Biotechnology

Unit 1

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1.1 What is biotechnology?

By the end of this section you should be able to:

- Define biotechnology.
- Discuss the significance of biotechnology.
- Explain some of the traditional uses of biotechnology, for example, in preparing bread, yoghurt, cheese and beer.

Biology, as you discovered last year, is the study of living organisms. Now, at the beginning of your grade 10 biology course, you are going to be studying **biotechnology**.

Biotechnology is the use of micro-organisms to make things that people want, often involving industrial production.

Biotechnology has always been extremely important. It involves ways of making and preserving foods and making alcoholic drinks. Traditional applications of biotechnology involve brewing beers, making wines, making bread, and making cheese and yoghurt. Modern applications of biotechnology include using genetic engineering to change crops and animals; producing new medicines; and helping to provide new energy sources. It has enormous significance in helping people to improve and control their lives.

Biotechnology is based on **microbiology**. As you know, microbiology is the study of micro-organisms – tiny living organisms including **bacteria**, **viruses**, **fungi** and **protoctista**,

KEY WORDS

biotechnology *use of micro-organisms to make things that people want, often involving industrial production*

microbiology *study of micro-organisms and their effect on humans*

bacteria *unicellular micro-organisms*

viruses *sub-microscopic infectious agents that are unable to grow or reproduce outside a host cell*

fungi *simple organisms, often microscopic, that cannot photosynthesise and feed as parasites or saprophytes*

protoctista *unicellular organisms*

which are usually too small to be seen with the naked eye. Some micro-organisms cause disease; others are enormously useful to people – for example, they play a vital role in decay and the recycling of nutrients in the environment. With the arrival of new technologies such as genetic engineering, micro-organisms are becoming more useful all the time.

Not all types of micro-organism are used in biotechnology. The main groups are bacteria and fungi, although viruses are being used more and more for genetic engineering. Just to remind you – bacteria are single-celled organisms that are much smaller than the smallest plant and animal cells. In ideal conditions, they can reproduce very quickly. Viruses are even smaller than bacteria. They do not carry out any of the normal functions of living things. Moulds and yeasts are both fungi – living organisms which obtain their food from other dead or living organisms. Yeasts are single-celled organisms, while moulds are made up of thin, thread-like structures called hyphae.

KEY WORDS

anaerobically *without oxygen*

fermentation *anaerobic respiration in yeast that produces ethanol*

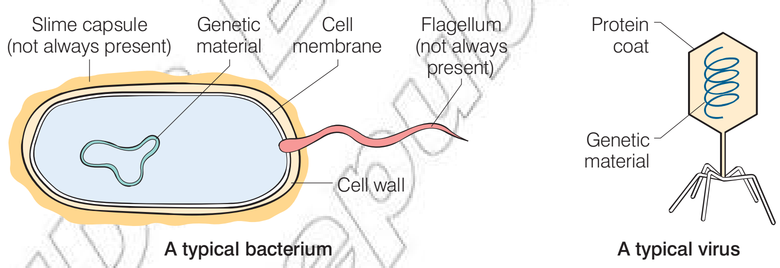


Figure 1.1 *Bacteria (left) and viruses (right) are both used in biotechnology.*

Developing new applications of biotechnology is one of the fastest-growing industries around the world, and is beginning to grow in Ethiopia too. It is easy to think that biotechnology is very new, but much of it has been in use for thousands of years. People have used micro-organisms to make food and drink almost as far back as our records go. Bacteria are used in the manufacture of *irgo* (yoghurt) and *Ayib* (cheese). Yeast is used to make many traditional Ethiopian fermented foods, including injera, and also to produce alcoholic drinks, such as tej and tella.

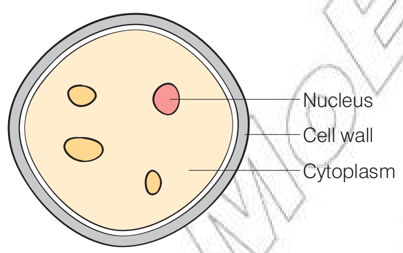
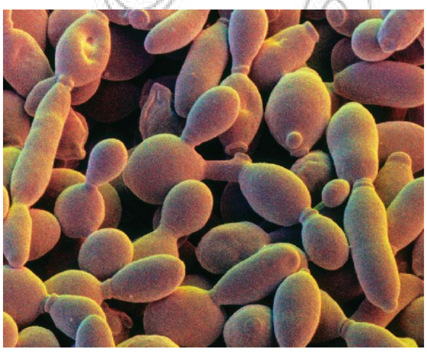


Figure 1.2 *Yeast cells – these microscopic organisms have been useful to us for centuries.*



Traditional technology using yeast

One of the most useful micro-organisms is yeast. The yeasts are single-celled organisms. Each yeast cell has a nucleus, cytoplasm and a membrane surrounded by a cell wall. The main way in which yeasts reproduce is by asexual budding – splitting into two, to form new yeast cells. Just one gram of yeast contains about 25 billion cells!

When yeasts have plenty of oxygen, they respire aerobically, breaking down sugar to provide energy for the cells, and producing water and carbon dioxide as waste products. But yeasts are useful because they can also respire **anaerobically**. When yeast cells break down sugar in the absence of oxygen, they produce ethanol (commonly referred to as alcohol) and carbon dioxide.

Aerobic respiration provides more energy than anaerobic respiration, allowing yeast cells to grow and reproduce. However, once they exist in large numbers, yeast cells can survive for a long time in low-oxygen conditions, and will break down all the available sugar to produce ethanol. The anaerobic respiration of yeast is sometimes referred to as **fermentation**.

We have used yeast for making bread and alcoholic drinks almost as far back as human records go. We know yeast was used to make bread in Egypt in 4000 BC, and some ancient wine found in Iran dates back to 5400–5000 BC. Here in Ethiopia yeast (known locally as ershoo) has been used to make injera (bread) possibly since even earlier times.

