant – 'nature's own genetic engineer'. This ability is used by geneticists (scientists who study genetics) to insert other genes of interest. **Cereals** are genetically modified using a gene gun. The gun fires tungsten (a type of metal) particles coated in DNA at the plant. The particles penetrate the plant cell wall and some enter the nucleus where the foreign DNA becomes incorporated into the cell's own DNA. A bizarre method that works!