

## Chapter 6

# How do the frequencies of genes change when the environment changes?

### Concepts to be addressed

The gene pool concept is often not well understood. Students should be encouraged to think of this in terms of both a species and of a population. The gene pool determines the genetic and physical nature of the population/species. An analogy can be made to the laws of a country that define the nature of the society. New laws are analogous to new genes that arise as a result of mutation. The difference is, of course, that all individuals do as their genes say!

Given the concept of the gene pool, we can begin to investigate allele frequencies and genotype frequencies in populations. Students need to appreciate the difference between the two. At the outset, they need to understand that frequencies are best expressed as a decimal fraction. For a population of 500 diploid individuals:

- There will be 1000 copies of a particular gene in the gene pool.
- If the gene has two alleles, the frequency of each allele is the number of occurrences of the allele divided by 1000 (total number of occurrences of all *alleles* of the gene in the population)
- The sum of the frequencies of all the alleles must equal 1.
- The individuals showing the feature determined by the recessive allele have two recessive alleles, so the frequency of this genotype is the number of individuals showing the feature divided by 500 (total number of *individuals* in the population)
- The individuals showing the feature determined by the dominant allele are either homozygous or heterozygous. There is no way of distinguishing between them and their frequency cannot be calculated from observation.
- The numbers of all the different genotypes must add up to the number of individuals in the population (500), so the sum of the frequencies of genotypes must also equal 1.

The Hardy–Weinberg equations look off-putting to non-mathematicians. However, if the above points are understood, it is merely a question of assigning symbols to the various alleles and genotypes.

Students need practice in using the Hardy–Weinberg equations and need to understand the following, which appears time and time again in examinations:

- If the numbers of individuals showing the dominant feature in a population (and the size of the population) are given, then subtraction gives the number of individuals that are homozygous for the recessive feature — this is  $q^2$ .  
 $q = \sqrt{q^2}$   
 $p = 1 - q$
- Knowing  $p$  and  $q$ , all genotype frequencies can be calculated.
- Multiplying genotype frequency by the size of the population gives the number of individuals with that genotype.
- Multiplying allele frequency by the total number of alleles gives the number of alleles of that type in the gene pool.

The principles of natural selection will not be new to most students; they will have met them in GCSE science. However, an explanation in terms of allele frequency will be new, and the myth of a dominant allele always being advantageous must be eliminated. Students should appreciate that, when they are asked to explain the consequences of selection in an examination question (whatever the question), the answer is usually the following:

- Some allele or some feature confers some kind of advantage (the student will have to work out what advantage, and why, depending upon the specific example).

- Organisms with this allele/feature will reproduce in greater numbers.
- Greater numbers of the advantageous allele will be passed on.
- The allele frequency will increase in the next generation.
- There will be greater numbers of organisms with the advantageous feature in the next generation.

Students should appreciate that directional selection operates in a changing environment to shift the range of phenotypes to become adapted to the new environment. Stabilising selection operates in a stable environment to increase the adaptiveness of the population to the environment.

Before discussing speciation, the species concept should be revisited. This sets the need to establish reproductive isolation in an appropriate context.

### Related activities

There are a number of ways of modelling the effect of selective pressures on allele frequencies. Typing 'gene frequency classroom activities' into the internet will produce a number of quite useful methods, as well as some sites that give data about common human conditions that can be used for Hardy–Weinberg calculations.

