12. A plant of genotype

\[
\begin{array}{c|c}
A & B \\
\hline
a & b \\
\end{array}
\]

is testcrossed with

\[
\begin{array}{c|c}
a & b \\
\hline
\end{array}
\]

If the two loci are 10 m.u. apart, what proportion of progeny will be \(AB/ab\)?

Answer: You perform the following cross and are told that the two genes are 10 m.u. apart.

\[A B/a b \times a b/a b\]

Among their progeny, 10 percent should be recombinant (\(A b/a b\) and \(a B/a b\)) and 90 percent should be parental (\(A B/a b\) and \(a b/a b\)). Therefore, \(A B/a b\) should represent 1/2 of the parentals or 45 percent.
13. The $A$ locus and the $D$ locus are so tightly linked that no recombination is ever observed between them. If $Ad/Ad$ is crossed with $aD/aD$ and the $F_1$ is intercrossed, what phenotypes will be seen in the $F_2$ and in what proportions?

Answer:

<table>
<thead>
<tr>
<th></th>
<th>$Ad/Ad$</th>
<th>$aD/aD$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$F_1$</td>
<td>$Ad/aD$</td>
<td></td>
</tr>
<tr>
<td>$F_2$</td>
<td>1</td>
<td>$Ad/Ad$</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>$Ad/aD$</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>$aD/aD$</td>
</tr>
</tbody>
</table>

phenotype: $A$ d

phenotype: $A$ D

phenotype: $a$ D

14. The $R$ and $S$ loci are 35 m.u. apart. If a plant of genotype

$$\begin{array}{c|c}
R & S \\
\hline
r & s \\
\end{array}$$

is selfed, what progeny phenotypes will be seen and in what proportions?

Answer:

<table>
<thead>
<tr>
<th></th>
<th>$RS/rs$</th>
<th>$RS/rs$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P$</td>
<td></td>
<td>$RS/rs$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>$0.1056$</th>
<th>$0.1138$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$F_1$ genotypes</td>
<td>$RS/RS$</td>
<td>$rs/rs$</td>
</tr>
<tr>
<td>$0.1056$</td>
<td>$rs/rs$</td>
<td>$0.1138$</td>
</tr>
<tr>
<td>$0.2113$</td>
<td>$RS/RS$</td>
<td>$0.0306$</td>
</tr>
<tr>
<td>$0.1138$</td>
<td>$RS/RS$</td>
<td>$0.0613$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>$R S$</th>
<th>$rs$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$F_1$ phenotypes</td>
<td>$0.6058$</td>
<td>$rs$</td>
</tr>
<tr>
<td>$0.1056$</td>
<td>$rs$</td>
<td></td>
</tr>
<tr>
<td>$0.1444$</td>
<td>$Rs$</td>
<td></td>
</tr>
<tr>
<td>$0.1444$</td>
<td>$rs$</td>
<td></td>
</tr>
</tbody>
</table>
17. A female animal with genotype $A/a \cdot B/b$ is crossed with a double-recessive male ($a/a \cdot b/b$). Their progeny include 442 $A/a \cdot B/b$, 458 $a/a \cdot b/b$, 46 $A/a \cdot b/b$, and 54 $a/a \cdot B/b$. Explain these results.

Answer: The problem states that a female that is $A/a \cdot B/b$ is testcrossed. If the genes are unlinked, they should assort independently, and the four progeny classes should be present in roughly equal proportions. This is clearly not the case. The $A/a \cdot B/b$ and $a/a \cdot b/b$ classes (the parentals) are much more common than the $A/a \cdot b/b$ and $a/a \cdot B/b$ classes (the recombinants). The two genes are on the same chromosome and are 10 map units apart.

$$RF = 100\% \times (46 + 54)/1000 = 10\%$$

---

18. If $A/A \cdot B/B$ is crossed with $a/a \cdot b/b$ and the $F_1$ is testcrossed, what percentage of the testcross progeny will be $a/a \cdot B/b$ if the two genes are (a) unlinked; (b) completely linked (no crossing over at all); (c) 10 m.u. apart; (d) 24 m.u. apart?

