IGCSE BIOLOGY 0610 · CHAPTER 15 NOTES · ~18 MIN READ

Biotechnology & genetic modification

How bacteria, yeast and fungi make useful products, how enzymes are used in fruit juice, washing powders and milk, how fermenters work, and how a gene is cut out, moved and used to make human insulin and better crops.

Bacteria & yeast | Enzymes in industry | Fermenters | Genetic modification

AS
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No tag = **Core** (everyone) EXTENDED Extended only highlight = comes up again and again

Test yourself at the end

IN 30 SECONDS

- **Biotechnology** uses **living organisms** or their **enzymes** to make useful products. **Bacteria** (fast breeders), **yeast** (ethanol and bread) and **fungi** (penicillin, mycoprotein) are grown in **fermenters** under controlled conditions.
- **Enzymes** are used in **industry**: **pectinase** in fruit juice, **protease, lipase and amylase** in washing powders, and **lactase** in lactose-free milk.
- **Genetic modification** moves a **gene** into another organism. **Restriction enzymes cut**, **ligase joins**, and a **plasmid** carries the gene into bacteria, which then make **human insulin**. GM crops can resist **herbicides and pests** or contain extra **nutrients**.

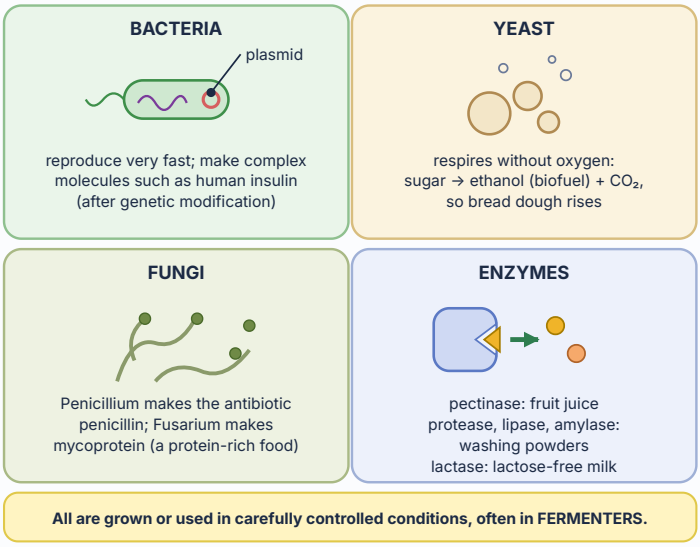
BY THE END YOU CAN

- Explain why bacteria are useful in biotechnology and genetic modification.
- Describe how yeast is used to make ethanol for biofuel and in bread-making.
- Describe the use of pectinase in fruit juice and of enzymes in biological washing powders.
- Define genetic modification and give examples of GM bacteria and GM crops.
- Explain why bacteria are suitable for biotechnology: rapid reproduction, few ethical concerns and plasmids. EXT
- Describe the use of lactase to make lactose-free milk. EXT
- Describe how fermenters are used to make insulin, penicillin and mycoprotein, and which conditions are controlled. EXT
- Outline how a gene is transferred, using restriction enzymes, sticky ends, DNA ligase and recombinant plasmids. EXT
- Discuss the advantages and disadvantages of GM crops. EXT

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1 Microorganisms in biotechnology

Bacteria, yeast and fungi



Bacteria, yeast, fungi and enzymes all do useful jobs for people, often in controlled conditions.

Biotechnology — the use of **living organisms** (or **parts of them**, such as **enzymes**) to **make useful products** or carry out useful processes.

- **Why bacteria are useful:** they **reproduce very fast** (some divide about **every 20 minutes**), so large numbers grow **cheaply and quickly**. They can also make **complex molecules**, such as **proteins**, that are very **hard to make** in any other way.
- EXT **Why bacteria suit genetic modification:** (1) **fewer ethical concerns** than using animals; (2) they contain **plasmids**, which are **easy to cut open and put genes into**; (3) the **genetic code is the same in all living things**, so a bacterium can **read a human gene** and make the human protein.

Plasmid — EXT a small **circular ring of DNA** in a bacterium, **separate from the main chromosome**.

COMMON MISTAKE

"All bacteria are harmful germs." **No.** Most bacteria are **harmless** and many are **very useful** (making insulin, enzymes and food). Only some cause disease (pathogens).

