17 Species, selection and genetic engineering

For over 200 years humans have **selected** and **crossed** plants and animals to produce new and improved varieties due to mixing genetic material. Since the structure of DNA was discovered in 1953, **gene technology** has moved at an ever increasing pace to change the traits of organisms, treat genetic disorders and produce medicinal drugs.

Species

*A **species** is a group of organisms of common ancestry that closely resemble each other and are normally capable of interbreeding to produce fertile offspring.*

Members of some closely related species are capable of interbreeding and producing offspring; however, their offspring are usually either **sterile** or are so **biologically weak** that they rarely produce offspring. This keeps species as **distinct groups**.

Species that can interbreed include some birds, e.g. certain species of owls, gulls, crows and ducks, and many species of plants, e.g. interbreeding of shaddock and Jamaican sweet orange created the grapefruit, and spearmint and water mint created peppermint. Mammal species that can interbreed include a donkey and a horse which produce a **mule** or a **hinney**, and a lion and a tiger which produce a **liger** or a **tigon**.

The formation of new species – speciation

As long as organisms from different groups within a species can interbreed and genes can flow between them, the groups remain members of the same species. If groups become **separated** or **isolated**, the flow of genes between them stops. **Genetic differences** gradually develop and a point is reached where members of the groups can no longer successfully interbreed. They become **separate species**, each with its own pool of genes.

- **Speciation by geographical separation**

  This occurs when a **physical barrier** prevents two groups of organisms of the same species from meeting and interbreeding. Such barriers include mountain ranges, deserts, oceans, rivers or even streams.

- **Speciation by ecological and behavioural separation**

  Speciation can occur when two groups of organisms of the same species inhabit the same region but they become adapted to different **habitats** in that region, which reduces gene flow.

  Speciation can also occur when animals exhibit elaborate **courtship behaviours** before mating, which may be stimulated by the colour, markings, calls or actions of the opposite sex. If small differences occur in any of these stimuli it can prevent mating, which prevents gene flow.

Extinction of species

Over time species can also become **extinct**, i.e. they no longer exist. Habitat loss, disease, predation by introduced species, competition with introduced species or overexploitation by humans, e.g. overfishing or overhunting, can all lead to extinction of species. For example, the **Caribbean monk seal** has become extinct due to it being overhunted for its fur, meat and oil.

The role of natural selection in biological evolution

Natural selection is the process by which populations change over time or **evolve**, so that they remain well adapted to their environment. Charles Darwin was the first person to put forward the idea of evolution by natural selection in 1859 in his book *On the Origin of Species*. The **theory of natural selection** is based on the following:

- Most organisms produce **more offspring** than are needed to replace them, yet the numbers of individuals in populations remain relatively constant. In nature there must, therefore, be a constant **struggle for survival**.
- All organisms show **variation** and much of this can be inherited. Those organisms possessing variations that make them **well adapted** to their environment are most likely to survive in the struggle, i.e. there is **survival of the fittest**.
- Since the well adapted organisms are the most likely to survive, they are the ones most likely to **reproduce**, thereby passing on their advantageous characteristics to their offspring. Species, therefore, remain well adapted to their environment or they gradually **change** and **improve** by becoming even better adapted.

Natural selection **preserves useful adaptations** since the genes that produce advantageous characteristics are passed on to offspring **more frequently** than the genes that produce less advantageous characteristics. It is the mechanism by which populations retain the genes that make them well adapted to their environments.

Genetic **variation**, especially that resulting from beneficial mutations, is the **raw material** for natural selection.

Evidence for natural selection

Natural **selection** in action can be seen in the following examples:

- **The peppered moth**

  The **peppered moth** lives in Britain and is eaten by birds. Before the Industrial Revolution, the moths were black and white speckled and were well camouflaged against the pale lichen-covered tree trunks on which they rested.

  During the Industrial Revolution, a **melanic** (all black) variety appeared in the industrial area around Manchester. This melanic variety arose as a result of a dominant mutation and was well camouflaged against the tree trunks which were blackened with soot. This gave the melanic variety a **selective advantage** in industrial areas and, over time, it became far more numerous in these areas than the speckled variety.