Answer: The cross is $A/A \cdot B/B \times a/a \cdot a/a$. The $F_1$ would be $A/a \cdot B/b$.

a. If the genes are unlinked, all four progeny classes from the testcross (including $a/a \cdot b/b$) would equal 25 percent.

b. With completely linked genes, the $F_1$ would produce only $A B$ and $a b$ gametes. Thus, there would be a 50 percent chance of having $a b/a b$ progeny from a testcross of this $F_1$.

c. If the two genes are linked and 10 map units apart, 10 percent of the testcross progeny should be recombinants. Since the $F_1$ is $A B/a b$, $a b$ is one of the parental classes ($A B$ being the other) and it should equal 1/2 of the total parentals or 45 percent.

d. 38 percent (see part c).
24. Chromosome 3 of corn carries three loci (b for plant-color booster, v for virescent, and lg for liguleless). A testcross of triple recessives with F₁ plants heterozygous for the three genes yields progeny having the following genotypes: 305 + v lg, 275 b +, 128 b + lg, 112 + v +, 74 ++ lg, 66 b v +, 22 + + +, and 18 b v lg. Give the gene sequence on the chromosome, the map distances between genes, and the coefficient of coincidence.

Answer: By comparing the most frequent classes (parental: + v lg, b + +) with the least frequent classes (DCO: + + +, b v lg) the gene order can be determined. The gene in the middle switches with respect to the other two, yielding the following sequence: v b lg. Now the cross can be written:

\[ P \quad v b^+ lg/v+ \quad b \quad lg^+ \times v \quad b \quad lg/v \quad b \quad lg \]

<table>
<thead>
<tr>
<th>F₁</th>
<th>305</th>
<th>v b⁺ lg/v b lg</th>
<th>parental</th>
</tr>
</thead>
<tbody>
<tr>
<td>275</td>
<td>v⁺ b lg⁺/v b lg⁺</td>
<td>parental</td>
<td></td>
</tr>
<tr>
<td>128</td>
<td>v⁺ b lg/v b lg</td>
<td>CO b-lg</td>
<td></td>
</tr>
<tr>
<td>112</td>
<td>v b⁺ lg⁺/v b lg</td>
<td>CO b-lg</td>
<td></td>
</tr>
<tr>
<td>74</td>
<td>v⁺ b⁺ lg/v b lg</td>
<td>CO v-b</td>
<td></td>
</tr>
<tr>
<td>66</td>
<td>v b lg⁺/v b lg</td>
<td>CO v-b</td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>v⁺ b⁺ lg⁺/v b lg</td>
<td>DCO</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>v b lg/v b lg</td>
<td>DCO</td>
<td></td>
</tr>
</tbody>
</table>

\[ v-b: \quad 100\%(74 + 66 + 22 + 18)/1000 = 18.0 \text{ m.u.} \]
\[ b-lg: \quad 100\%(128 + 112 + 22 + 18)/1000 = 28.0 \text{ m.u.} \]

\[ \text{c.c. = observed DCO/expected DCO} = (22 + 18)/(0.28)(0.18)(1000) = 0.79 \]
From several crosses of the general type $A/A \cdot B/B \times a/a \cdot B/b$ the $F_1$ individuals of type $A/a \cdot B/b$ were testcrossed with $a/a \cdot B/b$. The results are as follows:

<table>
<thead>
<tr>
<th>Testcross of $F_1$ from cross</th>
<th>Testcross progeny</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$A/a \cdot B/b$</td>
</tr>
<tr>
<td>1</td>
<td>310</td>
</tr>
<tr>
<td>2</td>
<td>36</td>
</tr>
<tr>
<td>3</td>
<td>360</td>
</tr>
<tr>
<td>4</td>
<td>74</td>
</tr>
</tbody>
</table>

For each set of progeny, use the $\chi^2$ test to decide if there is evidence of linkage.

Answer: Assume there is no linkage. (This is your hypothesis. If it can be rejected, the genes are linked.) The expected values would be that genotypes occur with equal frequency. There are four genotypes in each case ($n = 4$) so there are 3 degrees of freedom.

$$\chi^2 = \sum (\text{observed} - \text{expected})^2/\text{expected}$$

Cross 1: $\chi^2 = [(310-300)^2 + (315-300)^2 + (287-300)^2 + (288-300)^2]/300$

$= 2.1266; \ p > 0.50$, nonsignificant; hypothesis cannot be rejected

Cross 2: $\chi^2 = [(36-30)^2 + (38-30)^2 + (23-30)^2 + (23-30)^2]/30$

$= 6.6; \ p > 0.10$, nonsignificant; hypothesis cannot be rejected

Cross 3: $\chi^2 = [(360-300)^2 + (380-300)^2 + (230-300)^2 + (230-300)^2]/300$

$= 66.0; \ p < 0.005$, significant; hypothesis must be rejected

Cross 4: $\chi^2 = [(74-60)^2 + (72-60)^2 + (50-60)^2 + (44-60)^2]/60$

$= 11.60; \ p < 0.01$, significant; hypothesis must be rejected
33. In the tiny model plant *Arabidopsis*, the recessive allele *hyg* confers seed resistance to the drug hygromycin, and *her*, a recessive allele of a different gene, confers seed resistance to herbicide. A plant that was homozygous *hyg/hyg* · *her/her* was crossed with wild type, and the F₁ was selfed. Seeds resulting from the F₁ self were placed on petri dishes containing hygromycin and herbicide.