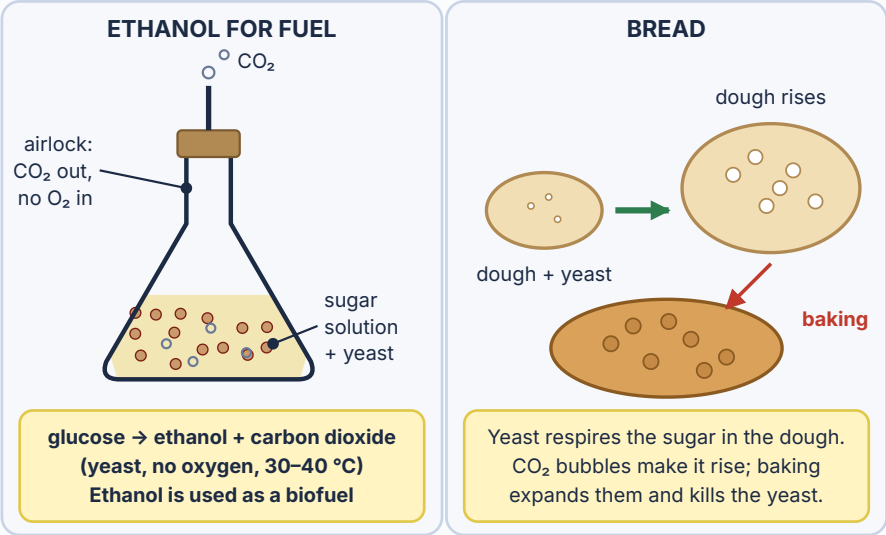
WORKED EXAMPLE

One bacterium divides every 30 minutes. How many bacteria could there be after 5 hours if there are no limits?

1. 5 hours = 300 minutes
2. 300 ÷ 30 = **10 divisions**
3. each division **doubles** the number: 2^{10} = **1 024 bacteria**
4. **in a real culture food and space run out first (growth curve)**

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Yeast: ethanol and bread



Yeast ferments sugar without oxygen, making ethanol and carbon dioxide. Ethanol is a fuel and CO_2 makes dough rise.

- **Yeast** is a **single-celled fungus**. With **no oxygen** it respires **anaerobically**, turning **sugar** into **ethanol** and **carbon dioxide** (anaerobic respiration). This is **fermentation**.

glucose → ethanol + carbon dioxide

anaerobic respiration in yeast (fermentation)

- **Biofuel:** yeast ferments sugars from crops such as **sugar cane** or **maize**. The **ethanol** is separated and used as a **fuel**, often mixed with petrol. It is **renewable**, because the crop can be grown again.
- **Bread-making:** yeast respires the **sugar in the dough**. The **CO_2 bubbles** make the dough **rise**. **Baking** makes the bubbles **expand** (and kills the yeast), giving a **light** texture.

EXAM TIP

Yeast works best when **warm (about 30–40 °C)**. If it is **too cold** it is **slow**. If it is **too hot** its **enzymes denature** and it dies.

WORKED EXAMPLE

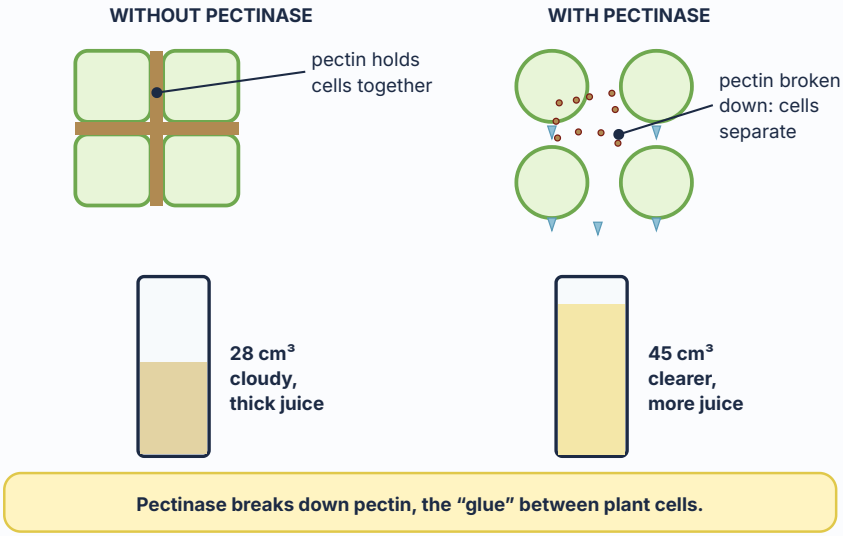
Yeast is added to sugar solution at four temperatures and the CO_2 bubbles in 1 minute are counted: 20 °C = 15, 30 °C = 32, 40 °C = 48, 70 °C = 0. Describe and explain the results.