Injera needs yeast

When you make injera, grind your teff or barley and then add water. Mix it well and leave the dough at room temperature for about two days. Natural yeasts start to grow and respire in the dough. At first the yeast respires aerobically, although this may change to anaerobic respiration. The yeast produces carbon dioxide, making the mix rise a little and giving it a tangy flavour. When you cook the mixture, the bubbles of gas expand in the high temperature, giving injera its typical texture, which is so good for soaking up the food. The yeasts are killed during the cooking process.

Figure 1.3 *When you make injera, the mix needs to be left for at least two or three days so the yeast can make the carbon dioxide gas needed to produce the holes in the bread.*

Activity 1.1: Making injera

You are going to investigate the factors that affect the growth of yeast in injera mix. Yeasts are living organisms – by changing their conditions, you can change the speed at which they respire and produce carbon dioxide in your dough.

1. Mix up some teff or barley flour with water, then divide your mix into three containers.
2. Leave one container at room temperature in the normal way for making injera.
3. Put the second container in the coolest place you have available. If there is a fridge, put your mixture in it.
4. Take your third mixture and heat it in a water bath to at least 50 °C. Make sure the mixture itself reaches 50 °C for 5 minutes. Then allow the mixture to cool down to room temperature and leave it with the other sample at room temperature.
5. After two to three days, observe the three mixtures very carefully. Describe their appearance and smell.
6. Then cook each of the three samples. Observe their appearance very carefully as they cook – the number of air bubbles that appear, and the texture of the bread that results.
7. Write up your experiment carefully, and explain your observations.

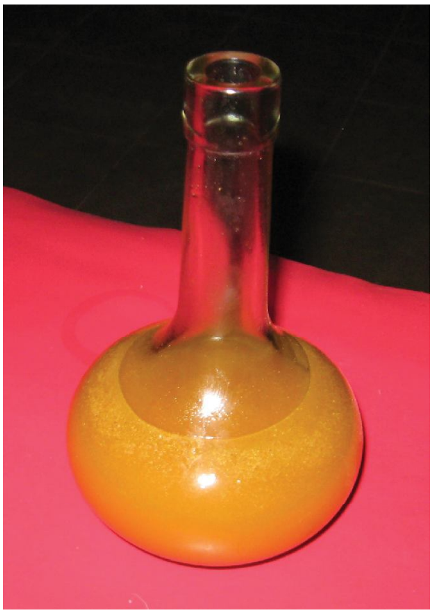


Figure 1.4 *Here in Ethiopia people have been drinking tej for thousands of years – the fermentation process by which it is made is an example of biotechnology.*

Making alcoholic drinks

When fruits fall to the ground and begin to decay, wild yeasts on their skin break down the fruit sugar to form ethanol and carbon dioxide. These fermented fruits can cause animals to become drunk when they eat them – and this is probably how our ancestors discovered alcohol! We now use this same reaction in a controlled way to make drinks such as beer, tej and wine. In both cases the yeast has to be supplied with carbohydrates to act as an energy source for respiration.

Tej is one of the oldest drinks known to the human race – it has been known since at least 400 BC. When you make tej, you need honey, water and gesho leaf or gesho stick. Gesho gives a bitter edge to the brew, and wild yeasts found on the plant start the fermentation going. The yeasts use the honey as a source of food. As the yeast colonies grow they start to respire anaerobically, and this produces ethanol and carbon dioxide. The alcohol content of tej varies from about 6 to 11%. Tej and tella are the most commonly consumed alcoholic drinks in Ethiopia.

In contrast, winemaking uses natural sugar, found in fruit such as grapes, as the energy source for the yeast. You press the fruit and mix the juice with yeast and water. You then let the yeast respire anaerobically until most of the sugar has been used up. At this stage, you filter the wine to remove the yeast and put it in bottles, where it will remain for some time to mature before it is sold. Most commercially sold wine is made from grapes, but wine can be made from almost any fruit or vegetable – the yeast doesn't care where the sugar it uses comes from!

Interestingly, alcohol in large amounts is poisonous to yeast as well as to people. This is why the alcohol content of wine is rarely more than 14% – once it gets much higher, it kills all the yeast and stops the fermentation.

Remember: yeast *can* respire aerobically in bread making, but *must* respire anaerobically to make alcoholic drinks.

Activity 1.2: Visiting a brewery/tej production

One way to become more familiar with the role of yeast in brewing is to visit a place where beer is brewed, or where tej or other alcoholic drinks are made in your neighbourhood. You can discuss with the craftsmen what might affect the growth of the yeast, and how much ethanol they produce during anaerobic respiration. Discuss what you discover in class with your teacher and other students.

Food production using bacteria

People began to domesticate animals quite early in human history. They soon realised that the milk female animals made for their babies could be used as food for us too. People have used milk from many different types of animal, including cows, sheep, goats, camels and horses. However, there is one big drawback in using milk as part of the diet – it very rapidly goes off, smelling and tasting disgusting! It didn't take people long to discover ways of changing milk, turning it into milk-based foods with a much longer life than the original milk. These changes depend on the action of micro-organisms.

Yoghurt has long been a staple part of the diet in the Middle East and Africa including Ethiopia. Cheese has also been around for a very long time almost all over the world.

Figure 1.5 *Many different animals, including cows, camels, horses, sheep and goats, are used for milking.*

Making yoghurt (irgo)

Traditionally, yoghurt is fermented whole milk. Yoghurt is formed by the action of bacteria on the lactose (milk sugar) in the milk.