## Questions

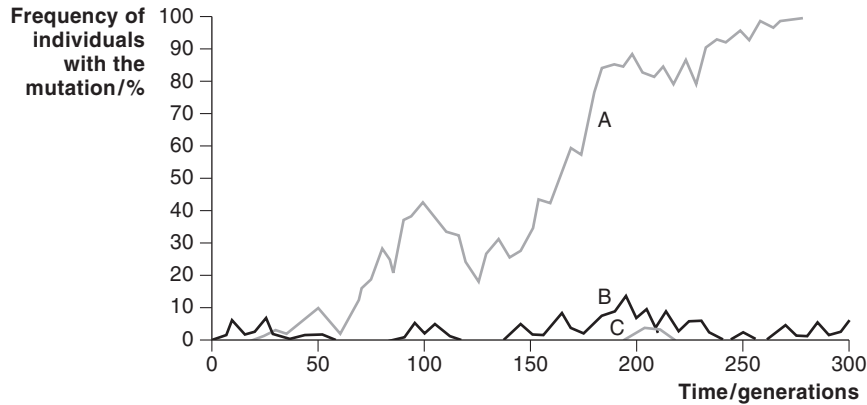
### Multiple-choice

- 1 The gene pool is:
  - A all the genes in an individual
  - B all the alleles in an individual
  - C all the alleles in a population
  - D all the genes in a population
- 2 In the Hardy–Weinberg equations:
  - A  $p + q = 1$  and  $p^2 + pq + q^2 = 1$
  - B  $p^2 + q^2 = 1$  and  $p^2 + 2pq + q^2 = 1$
  - C  $p + q = 1$  and  $p^2 + 2pq + q^2 = 1$
  - D  $p^2 + q^2 = 1$  and  $p^2 + pq + q^2 = 1$
- 3 In natural selection, those most adapted to an environment survive to reproduce because:
  - A resources are limited
  - B resources are limited and there is a natural variation between members of a population
  - C resources are limited, there is a natural variation between members of a population and living things tend to over-reproduce
  - D none of the above
- 4 Conditions for the Hardy–Weinberg equations to be valid include:
  - A a large population, diploid individuals and random mating
  - B a large population, haploid individuals and random mating
  - C a small population, diploid individuals and random mating
  - D a large population, diploid individuals and non-random mating
- 5 Allopatric speciation involves:
  - A a period when individuals of two populations are prevented from interbreeding
  - B geographical isolation
  - C a period of increasing genetic diversity of two populations
  - D all of the above
- 6 In directional selection, the selection pressure operates:
  - A in favour of those individuals showing the mean values for a feature
  - B in favour of those individuals at one extreme of the range of values for a feature
  - C in favour of those individuals showing both extremes of the range of values for a feature
  - D none of the above
- 7 New alleles arising from mutations in a population will:
  - A increase in frequency if they are beneficial in their effect and decrease in frequency if they are neutral in their effect
  - B increase in frequency if they are neutral in their effect and decrease in frequency if they are harmful in their effect
  - C increase in frequency if they are beneficial in their effect and increase in frequency if they are neutral in their effect
  - D increase in frequency if they are beneficial in their effect and decrease in frequency if they are harmful in their effect
- 8 Sympatric speciation involves:
  - A a period when individuals of two populations are prevented from interbreeding
  - B geographical isolation
  - C a period of decreasing genetic diversity of two populations
  - D all of the above
- 9 In stabilising selection, the selection pressure operates:
  - A in favour of those individuals that show the mean values for a feature
  - B in favour of those individuals at one extreme of the range of values for a feature
  - C in favour of those individuals showing both extremes of the range of values for a feature
  - D none of the above

- 10** Bacterial populations can develop resistance to antibiotics. In this case, the selection pressure is the result of:
- A** random mutations in the bacterial population
  - B** the use of the antibiotic on the bacterial population
  - C** both A and B
  - D** neither A nor B

## Examination-style

- 1 Gene mutations can be advantageous, harmful or neutral. The graph shows the change in frequency of the individuals possessing some mutations over a number of generations.



- (a) Give *two* ways in which point mutations of DNA can occur. (1 mark)
- (b) Which of the lines A, B and C represent a harmful, neutral and beneficial mutation? Explain your answer. (3 marks)
- (c) Explain why it is impossible to use the Hardy–Weinberg equation to calculate genotype frequencies using data from the graphs. (2 marks)

**Total: 6 marks**

- 2 King cheetahs have a different pattern of spots from ordinary cheetahs. The king cheetah coat pattern is the result of a mutation; the resulting allele is recessive to that for normal coat pattern. A population of 100 cheetahs contained nine king cheetahs.

- (a) At first, it was thought that the two might be different species. How could it have been proved that they were members of the same species? (2 marks)
- (b) Use the Hardy–Weinberg equation to calculate:
- (i) the *frequency* of the dominant allele (2 marks)
- (ii) the *number* of heterozygotes in the population (2 marks)
- (c) Give *two* reasons why the use of the Hardy–Weinberg equation might not be valid on this occasion. (2 marks)

**Total: 8 marks**

- 3 Biologists investigated stinging nettles in two areas of a large National Park in Japan. There had been a large population of deer in one area for more than 1200 years. The other area had had deer in it only rarely.

Nettles from the area that contained the deer were found to have, on average, 100 times more stinging hairs than the nettles in the other area. When seeds from these plants were grown in the laboratory, they developed into plants that also had high numbers of stinging hairs.

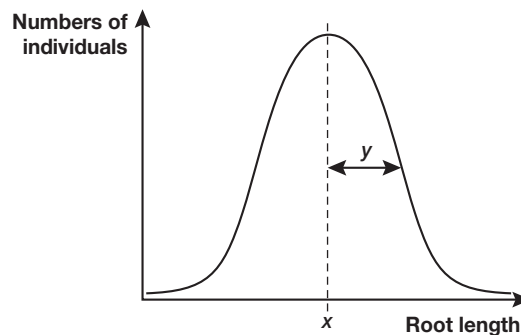
- (a) Explain the evidence that suggests that:
- (i) the numbers of stinging hairs per leaf is controlled genetically (2 marks)
- (ii) the difference in the number of stinging hairs on the leaves of the nettles in the two populations is a result of natural selection (3 marks)
- (b) Despite their differences, the two populations have not evolved into different species. Suggest why. (2 marks)

**Total: 7 marks**

- 4 (a) In each of the following examples of natural selection, identify the selection pressure and the variant within the population that is best adapted:
- (i) wildebeest hunted by lions
  - (ii) bacteria in a hospital where penicillin is widely used
  - (iii) nettle plants with different-sized leaves in a shaded woodland area (3 marks)
- (b) Allopatric speciation and sympatric speciation are two processes by which new species can evolve. Explain:
- (i) one similarity between the two processes (2 marks)
  - (ii) one difference between the two processes (2 marks)

**Total: 7 marks**

- 5 The graph below shows the distribution of root length in a population of a species of grass. The population inhabits an area in which the soil water is held mainly in the top 20 cm.



