



Question 1: Interpreting and Evaluating Experimental Results

In many countries, *Anopheles gambiae* mosquitoes are responsible for transmitting the parasite that causes malaria to people through their bites. A primary tool for mosquito control is the use of insecticidal nets sprayed with chemicals known as pyrethroids, which are relatively safe for people but toxic to mosquitoes. However, mosquito resistance to pyrethroids has now become widespread. Pyrethroids interfere with the function of a transmembrane sodium channel found in cells of the mosquitoes (Figure 1). In one common mutation to the channel protein, a phenylalanine is substituted for a leucine at amino acid position 1014. Scientists hypothesize that this mutation is responsible for some cases of pyrethroid resistance.

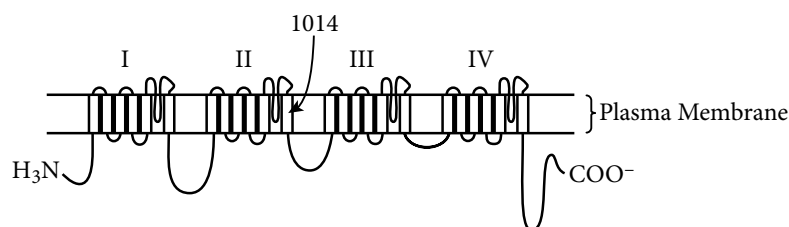


Figure 1. Schematic drawing of the transmembrane sodium channel targeted by pyrethroids and other insecticides. The arrow points to the position of amino acid 1014.

To investigate pyrethroid resistance, mosquitoes were collected four times over a two-year period from the following two regions.

- Region A: a southern vegetable-growing region where large amounts of insecticide are applied for crop protection
- Region B: a northern rice-growing region where very little insecticide is applied for rice protection

Scientists exposed the collected mosquitoes to filter papers soaked in two different pyrethroid insecticides, deltamethrin and permethrin, and the percent mortality of the mosquitoes was determined after 24 hours (Figure 2). The scientists simultaneously determined whether leucine or phenylalanine was encoded at position 1014 by each of the two copies of the sodium channel gene (Table 1).

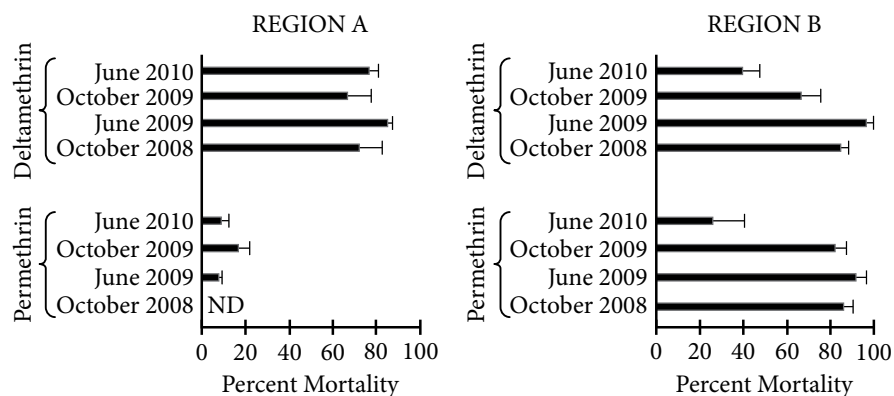


Figure 2. Susceptibility of *A. gambiae* mosquitoes from two regions to the pyrethroids deltamethrin and permethrin. A mosquito strain that is susceptible to the insecticides displayed at least 95% mortality in all experiments, and mosquitoes exposed to untreated filter paper displayed less than 10% mortality. Error bars represent standard deviation. “ND” means no data are available.

Table 1. Frequencies of leucine and phenylalanine at position 1014 of the sodium channel

Region	Date	Total Mosquitoes Tested	Homozygous for Leucine	Heterozygous for Leucine and Phenylalanine	Homozygous for Phenylalanine
A	October 2008	39	3	5	31
A	June 2009	29	-	5	24
A	October 2009	28	-	1	27
A	June 2010	46	-	9	37
B	October 2008	27	20	5	2
B	June 2009	26	18	7	1
B	October 2009	34	20	8	6
B	June 2010	44	12	20	12