Peppered moth

- **Antibiotic and pesticide resistance**

  In natural populations of bacteria and various pests, e.g. insects, fungi and weeds, a few individuals may carry genes that make them **resistant** to antibiotics or various pesticides, e.g. insecticides, fungicides and herbicides. These genes arise from mutations. When exposed to antibiotics or pesticides, these resistant organisms have a **selective advantage**; they are more likely to survive and reproduce than non-resistant organisms, passing on their resistance to their offspring. This is causing increasing numbers of resistant organisms to appear within populations.

Two of Darwin's finches

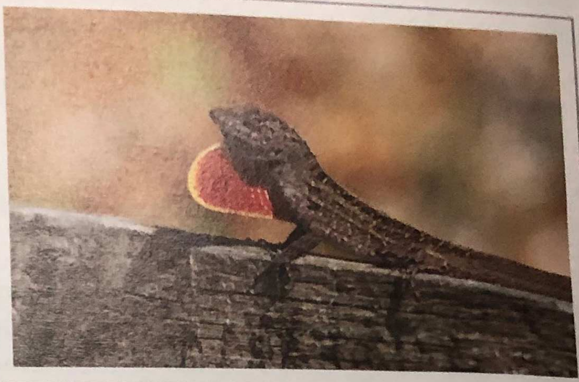
- **Galapagos finches**

  The Galapagos Islands in the Pacific Ocean have at least 13 different species of finches which are possibly all descendants of a single South American species that colonised the islands from the mainland.

The main difference between species is in the shape and size of their beaks. As a result of **natural selection**, their beaks have become highly adapted to the different types of food present on the various islands, e.g. seeds, insects, nectar or fruits.

- **Caribbean lizards**

  Anole lizards are thought to have colonised the islands of the Caribbean from Central and South America. Through **natural selection**, lizards stranded on the four larger islands of Cuba, Hispaniola, Jamaica and Puerto Rico independently evolved into different species with similar characteristics that enabled them to fit similar ecological niches on each island, e.g. twig anoles developed long, slender bodies and tails and short legs; trunk ground anoles developed long, muscular legs, and canopy anoles developed large toe pads. Today, the different species have **equivalent species** with similar body types on each island.



A twig anole

Artificial selection

Artificial selection involves humans selecting and breeding organisms showing **desirable characteristics**. As a result, new breeds, strains or varieties of plants and animals are produced with characteristics to suit human needs. Undesirable characteristics are 'bred out'. Artificial selection produces new varieties of organisms in a **shorter time** than natural selection. It has the disadvantage that it **reduces variation** in populations making them more vulnerable if environmental conditions change.

- **Inbreeding** involves breeding **closely related** individuals showing desirable characteristics. It is usually used to improve one particular trait. Continued inbreeding reduces the gene pool which increases the frequency of **undesirable genes** and reduces the overall fitness of the organisms. After several generations of inbreeding, outbreeding must take place to introduce new genes into a population.
- **Outbreeding** involves breeding individuals from **genetically distinct** populations showing desirable characteristics. Offspring produced are called **hybrids** and usually show characteristics that are superior to both parents. This is known as **hybrid vigour**.

Artificial selection is used extensively in agriculture to produce crop plants and farm animals with:

- **Increased yields**, e.g. cattle that produce more milk or meat, chickens that lay more or larger eggs, sugar cane that produces more sucrose and cereal crops that produce more grain.
- **Increased quality** of product, e.g. meat with less fat, and cereals and ground provisions with a higher protein content.
- **Faster growth rates.**
- **Increased number of offspring.**
- **Shorter time to reach maturity** so that more generations are produced per year.
- **Increased resistance** to pests and disease. This reduces product loss and the need for pesticides.
- **Increased suitability to the environment.**

Artificial selection in action in the Caribbean

- **Jamaica Hope**, a breed of dairy cattle, was developed in Jamaica by breeding Jersey, Zebu and Holstein cattle. The breed is heat tolerant, has a high resistance to ticks and tick borne diseases, and produces a high yield of milk, even when grazing on the poor pasturelands of the Caribbean.
- **Sugar cane** has been bred to produce varieties with a high sucrose content, increased resistance to disease and insect pests, greater suitability to its environment and improved ratooning ability.