To make yoghurt, you add a starter culture of the right kind of bacteria to warm milk. Often this starter culture is just a small amount of yoghurt you have already made. The mixture needs to be warm so the bacteria begin to grow, reproduce and ferment. As the bacteria break down the lactose in the milk, they produce **lactic acid**, which gives the yoghurt its sharp, tangy taste. This is known as lactic fermentation. The lactic acid produced by the bacteria causes the milk to clot and solidify into yoghurt. The action of the bacteria also gives the yoghurt a smooth, thick texture. Once the yoghurt-forming bacteria have worked on the milk, they also help prevent the growth of other bacteria that normally send the milk bad. Yoghurt, if it is kept cool, will last almost three weeks before it goes bad. Ordinary milk lasts only a few days – and then only if it's kept really cold. Once you have made your basic yoghurt, you can mix in flavourings, spices and fruit.

KEY WORD

lactic acid *product of anaerobic respiration in animal cells*

In Ethiopia, we often make yoghurt (irgo) in gourds or hollowed-out wooden vessels that have had sticks burned in them. These sticks are obtained from different plants such as the olive tree, and so on. As well as giving the yoghurt a pleasant flavour, this disinfects the vessel so that only good bacteria grow in the milk.

Activity 1.3: Making yoghurt

Discuss different factors that might affect the making of yoghurt. Mix up a class starter culture of milk and a small amount of live yoghurt. Discuss with your teacher what factors might affect how the bacteria work, and why. Plan your experiment carefully.

1. Working in groups, try different temperature conditions and see how they affect the formation of yoghurt. You might also change the pH of the mixture by adding substances such as lemon juice, and see how this affects the process.
2. After two or three days, make careful observations of your yoghurt culture.
3. Each group should share their results with the class and write them up on the board.
4. Write up your experiments carefully, and explain your observations.

Figure 1.6 *Curds are formed by the action of bacteria on the milk – this is the basis of ayib, although we often add seasoning and flavours before we eat it.*

> **DID YOU KNOW?**
>
> No one really knows when yoghurt making first started. It seems to have come from Turkey. Legend has it that travellers took some milk on a journey in a bag made of a sheep's stomach. The heat of the sun and the bacteria in the stomach worked on the milk, and in the cool of the desert night they discovered the bag was full of yoghurt! Carrying milk in the stomach of a camel has a similar effect.

Cheese making

Like yoghurt making, cheese making depends on the reactions of bacteria with milk changing the texture and taste, and also preserving the milk. Cheese making is very successful in preserving milk, and some cheeses can survive for years without decay. Around 900 different types of cheese are made around the world, but the basis of the production method is the same for them all.

Just as in yoghurt making, you add a starter culture of bacteria to warm milk. The difference is in the type of bacteria added. The bacteria in cheese making also convert lactose to lactic acid, but they make much more lactic acid. As a result, the solid part (curds) is much more solid than in yoghurt. Enzymes are also added to increase the separation of the milk. These often come from the stomachs of calves or other young animals. When it has completely curdled, you can separate the curds from the liquid whey (known as aguat here in Ethiopia). Then you can use the curds for cheese making. The whey is often used in other dishes.

The curds can be used fresh, and can be seasoned or flavoured. This is the basis of ayib. Alternatively, you can cut and mix the curds with salt along with other bacteria or even moulds, before you press them and leave them to dry out. The bacteria and moulds added at this stage of the process are very important. They affect the development of the final flavour and texture of the cheese as it ripens – a process that may take months or years, depending on the type of cheese being made. This is how the majority of cheeses are made in countries such as the UK and the USA.

Here in Ethiopia cheese is traditionally made by first making yoghurt from fresh milk, extracting the butter by continuous agitation, and finally boiling the remaining part to make the cheese.

Review questions

1. Which of the following statements about biotechnology is not true?
   A Biotechnology is the use of micro-organisms to make things that people want.
   B Biotechnology is a new, modern concept.
   C Biotechnology is based on microbiology.
   D Biotechnology is one of the fastest-growing industries in the world.
2. How many cells does one gram of yeast contain?
   A about 10 million
   B 25 million
   C 4000
   D about 25 billion

3. Which **two** of the following are the waste products of anaerobic respiration in yeast?
   A sugar
   B carbon dioxide
   C water
   D ethanol
4. Which of the following statements about lactic fermentation is not true?
   A It gives yoghurt its sharp, tangy taste.
   B It gives yoghurt a smooth, thick texture.
   C It means the yoghurt will only last a few days.
   D It causes the milk to clot and solidify into yoghurt.

1.2 New applications of biotechnology

By the end of this section you should be able to:

- Identify new applications of biotechnology in agriculture, food production, medicine and energy production.

Around the world traditional biotechnologies – brewing, winemaking, bread making and the production of yoghurt and cheese – are extremely important. In many countries they are not only carried out in the home on a small scale, they also take place in massive industrial production processes.

Some new applications of biotechnology also take place in an industrial setting. Many advances in agriculture are the result of one of the most important new areas of biotechnology – **genetic engineering** (also known as **genetic modification**). Genetic engineering is used to change an organism and give it new characteristics which people want to see.

KEY WORDS

genetic engineering/ genetic modification *process of inserting new genetic information into existing cells in order to modify a specific organism for the purpose of changing its characteristics*

What is genetic engineering?

Genetic engineering involves changing the genetic material of an organism. Genetic material carries the instructions for a new organism, found in the nucleus of every cell. You take a small piece of information – a gene – from one organism and transfer it to the genetic material of a completely different organism. So, for example, a gene from one of your human cells can be 'cut out' using enzymes, and transferred to the cell of a bacterium. Your gene carries on making a human protein, even though it is now in a bacterium.