1. from 20 to 40 °C the bubbles **increase** (15 → 32 → 48), so the **rate of fermentation rises** with temperature
2. enzymes and sugar have **more kinetic energy**, so **more collisions**
3. at 70 °C there are **no bubbles**: the **enzymes are denatured** and the yeast has died
4. **the rate at 40 °C is 48 ÷ 15 = 3.2 times the rate at 20 °C**

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2 Enzymes in industry

Pectinase and fruit juice



Pectinase breaks down the pectin that holds plant cells together, so more juice runs out.

Pectinase — an **enzyme** that **breaks down pectin**.

- **Pectin** is a carbohydrate that **holds plant cells together**. When **pectinase** is added to crushed fruit, the cells **separate** and **release more juice**.
- **Benefits: more juice** (a higher yield), **clearer** juice, and juice that is **less thick**, so it is **easier to filter**.

WORKED EXAMPLE

Crushed apple pulp gives 28 cm³ of juice without pectinase and 45 cm³ with pectinase. Calculate the percentage increase in juice.

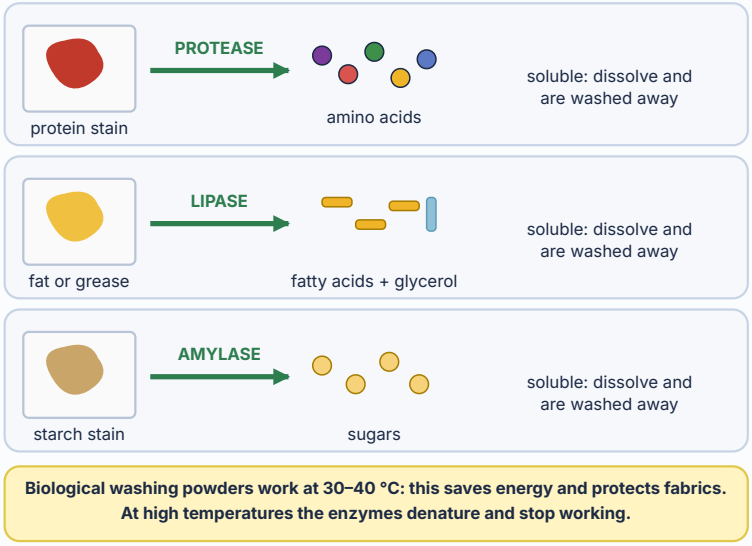
1. increase = 45 − 28 = **17 cm³**
2. % increase = 17 ÷ 28 × 100
3. **= 61% (to the nearest whole number)**

EXAM TIP

In a pectinase investigation use the **same mass of pulp, same temperature and same time**. The **only difference** is whether the **enzyme** is added (enzymes).

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Enzymes in washing powders



Biological washing powders contain enzymes that break stains into small soluble molecules that wash away.

- **Biological washing powders** contain **protease** (breaks down **protein** stains such as blood and egg), **lipase** (breaks down **fats and oils**) and **amylase** (breaks down **starch** from food).
- The enzymes turn the stains into **small, soluble molecules**, which **dissolve** in the water and are **washed away**.
- They work at **low temperatures (30–40 °C)**, which **saves energy** and **protects fabrics**. At **high temperatures** the enzymes **denature** and stop working.