Genetic engineering

Genetic engineering involves changing the traits of one organism by inserting genetic material from a different organism into its DNA. The organism receiving the genetic material is called a **transgenic organism** or **genetically modified organism (GMO)**.

Genetic engineering is used to:

- Protect agricultural crops against environmental threats, e.g. pathogens, pests, herbicides and low temperatures.
- Modify the quality of a product, e.g. increasing nutritional value.
- Make organisms produce materials that they do not usually produce, e.g. vaccines and drugs.
- Improve yields, e.g. increasing size or growth rate, or making organisms more hardy.

Genetic engineering and food production

Genetic engineering is used to improve food production.

Examples

- **Golden rice**

  By inserting two genes into rice plants, one from maize and one from a soil bacterium, the endosperm of the rice grains is stimulated to produce **beta-carotene** which the body converts to vitamin A. Golden rice should help fight vitamin A deficiency which is a leading cause of blindness, and often death, of children in many underdeveloped countries.

Golden rice

- **Roundup resistant crops**

  By inserting a gene from a soil bacterium into certain crop plants, e.g. soya bean, corn and canola, the plants become **resistant** to the herbicide called 'Roundup'. The herbicide can be sprayed on the crops to destroy weeds, but not harm the crops.

- **Bt corn**

  By inserting a gene from a soil bacterium into corn plants, the plants are stimulated to produce a chemical that is toxic to corn-boring caterpillars. This makes the corn plants **resistant** to the caterpillars.

- **Bovine somatotrophin (BST) hormone**

  By transferring the gene that controls the production of BST hormone from cattle into bacteria, the bacteria produce the hormone which is then injected into cattle to increase milk and meat production.

- **Chymosin (rennin)**

  By transferring the gene that controls the production of chymosin from calf stomach cells into bacteria or fungi, the micro-organisms produce chymosin which is used in **cheese** production. This has considerably increased the production of cheese worldwide.

Genetic engineering and medical treatment

Genetic engineering is used to produce many drugs used in medical treatment.

Examples

- **Insulin**

  By transferring the gene that controls insulin production in humans into bacteria, the bacteria produce insulin which is used to treat **diabetes**.

- **Human growth hormone (HGH)**

  By transferring the gene controlling the production of HGH into bacteria, the bacteria produce the hormone which is used to treat **growth disorders** in children.

- **Hepatitis B vaccine**

  By transferring the gene controlling the production of hepatitis B antigens in the hepatitis B virus into yeast, the yeast produces the **antigens** which are used as a **vaccine**.

Other drugs produced by genetic engineering include:

- **Blood clotting drugs** for people with haemophilia.
- **Follicle stimulating hormone (FSH)** used to stimulate the ovaries to produce mature ova in women that are infertile.
- **Interferons** used to treat viral infections and certain cancers.
- **Anticoagulants** used to prevent the development of life-threatening blood clots in heart patients.
- **Human papilloma virus vaccine**.

Possible advantages of genetic engineering

- **Yields** can be **increased** by genetic engineering which should increase the world food supply and reduce food shortages.
- The **nutritional value** of foods can be increased by genetic engineering which should reduce deficiency diseases worldwide.
- The need for **chemical pesticides** that harm the environment can be reduced by genetically engineering crops to be resistant to pests.
- **Vaccines** produced by genetic engineering are generally **safer** than vaccines containing live and weakened, or dead pathogens.
- **Larger quantities** of drugs in a **safer** and **purer** form can be produced than were previously produced from animal sources resulting in more people worldwide having ready access to safe, life-saving drugs.
- It overcomes **ethical concerns** of obtaining certain drugs from animals, e.g. insulin used to be obtained from pigs and cows.

Possible disadvantages of genetic engineering

- Plants genetically engineered to be toxic to a pest may also be toxic to **useful organisms**, e.g. insects that bring about pollination. This could negatively affect wild plants and reduce reproduction in crops, reducing food production.
- Plants genetically engineered to be resistant to pests and herbicides could create **unpredictable environmental issues**, e.g. they could lead to the development of pesticide-resistant insects or they could interbreed with closely related wild plants and create herbicide-resistant superweeds.