There is a limit to the types of protein that bacteria are capable of making. Scientists have found that genes from one organism can be transferred to the cells of another type of animal or plant at an early stage of their development. As the animal or plant grows,

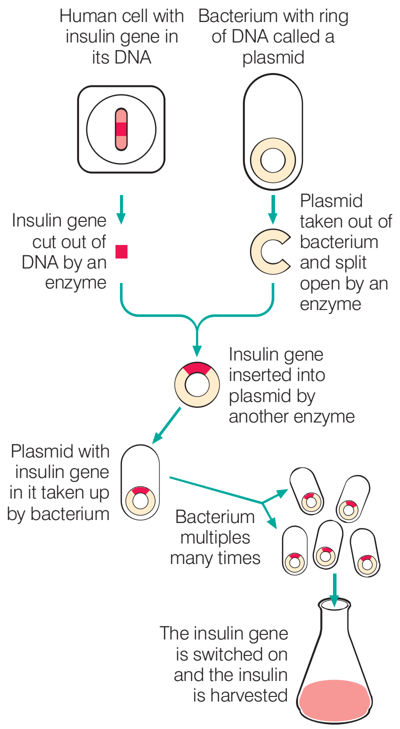


***Figure 1.7** The basic process of genetic engineering*

it develops with the new, desired characteristics from the other organism.

The technology

A lot of new biotechnology relies on growing large numbers of micro-organisms on an industrial scale in large vessels, known as fermenters. If a lot of micro-organisms are grown together, they can easily use up all the oxygen available and even poison each other with waste products. Industrial fermenters usually have a range of features to overcome the problems that stop a culture growing satisfactorily. They react to changes, keeping the conditions as stable as possible. This, in turn, means we can obtain the maximum yield. Industrial fermenters usually have:

- an oxygen supply – to provide oxygen for respiration by the micro-organisms
- a stirrer – to keep the micro-organisms in suspension, maintain an even temperature, and make sure oxygen and food are distributed evenly through the culture
- a water-cooled jacket – to remove the excess heat produced by the respiring micro-organisms – any rise in temperature is used to heat the water, which is constantly removed and replaced with more cold water
- measuring instruments – for continuous monitoring of factors such as pH and temperature so that adjustments can be made if necessary

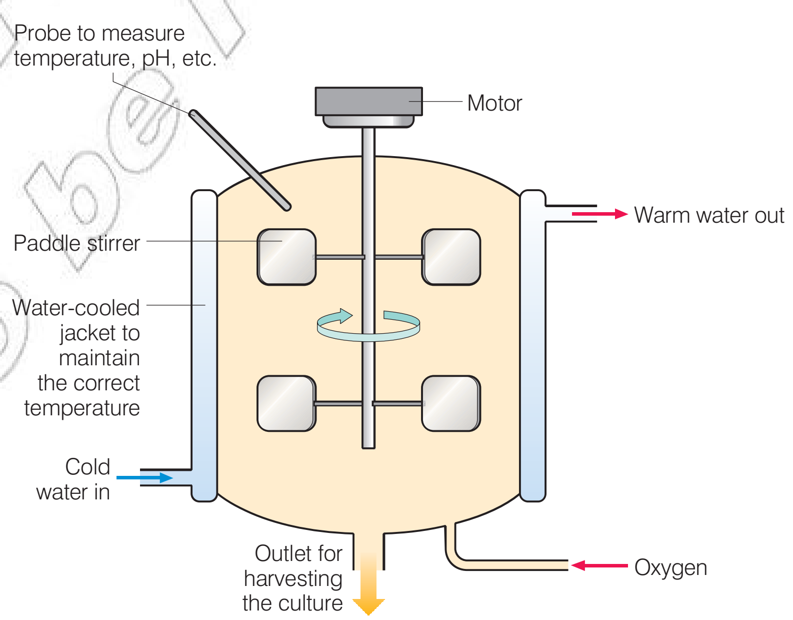


***Figure 1.8** The design of fermenters is improving all the time as new ways of keeping conditions inside the fermenter as stable as possible are developed all the time.*

There are many different areas where new biotechnology – and in particular genetic engineering – is very important. Some of them are summarised on the following pages.

Applications of biology in agriculture

For many years, we have used selective breeding to change our livestock and crops. We select animals or plants with characteristics we want, such as big grains, resistance to disease or plenty of milk, and breed from them. Gradually, the characteristics change to what we want. But selective breeding takes time, and there are limitations to it. You will be looking at this in more detail in the next unit.

By using genetic engineering, we can introduce new characteristics very rapidly. Engineered genes can be used to improve the growth rates of plants and animals. They can be used to improve the food value of crops. Genetic engineering has been used to make crop plants that are resistant to drought and to disease, and to produce plants that make their own pesticide chemicals. Glowing genes from jellyfish have even been used to produce crop plants that give off a blue light when they are attacked by insects so the farmer knows they need spraying! This means the farmer has to use less insecticide (chemicals that kill insects), which saves money and protects the environment.

Much of the research into genetically engineered crops and animals has been carried out in countries like the UK and the USA. However, here in Ethiopia our scientists are increasingly working with these new technologies. At the Ethiopian Institute of Agricultural Research and Addis Ababa University, scientists are analysing the genes of many of our most important crop plants, including teff. The Ethiopian Agricultural Research Institute is using modern biotechnology to improve teff, coffee, fruit plants and some of our forest trees for commercial cultivation.

However, there are some possible problems with the new biotechnologies, so we must be careful. Insects may become pesticide-resistant if they eat a constant diet of pesticide-forming plants. Genes from genetically modified plants and animals might spread into the wildlife of the countryside, which could make difficulties. Genetically modified crops are often not fertile, which means farmers have to buy new seed each year. But if these problems can be overcome, biotechnology offers us the hope of better crops and more food, both for our own people and to sell internationally.

Applications of biology in food

The new biotechnology is often used in food processing. One of the biggest changes is that enzymes are produced by genetically engineered bacteria, and the enzymes are then used in the production of processed foods and drinks. Enzymes are used to clarify beer. They are used to break down starch and convert the sugars into glucose syrup. They are used to make meat more tender, and to break down the food used to make commercial baby food.