COMMON MISTAKE

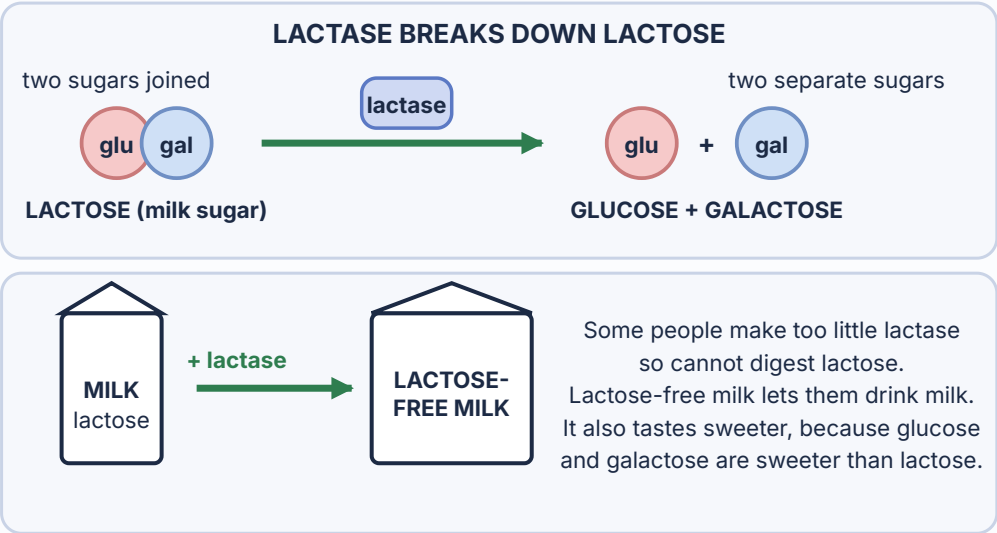
"Enzymes work best in a boiling wash." **No.** High temperatures **denature** enzymes. Biological powders are used at **30–40 °C**.

Enzyme	Breaks down	Into	Use
pectinase	pectin	smaller carbohydrate molecules	fruit juice
protease	protein	amino acids	washing powder
lipase	fats and oils	fatty acids and glycerol	washing powder
amylase	starch	sugars	washing powder
lactase EXT	lactose	glucose and galactose	lactose-free milk

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Lactase and lactose-free milk

EXTENDED

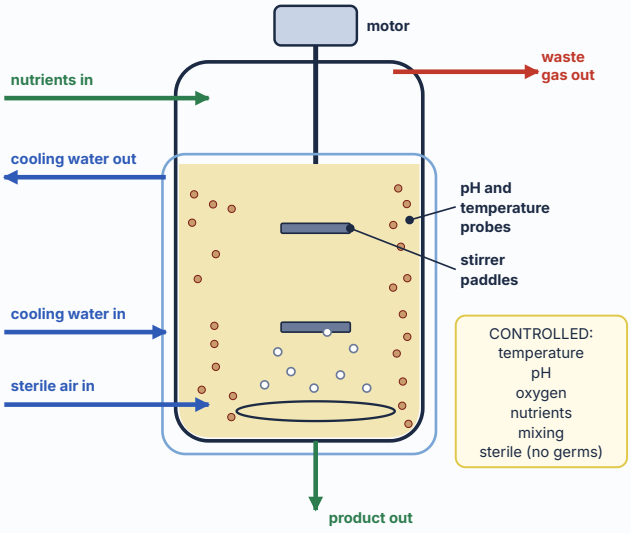


EXT Lactase splits lactose into glucose and galactose, so people who cannot digest lactose can drink the milk.

- EXT **Lactose** is the **sugar in milk**. The enzyme **lactase** breaks lactose down into **glucose and galactose**.
- EXT Some people are **lactose intolerant** (they make **too little lactase**). Milk treated with **lactase** is **lactose-free**, so they can drink it.
- EXT **Glucose and galactose taste sweeter** than lactose, so **less sugar** needs to be added to some milk products.

3 Fermenters EXT

Making products in fermenters



EXT A fermenter keeps temperature, pH, oxygen, nutrients and mixing at the best level for the microorganisms.

Fermenter — EXT a **large vessel** in which **microorganisms** are grown under **controlled conditions** to make a **product**.

- EXT **Products: insulin** (made by **genetically modified bacteria**), the antibiotic **penicillin** (made by the mould **Penicillium**, antibiotics) and **mycoprotein** (a **protein-rich food** made from the fungus **Fusarium**, used as a **meat substitute**).
- EXT The conditions are **controlled** so that the microorganisms **grow fastest** and make the **most product**.

Condition	How it is controlled	Why
temperature	**water jacket** with cooling water; **temperature probe**	respiration releases **heat**; the right temperature keeps the **enzymes working**
pH	**pH probe**; acid or alkali added	the wrong pH **denatures** enzymes
oxygen	**sterile air** bubbled in	most of the microorganisms need oxygen for **aerobic respiration**
nutrients	**added** (glucose, nitrogen source, minerals)	for **energy**, **growth** and **making the product**
mixing	**stirrer** (paddles)	spreads **nutrients, oxygen and heat** evenly
sterile conditions	vessel **steam-cleaned**; air **filtered**	other microorganisms would **compete** with the culture and **spoil** the product
waste	waste gases and product **removed**	a build-up of waste can **poison** the microorganisms

COMMON MISTAKE

"A fermenter must have **no oxygen**." **No.** That is true for yeast making ethanol, but many fermenters (for example for **penicillin**) are supplied with **sterile air** for **aerobic** respiration.