- Once a genetically modified organism is released into the environment, it cannot be **contained** or **recalled**. Any negative effects are irreversible.
- The number of **allergens** in foods could be increased by transferring genes causing allergic reactions between species.
- As yet **unknown health risks** may occur as a result of eating genetically modified plants and animals.
- Large companies with funds and technology to develop genetically modified organisms could make **large profits** at the expense of smaller companies and poorer nations.
- Future steps in genetic engineering might allow the genetic make-up of higher organisms, including humans, to be altered, e.g. to produce 'designer babies'. Difficult **moral** and **ethical issues** then arise, e.g. how far should we go in changing our own genes and those of other animals?

Other applications of gene technology

- **DNA testing or DNA fingerprinting**

  DNA testing involves analysing specific regions of DNA taken from cells of individuals, scenes of accidents or crime scenes. It is used:
  - To determine if two DNA samples are from the same person thereby helping to **solve crimes**.
  - To determine the **paternity** and, in some cases, the maternity of a child.
  - To **identify** a body.
  - To detect **genetic disorders** or **diseases** before birth or early in life so treatment can begin at an early age.
  - To help **genetic counsellors** predict the likelihood that a child who is born to parents who have a genetic disease, or are carriers of a genetic disease, will suffer from the disease.
  - To identify **family relationships** thereby reuniting families.
  - To determine **ancestral lines** and create family trees.

- **Gene therapy**

  Gene therapy is an experimental technique that involves **altering genes** inside body cells to cure a disease or help the body fight a disease. It is currently being tested for use in various ways:
  - By inserting a **functional gene** into cells to replace a defective gene that causes a disease.
  - By **inactivating** or 'turning off' a defective gene that causes a disease.
  - By introducing a gene into cells to help the body's immune system to **fight** a disease.

- **Captive breeding programmes**

  Captive breeding involves breeding and raising animals in human controlled environments, e.g. zoos, aquaria and wildlife reserves. The aim is to prevent the extinction of endangered species, conserve species that may not survive well in the wild, reintroduce animals back into the wild and preserve biodiversity. **DNA profiling** is used in these programmes:
  - To assess the **genetic diversity** of organisms to be bred thereby preventing breeding organisms that are too genetically similar, i.e. inbreeding (see page 160).
  - To help prevent the **loss** of genetic diversity within offspring and future generations of offspring produced by the breeding programmes.

Revision questions

1. Define the term 'species'.
2. Identify TWO ways in which new species may develop.
3. Explain how natural selection plays a role in biological evolution.
4. There are several pieces of evidence in existence today that support the theory of natural selection. Discuss TWO of these.
5. Humans are able to apply the principles of natural selection in agriculture. Using ONE plant and ONE animal as examples, explain how this is being done in the Caribbean.
6. What is genetic engineering?
7. Describe TWO ways in which genetic engineering is being used to improve food production and TWO ways in which it is being used in medical treatment.
8. Discuss THREE possible advantages and THREE possible disadvantages of genetic engineering.
9. Outline THREE uses of DNA testing.

Exam-style questions – Chapters 16 to 17

Structured questions

1 a) Figure 1 shows a dividing cell.

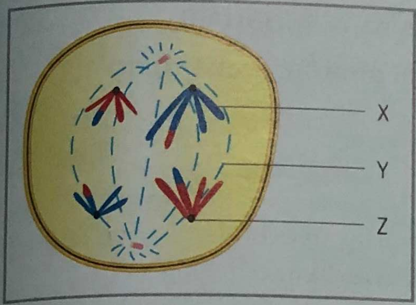


Figure 1 *A dividing cell*

i) Name the structures labelled X, Y and Z. **(3 marks)**

ii) Identify the type of cell division shown in Figure 1. **(1 mark)**

iii) Give TWO reasons for your answer to **ii)**. **(2 marks)**

iv) Name ONE place in the human body where they type of cell division shown in Figure 1 would occur. **(1 mark)**