Biotechnology plays a big part in food production. It has even been used to create a completely new food based on fungi, which has been developed in the UK. It is known as **mycoprotein**, which

KEY WORD

mycoprotein *fungal protein*

Figure 1.9 *Plant technologists at EIAR have improved different crops like this teff to ensure food security.*

means ‘protein from fungus’. It is produced using the fungus *Fusarium*, which grows and reproduces rapidly on a relatively cheap sugar syrup in large, specialised fermenters. It needs aerobic conditions to grow successfully, and can then double its mass every five hours or so. The fungal biomass is harvested and purified. Then it is dried and processed to make mycoprotein, a pale yellow solid with a faint taste of mushrooms. On its own, it has very little flavour, but mycoprotein can be given a range of tastes and flavours to make it similar to a whole range of familiar foods. It is a high-protein, low-fat meat substitute used by vegetarians, people who want to reduce the fat in their diet, and people who just want to eat cheap protein.

When mycoprotein was first developed, people thought a world food shortage was on its way. They were looking for new ways to make protein cheaply and efficiently. The food shortage never happened, but the fungus-based food continued. It is versatile, high in protein and fibre, and low in fat and calories, and so has found a secure and healthy place on the meal tables of the developed world.

Scientists in Ethiopia and elsewhere are trying to develop a local equivalent of mycoprotein, looking at different plants and fungi that have a relatively high protein content.

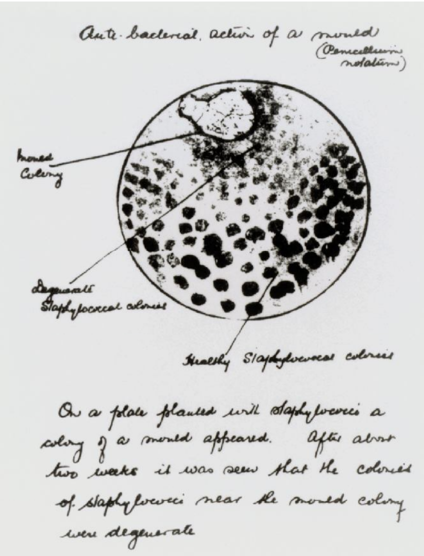


Figure 1.10 *The keen eyes of Alexander Fleming noticed the clear areas on his plates, and he realised he had made a discovery of enormous potential.*

Applications of biology in medicine

Biotechnology is extremely important in modern medicine. It is used to develop vaccines and to create new medicines. The first medicine that really relied on microbiology was penicillin. This antibiotic is one of the best-known medicines in the world, and has revolutionised medicine in the time since it was first manufactured. We are going to look more closely at this story because it shows clearly how changes in biotechnology make life easier.

In 1928 Alexander Fleming, a young researcher at St Mary’s Hospital in the UK, left some plates on which he was culturing bacteria uncovered near an open window. When he remembered to look at them, he found bacteria were growing on the surface of his dishes, as he expected. But Fleming also noticed spots of mould growing, and around these were clear areas of agar. The bacteria were no longer growing there. Whatever had blown in through the window and started growing on his plates was producing a chemical that killed the bacteria.

Fleming found that the micro-organism which had invaded his Petri dishes was a common mould called *Penicillium notatum*. He managed to extract a tiny amount of the chemical that killed the bacteria, and used it to treat an infected wound. He called his extract penicillin. But it was very hard to extract, and very unstable once extracted, so Fleming decided he wouldn’t be able to obtain useful amounts of penicillin from his mould.

Howard Florey and Ernst Chain were working at Oxford University in the UK in a desperate search to find a drug to kill the bacteria that infected wounds suffered by soldiers in the Second World War. They used Fleming's mould and finally managed to extract enough penicillin to show what it could do. They wanted to manufacture it in large amounts, but the yield of drug was very poor.

Fleming's original mould, *Penicillium notatum*, was extremely difficult to grow in large cultures, yielding only one part penicillin for every million parts of fermentation broth. Then a mould growing on a melon in a market was found to yield 200 times more penicillin than the original. What is more, it grew relatively easily in deep tanks, making large-scale production possible. By 1945, enough penicillin was made each year to treat seven million people.

Modern strains of *Penicillium* mould give even higher yields. We grow the mould in a sterilised medium, containing sugar, amino acids, mineral salts and other nutrients, which is made from soaking corn in water. It is grown in huge 10 000 dm^3 fermenters, and still saves many thousands of lives every year.

When genetically engineered bacteria are cultured on a large scale, they can make huge quantities of protein. We now use them to make a number of drugs and hormones used as medicines. These genetically engineered bacteria make exactly the protein needed, in exactly the amounts needed, and in a very pure form. For example, people with diabetes need supplies of the hormone insulin. It used to be extracted from the pancreas of pigs and cattle, but it wasn't quite the same as human insulin, and the supply was quite variable. Both problems have now been solved by the introduction of genetically engineered bacteria that can make human insulin.

Biotechnology also makes it possible to develop vaccines more easily.

A number of sheep and other mammals have been engineered to produce life-saving human proteins in their milk. These are much more complex proteins than those produced by bacteria, and have the potential to save many lives. For example, genetically modified sheep can make special blood-clotting proteins in their milk. These can be used for people with haemophilia, so they are no longer at risk from receiving contaminated blood.

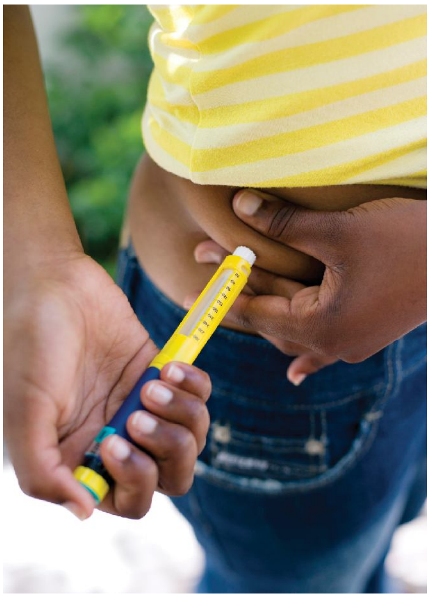


Figure 1.11 *Diabetes is a dangerous condition if it is not controlled with insulin. Biotechnology is making pure human insulin much more easily available.*

Applications of biology in energy production

Everyone needs fuel of some sort to provide them with energy. It might be direct energy such as heat to cook on, or it might be indirect energy – heat being used to make electricity, for example. However, there is only a limited amount of fossil fuels such as coal, oil and gas for us to use. Even wood and peat are becoming scarce. Around the world, we all need other, renewable forms of fuel. The generation of biogas from human and animal waste is becoming increasingly important in both the developing and the developed world. This depends on biotechnology.