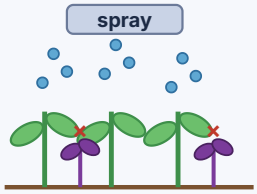
EXAM TIP

For a fermenter question, link every condition to a reason: "**temperature kept at the optimum so enzymes work fastest**", "**sterile so that other microbes do not compete**".

4 Genetic modification

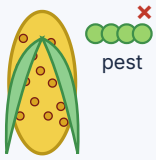
What is genetic modification?

herbicide-resistant soya



resistance gene: the crop survives the weedkiller, but the weeds die

insect-resistant maize



a bacterial gene makes the plant toxic to pests, so less insecticide is used

nutritional rice (golden rice)



an extra gene makes beta-carotene, which the body turns into vitamin A

In each case the new gene is inserted into the crop's cells.
GM crops are grown for higher yield, lower costs or better nutrition.

Genes can be inserted into crops to give them useful new features.

Genetic modification — changing the genetic material of an organism by **removing, changing or inserting individual genes**.

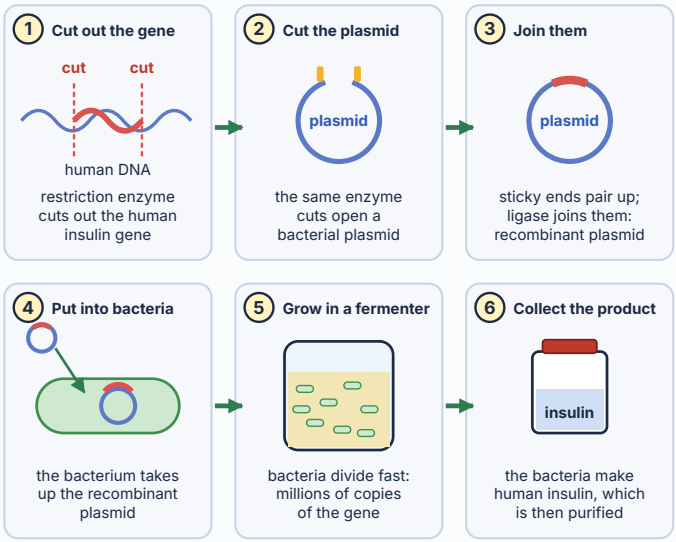
- A gene from **one species** can be put into **another species**. All living things use the **same genetic code**, so the cell can **read the new gene** and **make the protein**.
- **Human proteins in bacteria:** the gene for **human insulin** is put into bacteria, which make insulin for people with **diabetes** (diabetes).
- **Crops with new features: herbicide resistance** (soya survives the weedkiller), **pest resistance** (maize with a bacterial gene that makes it toxic to pest insects) and **extra nutrients** (**golden rice** makes **beta-carotene**, which the body turns into **vitamin A**).
- GM is **not** the same as selective breeding, which only mixes genes that are **already in the species**.

	Selective breeding	Genetic modification
what changes?	the **whole set of genes**, over **many generations**	**one chosen gene**, in **one step**
where do the genes come from?	the **same species**	**any species** (for example a bacterium or a human)
example	cattle that give more milk	bacteria that make human insulin

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Making human insulin in bacteria

EXTENDED



EXT The gene is cut out, joined into a plasmid, put into bacteria and the bacteria are grown in a fermenter.

Restriction enzyme — EXT an enzyme that **cuts DNA at a specific sequence of bases**, often leaving **sticky ends**.

DNA ligase — EXT an enzyme that **joins pieces of DNA** together.

Recombinant plasmid — EXT a plasmid that contains **DNA from another organism**.

- EXT **Step 1.** A **restriction enzyme cuts out** the **human insulin gene** from human DNA.
- EXT **Step 2.** The **same restriction enzyme** cuts open a **bacterial plasmid**. Both pieces now have **matching sticky ends**.
- EXT **Step 3.** The gene and the plasmid are mixed. The **sticky ends pair up**, and **DNA ligase** joins them to make a **recombinant plasmid**. The plasmid is the **vector** that carries the gene.
- EXT **Step 4.** The **recombinant plasmid is put into bacteria**.
- EXT **Step 5.** The bacteria are grown in a **fermenter**. They **divide quickly**, copying the plasmid, and **make human insulin**.
- EXT **Step 6.** The **insulin is collected and purified** for use by people with diabetes.