- (a) **Describe** the most likely cause of the amino acid substitution in the sodium channel protein. **Explain** how the substitution of a single amino acid in the channel protein could cause pyrethroid resistance in mosquitoes.
- (b) **Identify** the dependent variable in the experiment whose data are graphed in Figure 2. **Identify** the positive control in the experiment. **Justify** exposing some mosquitoes to untreated filter paper each time the experiment was performed.
- (c) Based on the data in Figure 2, **describe** whether mosquitoes from region A or from region B are more likely to exhibit greater evolutionary fitness if exposed to permethrin in their native environment over the time period of the experiment. Based on the data in Figure 2, **describe** any significant change in the susceptibility of mosquitoes from region B to each of the two insecticides over the two-year period. Use the data in Table 1 to **calculate** the frequency of the allele coding for phenylalanine in each population of mosquitoes in October 2008. Round your answers to two decimal places.
- (d) Using mosquitoes from insecticide-free areas, the scientists developed mosquito strains with amino acid substitutions at other positions in the sodium channel protein. They exposed the mosquito strains to nonpyrethroid insecticides. **Predict** the susceptibility of the mosquitoes to the insecticides. The scientists claim that the mosquito population of region B evolved resistance over the period of the experiment and that resistance arose as a result of the immigration of resistant mosquitoes from other regions. Based on the data in Table 1 and the information provided, **provide evidence** to support the scientists' claim.

Scoring Guidelines for Question 1: Interpreting and Evaluating Experimental Results

10 points

Learning Objectives: EVO-1.E EVO-1.H EVO-1.L IST-2.E SYI-1.C

- (a) Describe the most likely cause of amino acid substitution in the sodium channel protein. **1 point**
1.A
- A change occurred in the DNA sequence encoding the sodium channel polypeptide.

Explain how the substitution of a single amino acid in the channel protein could cause pyrethroid resistance by mosquitoes. **1 point**
1.C

- The substitution could change the shape of the protein channel so that pyrethroids can no longer affect it / bind to it / interfere with its function.

Total for part (a) 2 points

- (b) Identify the dependent variable in the experiment. **1 point**
3.C
- Accept one of the following:
- Percent mortality
 - Susceptibility to insecticide

Identify the positive control in the experiment. **1 point**
3.C

- Testing the strain that is susceptible to the insecticides

Justification of exposing some mosquitoes to untreated filter paper each time the experiment was performed. **1 point**
3.C

- Exposing mosquitoes to untreated filter paper confirms that any observed mortality is from the insecticides rather than from the filter paper itself or any other experimental conditions.

Total for part (b) 3 points

- (c) Describe whether mosquitoes from region A or from region B are more likely to exhibit greater evolutionary fitness if exposed to permethrin in their native environment over the time period of the experiment. **1 point**
4.B
- Mosquitoes from region A are much more likely to survive to reproduce, so the region A mosquitoes will have greater evolutionary fitness.

Describe any significant change in the susceptibility of mosquitoes from region B to each of the two insecticides over the two-year period. **1 point**
4.B

- For permethrin, there was little significant change in susceptibility until the June 2010 test, when the mosquitoes were significantly less susceptible than they had been for the previous three tests. For deltamethrin, there was a significant decrease in susceptibility from June 2009 to October 2009 and then a further significant decrease from October 2009 to June 2010.

Calculate the frequency of the allele coding for phenylalanine in each population of mosquitoes in October 2008. Answers must be rounded to two decimal places. No points are awarded for working, just answers in the acceptable range. **1 point**
5.A

- Mosquitoes from region A: $5 + 2(31) = 67$ and $\frac{67}{78} = 86$.
Acceptable range is .85 – .86
- Mosquitoes from region B: $5 + 2(2) = 9$ and $\frac{9}{54} = .17$.
Acceptable range is .16 – .17

Total for part (c) 3 points

(d) Predict the susceptibility of the mosquitoes to the insecticides.

1 point

Accept one of the following:

3.B

- The mosquitoes will all die.
- The mosquitoes will be 100% susceptible

Provide evidence to support the scientists' claim.

1 point

- The frequency of the phenylalanine allele increased from very low to much higher (OR: from 0.17 to 0.5) for population B mosquitoes that come from an area with low insecticide use. Thus insecticide use is not selecting for those mosquitoes with the phenylalanine allele; it is more likely that pyrethroid-resistant mosquitoes with the phenylalanine allele are immigrating to the area, thus increasing the frequency of the allele in the population.

6.B

Total for part (d)

2 points

Total for question 1

10 points

Question 5: Analyze Model or Visual Representation

In humans, the gene that determines a particular condition has only two alleles, one of which (B) is completely dominant to the other (b). The phenotypes of three generations of a family with respect to the condition are shown in the pedigree in Figure 1. Individuals are numbered.