Figure 1.12 Biogas generators like this have made an enormous difference to many families by producing cheap and readily available fuel.

What is biogas?

Biogas is a flammable mixture of gases, formed when bacteria break down plant material, or the waste products of animals, in anaerobic conditions. It is mainly methane, but the composition of the mixture varies depending on what is put into the generator and which bacteria are present.

Table 1.1 *The components of biogas*

Components	Percentage in the mixture by volume
Methane	50–80
Carbon dioxide	15–45
Water	5
Hydrogen sulphide	0–3
Other gases including hydrogen	0–1

Around the world, millions of tonnes of faeces and urine are produced by animals like cows, pigs, sheep and chickens. We produce our fair share of waste materials too! Also, in many parts of the world, plant material grows very rapidly. Both the plant material and the animal waste make up a potentially enormous energy resource – but how can we use it?

To produce biogas, you collect dung or plant material, which contains a high level of carbohydrates, and put it into a **biogas generator** or **digester**. Then you add a mixed population of many different types of bacteria which are needed to digest the carbohydrate. The bacteria you use are similar to those in the stomachs of ruminants such as cows or sheep. Some of the bacteria break down the cellulose in plant cell walls. Others break down the sugars formed, to produce methane and other gases. The biogas produced is passed along a pipe into your home, where you burn it to produce heat, light or refrigeration.

The bacteria involved in biogas production work best at a temperature of around 30 °C, so biogas generators tend to work best in hot countries. However, the process generates heat (the reactions are **exothermic**). This means that if you put some heat energy in at the beginning to start things off, and have your generator well insulated to prevent heat loss, biogas generators will work anywhere. Some generators are so simple, they are little more than a big plastic bag and some pipes. Yet they can make a big difference to our lives.

KEY WORDS

biogas generator/digester *takes in waste material or plants, and biogas and useful fertilisers come out the other end*

exothermic *reaction that produces heat energy*

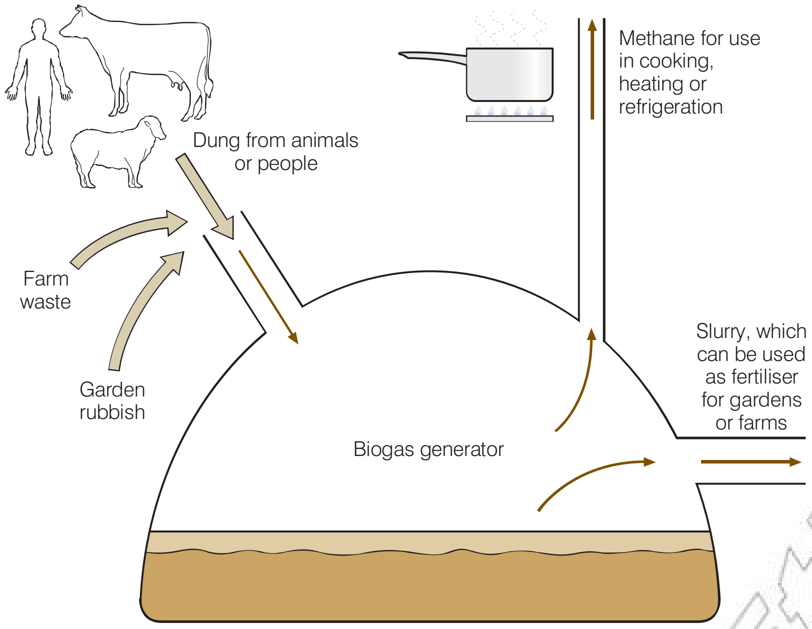


Figure 1.13 *Biogas generators take in waste material or plants, and biogas and useful fertilisers come out the other end. This simple generator, involving a big plastic bag, is being tried in Addis Ababa and the surrounding area.*

Scaling up the process

At the moment, most biogas generators around the world operate on a relatively small scale, supplying the energy needs of one family, a farm, or at most a village. What you put into your small generator has a big effect on what comes out.

Biogas units are widely used in China, where there are well over 7 million biogas units, producing as much energy as 22 million tonnes of coal. Waste vegetables, animal dung and human waste are the main raw materials. These Chinese digesters produce excellent fertiliser, but relatively low-quality biogas.

In India, there are religious and social taboos against using human waste in biodigesters. As a result, only cattle and buffalo dung is put into the biogas generators. This produces very high-quality gas, but much less fertiliser.

There are also different sizes and designs of biogas generator. The type chosen will depend on local conditions. For example, many fermenters are sunk into the ground, which provides very good insulation. Others are built above ground, which may be easier and cheaper, but offers less insulation. If night-time temperatures fall too low, it could cause problems.

Many countries are now looking at biogas generators, and experimenting with using them on a larger scale. The waste material we produce from sugar factories, sewage farms and rubbish tips all has the potential to act as a starting point for the production of biogas. We have some problems to overcome with scaling the process up, but the early progress looks promising. Biogas could

DID YOU KNOW?

Under ideal conditions, 10 kg of dry dung can produce 3 m^3 of biogas. That will give you three hours' cooking, three hours' lighting or 24 hours of running a refrigerator. Not only that, but you can use the waste from your generator as a fertiliser.