MEMORY TRICK

Restriction enzyme = **s**cissors (it **cuts**). **L**igase = **g**lue (it **joins**).

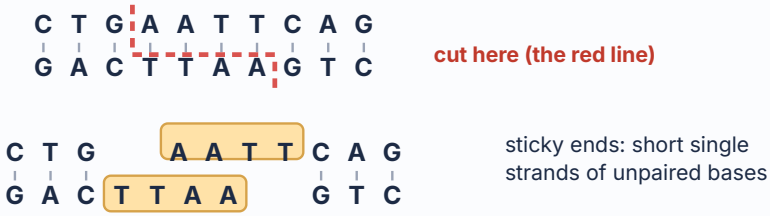
COMMON MISTAKE

"DNA ligase cuts out the gene." **No.** The **restriction enzyme cuts** and the **ligase joins**.

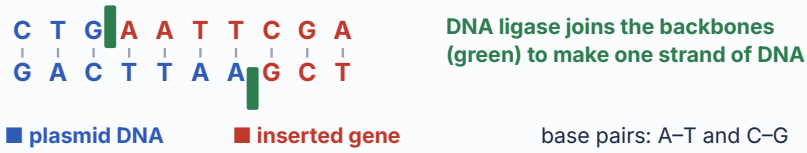
Restriction enzymes, sticky ends and ligase

EXTENDED

1 A restriction enzyme cuts DNA and leaves "sticky ends"



2 A piece cut with the same enzyme has matching sticky ends, so they pair up



EXT A restriction enzyme cuts both strands off-set, leaving single-stranded sticky ends that can pair with matching ones.

Sticky ends — EXT short **single-stranded** pieces of **unpaired bases** at the cut ends of DNA. They **pair with matching sticky ends** made by the same enzyme.

- EXT The enzyme **recognises one sequence** of bases and **cuts the two strands at different places**. This leaves **single-stranded overhangs**.
- EXT Sticky ends join by **complementary base pairing**: **A with T** and **C with G**. DNA from **any organism** cut with the **same enzyme** has **matching ends**, so the gene fits into the plasmid.
- EXT At first the pieces are held together only by **base pairs**. **DNA ligase joins the sugar–phosphate backbones** to make them **permanent**.

WORKED EXAMPLE

One sticky end has the bases A A T T. Which bases must the matching sticky end have?

1. bases pair up as **A with T** and **C with G**
2. A–**T**, A–**T**, T–**A**, T–**A**
3. **so the matching sticky end is T T A A**

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GM crops: advantages and disadvantages

EXTENDED

Advantages	Disadvantages
higher yield because the crop resists pests or weedkiller, so **more food** from the same land	the **gene may spread** to wild plants by pollen (for example herbicide resistance in **weeds**)
less insecticide is needed (insect-resistant maize), which **saves money** and reduces **pollution**	**harm to other organisms** (for example useful insects) and so to **biodiversity**
herbicide-resistant soya makes **weed control** easier	**long-term effects on human health** are not fully known, which worries some people
extra nutrients (golden rice has vitamin A), which helps prevent **deficiency diseases**	the **seeds are expensive**, so farmers depend on the companies that sell them

WORKED EXAMPLE

The yield of a GM maize crop is 9.6 tonnes per hectare and of ordinary maize 8.0 tonnes per hectare. Calculate the percentage increase.

1. increase = 9.6 − 8.0 = **1.6 t/ha**
2. % increase = 1.6 ÷ 8.0 × 100
3. **= 20%**

EXAM TIP

For a "discuss" question give **at least one advantage and one disadvantage**, each with a **reason**. Avoid saying GM crops are "unsafe" or "perfectly safe": say that **long-term effects are still being studied**.