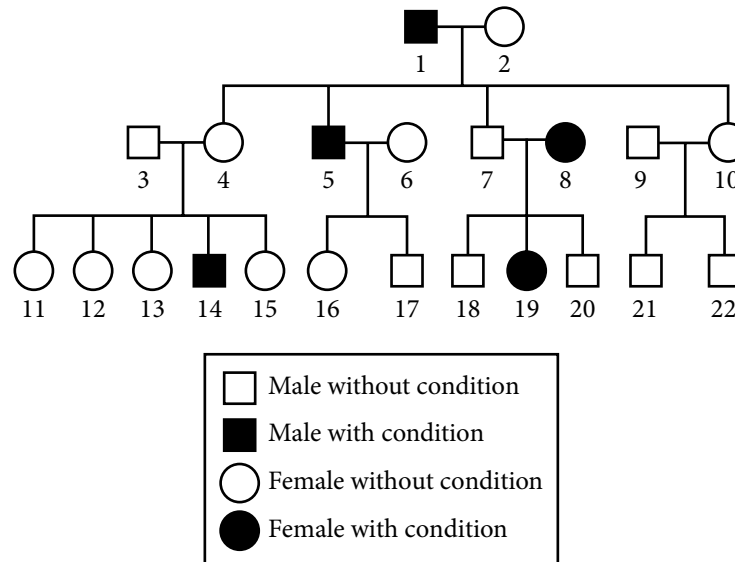
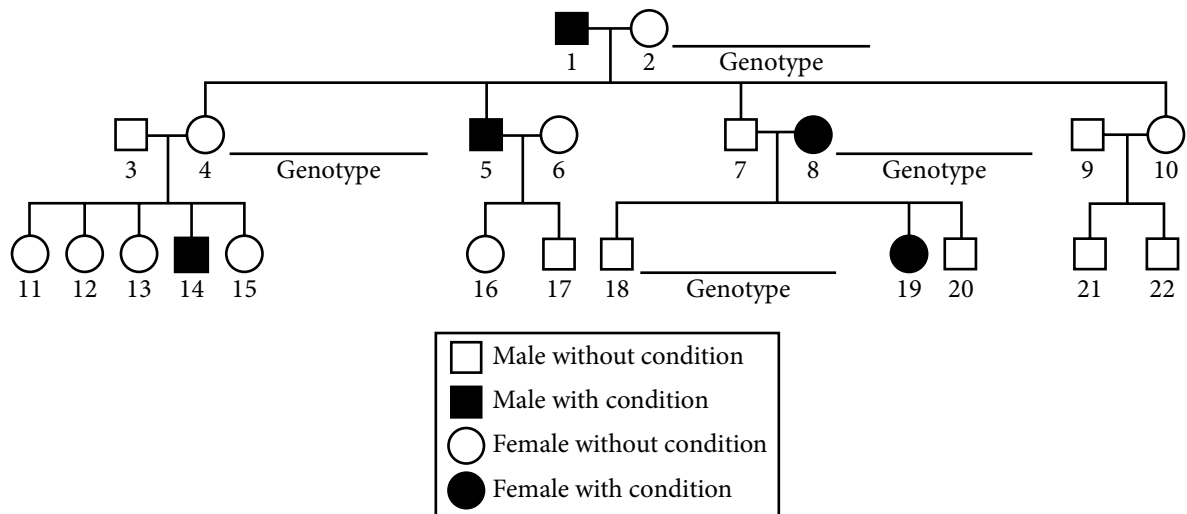


Figure 1. Inheritance of a particular condition over three generations of a family

- (a) **Describe** the process in eukaryotes that ensures that the number of chromosomes will not double from parent to offspring when gametes fuse during fertilization.
- (b) **Explain** how any one chromosome in individual 16 contains DNA that came from both individuals 1 and 2.
- (c) **Use the template** figure of the pedigree and the allele designations B and b to **indicate** the genotypes of individuals 2, 4, 8, and 18.



- (d) Based on the pedigree, **explain** whether the inheritance pattern of the condition is sex-linked or autosomal and dominant or recessive.

Scoring Guidelines for Question 5: Analyze Model or Visual Representation

4 points

Learning Objectives: **IST-1.H** **IST-1.I**

- (a) Describe the process in eukaryotes that ensures that the number of chromosomes will not double from parent to offspring when gametes fuse during fertilization. **1 point**
1.A
- Homologous pairs of chromosomes separate in meiosis I, so the gametes are haploid (n), and each gamete receives only one member of each chromosome pair.
-
- (b) Explain how any one chromosome in individual 16 contains “DNA” that came from both individuals 1 and 2. **1 point**
2.B
- Individual 5 inherited one member of each homologous pair of chromosomes from individuals 1 and 2. During gamete formation in individual 5, crossing over occurred between nonsister chromatids in each homologous pair. Thus each chromosome formed and passed on to individual 16 contains DNA from both 1 and 2.
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- (c) Indicate the genotypes of individuals 2, 4, 8, and 18. **1 point**
2.D
- Individual 2, 4, and 18: The genotype of all three is *Bb*.
 - Individual 8: The genotype is *bb*.
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- (d) Explain whether the inheritance pattern of the condition is sex-linked or autosomal and dominant or recessive. **1 point**
2.C
- The disease phenotype is recessive and is autosomal/not sex-linked. It cannot be dominant because individuals 3 and 4 do not have it, but their offspring 14 does. It is not sex-linked because if it was Y-linked, all male offspring of males with the disease phenotype would have the trait, and they do not.

Total for question 5 **4 points**