Figure 1.14 Conditions in Ethiopia allow plants like this sugar cane to photosynthesise and grow very rapidly – the next step is to turn them into usable fuel.

KEY WORDS

carbohydrase *enzyme which breaks down carbohydrates*

distillation *process of purifying a liquid by boiling it and condensing its vapours*

well be an important fuel for the future for all of us. It would help us to get rid of much of the waste we produce, as well as providing a clean and renewable energy supply.

More biofuels

In countries such as Ethiopia, plants grow quickly. Sugar cane grows about 4–5 metres in a year, and has a juice which is very high in carbohydrates, particularly sucrose. Maize and sweet potatoes also grow fast. We can break down the starch in maize kernels or potato tubers into glucose, using the enzyme **carbohydrase**. We can convert the carbohydrates we grow into clean and efficient fuels.

Ethanol-based fuels

If sugar-rich products from cane and maize are fermented anaerobically with yeast, the sugars are broken down incompletely to give ethanol and water. You can extract the ethanol from the products of fermentation by **distillation**, and you can then use it in cars and other vehicles as a fuel.

Car engines need special modification to be able to use pure ethanol as a fuel, but it is not a major job. Many cars can run on a mixture of petrol and ethanol without any problems at all.

Advantages and disadvantages of ethanol as a fuel

In many ways, ethanol is an ideal fuel. It is efficient, and it does not produce toxic gases when you burn it. It is much less polluting than conventional fuels, which produce carbon monoxide, sulphur dioxide and nitrogen oxides. In addition, you can mix ethanol with conventional petrol to make a fuel known as gasohol. This is increasingly being done, and reduces pollution levels considerably, although there is still some pollution from the petrol part of the mix.

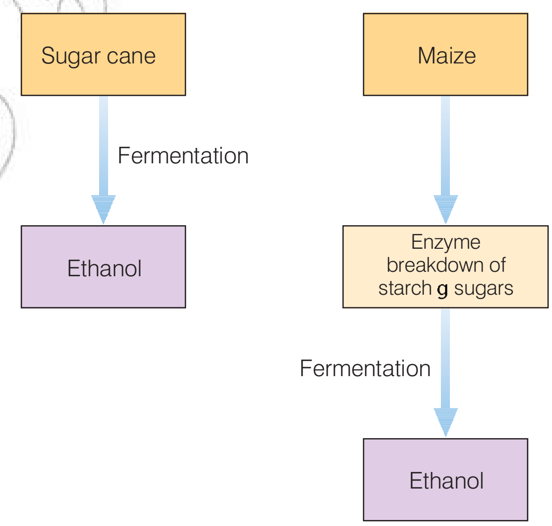


***Figure 1.15** The starch in maize needs to be broken down by enzymes before yeast can use it as fuel for anaerobic respiration. Although it takes more steps to produce ethanol from maize than from sugar cane, maize can be grown in many more countries around the world.*

Using ethanol as a fuel is a **carbon-neutral** activity. This means there is no overall increase in carbon dioxide in the atmosphere when you burn ethanol. The original plants removed carbon dioxide from the air during photosynthesis. When you burn the ethanol, you simply return it.

The biggest difficulty with using plant-based fuels for our cars is that it takes a lot of plant material to produce the ethanol. As a result, the use of ethanol as a fuel has largely been limited to countries with enough space, and a suitable climate, to grow a lot of plant material as quickly as possible. Here in Ethiopia, we have that capability.

The main problem for many countries is finding enough ethanol. If people in Europe added 5% ethanol to their fuel, it would reduce carbon dioxide emissions – but they would need 7.5 billion litres of ethanol a year, which they cannot produce themselves. The methods of ethanol production we use at the moment leave large quantities of unused cellulose from the plant material. To make ethanol production work financially in the long term, we need to find a way to use this cellulose. We might develop biogas generators, which can break down the excess cellulose into methane, another useful fuel. Genetically engineered bacteria or enzymes may be able to break down the cellulose in straw and hay and make it available for yeast to make more ethanol. We don't know exactly what the future will hold, but it seems likely that ethanol-based fuel mixes will be part of it. Here in Ethiopia the Ministry of Mines and Energy has already started mixing ethanol with petrol to provide fuel for cars.

Along with the production of biodiesel from plants such as castor oil beans and jatropha, which grows in dry climatic conditions that do not suit crop production, Ethiopia is making great strides in the use of biofuels. As long as we maintain a balance between the use of land to provide food and the use of land to provide us with fuel, the use of biotechnology in this way has great potential for us in the future.

KEY WORDS

carbon-neutral *process whereby the amount of carbon emitted is matched by the amount absorbed*

Review questions

1. Which of the following statements about genetic engineering is not true?

   A It is used to change an organism and give it new characteristics that people want.

   B It involves changing the genetic material of an organism.

   C It can be used to produce crops that are resistant to disease.

   D It does not allow genes to be transferred from one type of organism to another.

2. Which of the following is not a component of biogas?

   A carbon dioxide

   B ethanol

   C methane

   D water

3. Put the following stages of the process of making and using biogas into the correct order:
   - A Some of the bacteria break down the plant cell walls while others break down the sugars formed, producing methane and other gases.
   - B Dung or plant material is collected and put into a biogas generator, or digester.
   - C The biogas produced is piped into homes, where it is burned to produce light, heat or refrigeration.
   - D A mixed population of different types of bacteria is added.
4. Which of the following are advantages of using ethanol as a fuel, and which are disadvantages? Can you explain why?
   - A It is a carbon-neutral activity.
   - B It takes a lot of plant material to produce the ethanol.
   - C It does not produce toxic gases when burnt.
   - D It can be mixed with conventional petrol to make gasohol.