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5 Test yourself

Test yourself — cover the answers first

QUICK CHECK

1. Define biotechnology.
2. Give two reasons why bacteria are useful in biotechnology.
3. What does yeast make when it respires without oxygen?
4. Write the word equation for fermentation in yeast.
5. Why does bread dough rise?
6. What is bioethanol used for?
7. What does pectinase do?
8. Give two benefits of adding pectinase to crushed fruit.
9. Which enzymes in washing powders break down protein, fats and starch?
10. Why do biological washing powders work well at 30–40 °C?
11. Define genetic modification.
12. Name one human protein made by GM bacteria.
13. Give one example of a useful feature given to a GM crop.
14. EXT What is a plasmid?
15. EXT Give two reasons why bacteria are suitable for genetic modification.
16. EXT What does lactase do?
17. EXT Name two products made in fermenters.
18. EXT Why must a fermenter be sterile?
19. EXT Why is cooling water used in a fermenter?
20. EXT Which enzyme cuts DNA at a specific sequence of bases?
21. EXT What are sticky ends?
22. EXT Which enzyme joins DNA fragments together?
23. EXT What is a recombinant plasmid?
24. EXT Give one advantage and one disadvantage of GM crops.

EXAM-STYLE

25. Describe how yeast is used in bread-making. [3]
26. Describe how biological washing powders remove stains, and explain why they are used at low temperatures. [4]
27. Describe the use of pectinase in making fruit juice. [3]
28. State two reasons why bacteria are used to make human proteins. [2]
29. EXT Explain why lactase is added to milk. [3]
30. EXT Describe how the conditions in a fermenter are controlled and why. [5]
31. EXT Describe how a bacterium can be genetically modified to make human insulin. [6]
32. EXT Discuss the advantages and disadvantages of growing herbicide-resistant soya. [4]

Show answers

1. the use of living organisms (or parts of them, such as enzymes) to make useful products
2. they reproduce very quickly; they can make complex molecules such as proteins
3. ethanol and carbon dioxide
4. glucose → ethanol + carbon dioxide
5. yeast respires the sugar and the carbon dioxide bubbles make the dough rise
6. as a biofuel (mixed with petrol)
7. it breaks down pectin, which holds plant cells together
8. more juice, clearer juice, easier to filter
9. protease, lipase, amylase
10. this saves energy and protects fabrics, and the enzymes work without being denatured
11. changing the genetic material of an organism by removing, changing or inserting individual genes
12. insulin
13. herbicide resistance, pest resistance, extra vitamin A
14. a small circular ring of DNA in a bacterium, separate from the main chromosome
15. fewer ethical concerns, they have plasmids, the genetic code is the same in all organisms, they reproduce fast
16. it breaks lactose down into glucose and galactose
17. insulin, penicillin, mycoprotein
18. so other microorganisms do not compete with the culture and spoil the product
19. respiration releases heat and the temperature must stay at the optimum for the enzymes
20. a restriction enzyme
21. short single-stranded pieces of unpaired bases at the ends of cut DNA that pair with matching ends
22. DNA ligase
23. a plasmid containing DNA from another organism
24. advantage: higher yield or less insecticide or extra nutrients; disadvantage: gene may spread to wild plants or harm other organisms or seeds are expensive
25. yeast is mixed into dough that contains sugar
    the yeast respires the sugar and makes carbon dioxide
    the carbon dioxide bubbles make the dough rise and baking makes the bubbles expand
26. they contain protease, lipase and amylase
    these break down protein, fat and starch stains
    into small soluble molecules that wash away
    low temperatures save energy and prevent the enzymes being denatured
27. pectinase is added to crushed fruit
    it breaks down pectin that holds the cells together
    so more juice is released and the juice is clearer
28. they reproduce very quickly
    they can make complex molecules such as proteins

29. lactase breaks lactose into glucose and galactose
    some people cannot digest lactose
    so the milk becomes lactose-free and they can drink it
30. temperature is controlled with a water jacket so that enzymes work at their optimum
    pH is monitored and adjusted so enzymes are not denatured
    sterile air supplies oxygen for respiration
    nutrients are added for growth
    a stirrer mixes everything and the vessel is kept sterile so other microorganisms do not compete
31. a restriction enzyme cuts out the human insulin gene
    the same enzyme cuts open a plasmid, leaving matching sticky ends
    the gene and plasmid are joined by DNA ligase
    this makes a recombinant plasmid
    the plasmid is put into bacteria
    the bacteria are grown in a fermenter and make insulin
32. advantage: weeds can be killed without harming the crop, giving a higher yield
    advantage: lower costs of weed control
    disadvantage: the resistance gene may spread to wild plants (weeds)
    disadvantage: harm to other organisms and biodiversity or unknown long-term effects

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