iv) How many chromosomes would each daughter cell possess when the cell shown in Figure 1 has finished dividing? **(1 mark)**

v) Give TWO ways in which the cell division shown in Figure 1 differs from the cell division occurring in a growing embryo. **(2 marks)**

b) i) What is cloning? **(2 marks)**

ii) Despite the fact that sugar cane can reproduce sexually, most sugar cane is grown from stem cuttings. Suggest TWO advantages of using this method. **(2 marks)**

iii) Suggest ONE disadvantage of cloning in plants. **(1 mark)**

Total 15 marks

2 Albinism is a condition in which the external pigmentation fails to develop. It is caused by a recessive allele and is not sex-linked. The family tree in Figure 2 below shows the inheritance of albinism in a family.

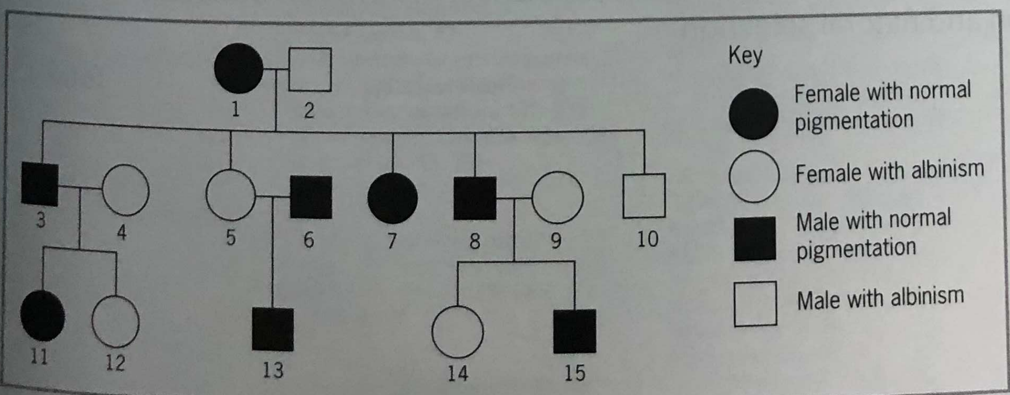


Figure 2 *The inheritance of albinism in a family*

a) i) Using appropriate symbols, give the genotypes of persons 1 and 2. (2 marks)

ii) If persons 11 and 15 were to marry, what is the chance that any of their offspring would have albinism? Using a genetic-cross diagram, explain your answer. (3 marks)

iii) If the albinism was sex-liked, give the possible phenotypes of the children of persons 5 and 6. Use a genetic-cross diagram to explain your answer. (4 marks)

b) i) What type of variation is shown in Figure 2? (1 mark)

ii) Identify TWO other human characteristics that show the same type of variation as that shown in Figure 2. (2 marks)

iii) Give TWO reasons why variation among living organisms is important. (2 marks)

iv) How is it possible for organisms that have the identical genetic make-up to show variation? (1 mark)

Total 15 marks

Extended response questions

3 a) Distinguish between the following pairs of terms:

i) genotype and phenotype

ii) dominant trait and recessive trait. (4 marks)

b) In pea plants, resistance to fungal disease is a recessive trait. Use appropriate symbols and a genetic diagram to work out the possible phenotypes from a cross between a non-resistant, heterozygous plant and a resistant plant. (4 marks)

c) Genetic engineering is used to change the traits of organisms and it may be used to cure genetic diseases in the future.

i) Outline TWO ways genetic engineering is currently being used to improve medical treatment and discuss how it may be used in the future to cure genetic diseases. (5 marks)

ii) Give TWO concerns that people might have about the use of genetic engineering to change the traits of organisms. (2 marks)

Total 15 marks

4 a) i) What is a species and what maintains species as distinct groups? (3 marks)

ii) Explain TWO ways in which new species can form. (4 marks)

b) Increasing numbers of bacteria are becoming resistant to commonly used antibiotics. Use the theory of natural selection to help explain how this situation arises. (4 marks)

c) By referring to specific examples other than resistance, distinguish between artificial selection and natural selection. (4 marks)

Total 15 marks