Summary

In this unit you have learnt that:

- Biotechnology is the use of micro-organisms to make things that people want, often involving industrial production.
- Biotechnology has been used for thousands of years to make bread, alcoholic drinks and fermented food products such as yoghurt and cheese.
- Yeast is a single-celled organism that can respire aerobically, producing carbon dioxide and water; this reaction is used in bread making to make the dough rise.
- Yeast can also respire anaerobically, producing ethanol and carbon dioxide in a process known as fermentation – the fermentation reaction of yeast is used to produce ethanol in the production of beer and wine.
- Bacteria are used in making both yoghurt and cheese. In the production of both, a starter culture of bacteria acts on warm milk. Lactose is converted to lactic acid in a lactic fermentation reaction. This changes the texture and taste of the milk to make yoghurt.
- In cheese making, a different starter culture is added to warm milk, giving a lactic fermentation which results in solid curds and liquid whey. The curds are often mixed with other bacteria or moulds before they are left to ripen.
- Modern biotechnology often involves genetic engineering and large-scale fermenters.

- In genetic engineering, desirable genes from one organism can be 'cut out' using enzymes and transferred to the cells of bacteria, animals and plants.
- Micro-organisms can be grown on a large scale in vessels known as fermenters, to make useful products such as antibiotics. Industrial fermenters have a range of features to make sure fermentation takes place in the best possible conditions.
- Modern biotechnology has many applications.
- In agriculture biotechnology is used to develop better crops and livestock, and to develop plants that contain their own pesticide.
- In food it is used in many ways: including to break down starch to form useful sugar syrups; to improve the production of beers and other fermented products; and to develop new foodstuffs.
- In medicine biotechnology is used to make drugs and medicines.
- Biotechnology is important in producing new forms of fuel to provide us with energy.
- Biogas – mainly methane – can be produced by anaerobic fermentation of a wide range of plant products and waste materials that contain carbohydrates.
- Ethanol-based fuels can be produced by the anaerobic fermentation of sugar cane juices and from glucose derived from maize starch by the action of the enzyme carbohydrase.

End of unit questions

1. What is biotechnology and why is it so important?
2. Name three different foodstuffs or drinks that are used by your family, and explain how biotechnology is involved in producing them.
3. a) You can leave injera mix in a fridge for hours without any gas bubbles being formed. Put it somewhere warm, and after a time bubbles start to appear again. Injera is usually ready to cook after two days. In a cool place it may take longer. Explain how these differences come about.

   b) Temperature is vital for successful beer and wine making. Why is it so important?
4. a) Write a brief report on 'Bacteria and fermented milk products'.

   b) Find out how fermented bean pastes are made and write about the biotechnology of this useful food.

5. Why are micro-organisms so important in the production of medicines? Describe two different medicines that rely on biotechnology in their production.

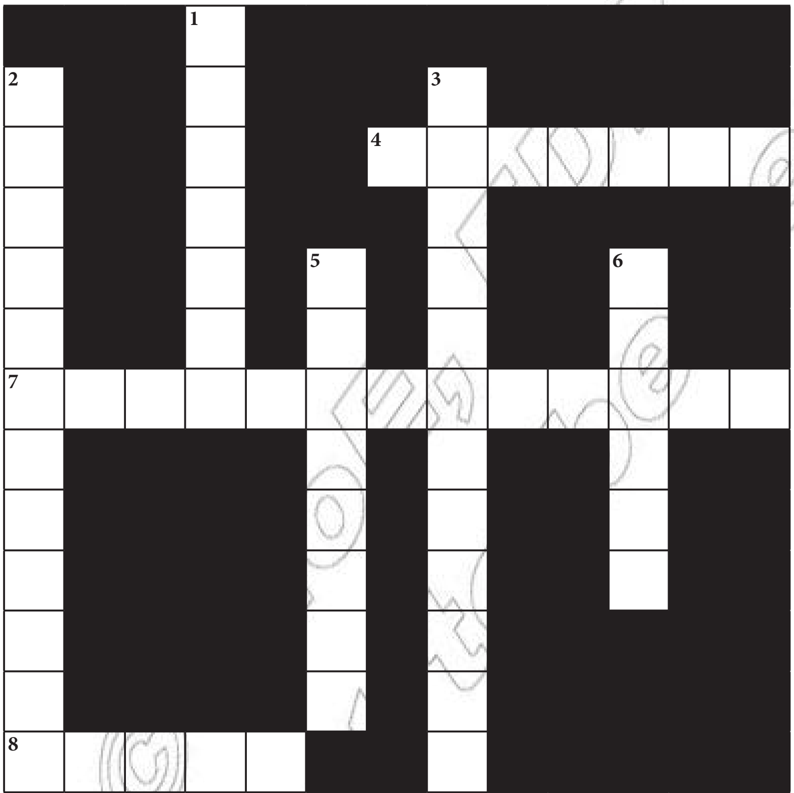
6. a) Using the data in the table on page 12, produce bar charts to compare high-quality biogas (high methane, low carbon dioxide) with poor-quality biogas (low methane, high carbon dioxide).

   b) What effect do you think differences in composition like this will have on the use of this gas as a fuel?

   c) Suggest ways in which people might improve the quality of the gas produced in their fermenter.

7. Write a letter to your head teacher or school administration explaining why you think they should look into the idea of providing energy for the school from biogas, and how they might do it.

Copy the crossword puzzle below into your exercise book (or your teacher may give you a photocopy) and solve the numbered clues to complete it.



ACROSS

4 Flammable gas made in biogas generator (7)

7 The study of living things used to perform industrial processes (13)

8 Microscopic fungi used to make alcoholic drinks and injera (5)

DOWN

1 Fermented whole milk (7)

2 The study of micro-organisms and their effect on humans (12)

3 Anaerobic respiration in yeast that produces ethanol (12)

5 Single-celled microscopic organisms which can reproduce very quickly (8)

6 Flammable mixture of gases formed when bacteria break down plant and animal material in anaerobic conditions (6)