- (a) (i) What does the term 'population' mean? (1 mark)
- (ii) Name the features of the distribution labelled  $x$  and  $y$ . (2 marks)
- (b) (i) Sketch, on the graph, the distribution of root lengths you would expect if some of these plants now colonised a different area in which the soil water was held mainly below 20 cm. (1 mark)
- (ii) Name, with a reason, the type of selection operating in this example. (1 mark)
- (iii) Describe the evolutionary mechanisms that would lead to this change in the distribution of root lengths. (4 marks)
- (c) In time, these populations may evolve into different species.
- (i) Would this be an example of sympatric or allopatric speciation? Explain your answer. (1 mark)
- (ii) Describe and explain the conditions essential for speciation to occur. (3 marks)
- (d) The two new species of grass would be members of the same genus and the same kingdom.
- (i) Name three other taxonomic groups to which they would both belong. (1 mark)
- (ii) Name the kingdom to which both species belong. (1 mark)

**Total: 15 marks**

## Answers/sample mark schemes

## Multiple-choice

- 1 C
- 2 C
- 3 C
- 4 A
- 5 D
- 6 B
- 7 D
- 8 A
- 9 A
- 10 C

## Examination-style

- 1 (a) Two of:  
 insertion;  
 deletion;  
 substitution;  
 inversion; (1 mark)
- (b) A: beneficial — increases in population;  
 B: neutral — sometimes maintained, sometimes disappears/always at low level;  
 C: harmful: disappears quickly from population; (3 marks)
- (c) Don't know whether allele is dominant or recessive;  
 Don't know if individuals with mutation represent  $q^2$  or  $p^2 + 2pq$ ; (2 marks)
- Total: 6 marks**
- 2 (a) Breed king cheetahs with other cheetahs;  
 If they produce fertile offspring, then they are the same species; (2 marks)
- (b) (i) King cheetahs are homozygous recessive, so frequency is  $q^2 = 9\% = 0.09$ ;  
 $q = 0.3$ , so  $p = 1 - 0.3 = 0.7$ ; (2 marks)
- (ii)  $p = 0.7$  and  $q = 0.3$ , so  $2pq = 0.42$ ;  
 $0.42 \times 100 = 42$ ; (2 marks)
- (c) Small population;  
 Mutations occurring; (2 marks)
- Total: 8 marks**
- 3 (a) (i) Two distinct ranges of numbers of hairs;  
 Interbreeding results in one phenotype not being expressed;  
 Suggests dominant and recessive alleles; (max. 2 marks)
- (ii) In area where deer graze, more stinging hairs confers survival advantage;  
 These plants reproduce in greater numbers;  
 Advantageous alleles passed on in greater numbers;  
 Increase in frequency of advantageous alleles;  
 Increase in frequency of individuals with more stinging hairs; (max. 3 marks)
- (b) Interbreeding still possible/no reproductive isolation;  
 Due to proximity of populations; (2 marks)
- Total: 7 marks**

## Chapter 6

### How do the frequencies of genes change when the environment changes?

- 4 (a) (i) Wildebeest: being hunted/chased by lions, fastest runners survive;  
(ii) Bacteria: use of penicillin, resistant bacteria survive;  
(iii) Nettle plants: amount of sunlight, those with largest leaves; (3 marks)
- (b) (i) A period when interbreeding is prevented;  
Allows genetic differences to accumulate; (2 marks)
- (ii) Interbreeding prevented by:  
geographical barrier in allopatric speciation;  
temporal/seasonal/ other isolating mechanism in sympatric speciation; (2 marks)
- Total: 7 marks**
- 5 (a) (i) All the individuals of one species in an area/habitat; (1 mark)
- (ii)  $x$ : mean;  
(Accept median/mode;)  
 $y$ : standard deviation; (2 marks)
- (b) (i) Same shape curve shifted to right; (1 mark)
- (ii) Stabilising selection: one extreme of range is favoured; (1 mark)
- (iii) Plants with longer roots have selective advantage;  
Because they can obtain more water;  
Reproduce in greater numbers;  
Pass on advantageous allele in greater numbers;  
Increase in frequency of advantageous allele over time;  
Increase in frequency of long-rooted plants over time; (max. 4 marks)
- (c) (i) Allopatric: different geographical areas are involved; (1 mark)
- (ii) Must be prevented from interbreeding;  
Allows genetic differences to accumulate;  
To the extent where interbreeding is impossible; (3 marks)
- (d) (i) Three from: phylum, class, order and family; (1 mark)
- (ii) Plantae/plants; (1 mark)
- Total: 15 marks**