a. If the two genes are unlinked, what percentage of seeds are expected to grow?

b. In fact, 13 percent of the seeds grew. Does this percentage support the hypothesis of no linkage? Explain. If not, calculate the number of map units between the loci.

c. Under your hypothesis, if the F₁ is testcrossed, what proportion of seeds will grow on the medium containing hygromycin and herbicide?

Answer:

a. If the genes are unlinked, the cross becomes:

\[ P \quad \text{hyg/hyg, her/her} \times \text{hyg}^+/	ext{hyg}^+; \text{her}^+/	ext{her}^+ \]

\[ F_1 \quad \text{hyg}^+/	ext{hyg}; \text{her}^+/	ext{her} \times \text{hyg}^+/	ext{hyg}; \text{her}^+/	ext{her} \]

\[ F_2 \quad \frac{9}{16} \quad \text{hyg}^+/--; \text{her}^+/-- \]

\[ \frac{3}{16} \quad \text{hyg}^+/--; \text{her}/\text{her} \]

\[ \frac{3}{16} \quad \text{hyg}/\text{hyg}; \text{her}^+/-- \]

\[ \frac{1}{16} \quad \text{hyg}/\text{hyg}; \text{her}/\text{her} \]

So only 1/16 (or 6.25 percent) of the seeds would be expected to germinate.
b. and c. No. More than twice the expected seeds germinated so assume the genes are linked. The cross then becomes:

\[
P \quad \text{hyg her/hyg her} \times \text{hyg}^+ \text{ her}^+/\text{hyg}^+ \text{ her}^+
\]

\[
F_1 \quad \text{hyg}^+ \text{ her}^+/\text{hyg her} \times \text{hyg}^+ \text{ her}^+/\text{hyg her}
\]

\[
F_2 \quad 13 \text{ percent} \quad \text{hyg her/hyg her}
\]

Because this class represents the combination of two parental chromosomes, it is equal to:

\[
p(\text{hyg her}) \times p(\text{hyg her}) = (1/2 \text{ parentals})^2 = 0.13
\]

and

\[
\text{parentals} = 0.72 \quad \text{so recombinants} = 1 - 0.72 = 0.28
\]

Therefore, a testcross of \text{hyg}^+ \text{ her}^+/\text{hyg her} should give:

\[
36\% \quad \text{hyg}^+ \text{ her}^+/\text{hyg her}
\]

\[
36\% \quad \text{hyg her/hy}g \text{ her}
\]

\[
14\% \quad \text{hyg}^+ \text{ her}/\text{hyg her}
\]

\[
14\% \quad \text{hyg her}^+/\text{hyg her}
\]

and 36 percent of the progeny should grow (the \text{hyg her/hy}g \text{ her} class).
49. In mice, the following alleles were used in a cross:

\[ W = \text{waltzing gait} \quad w = \text{nonwaltzing gait} \]
\[ G = \text{normal gray color} \quad g = \text{albino} \]
\[ B = \text{bent tail} \quad b = \text{straight tail} \]

A waltzing gray bent-tailed mouse is crossed with a nonwaltzing albino straight-tailed mouse and, over several years, the following progeny totals are obtained:

<table>
<thead>
<tr>
<th>Genotype</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>waltzing</td>
<td>gray</td>
</tr>
<tr>
<td>waltzing</td>
<td>albino</td>
</tr>
<tr>
<td>nonwaltzing</td>
<td>gray</td>
</tr>
<tr>
<td>nonwaltzing</td>
<td>albino</td>
</tr>
<tr>
<td>waltzing</td>
<td>gray</td>
</tr>
<tr>
<td>waltzing</td>
<td>albino</td>
</tr>
<tr>
<td>nonwaltzing</td>
<td>gray</td>
</tr>
<tr>
<td>nonwaltzing</td>
<td>albino</td>
</tr>
<tr>
<td>Total</td>
<td></td>
</tr>
</tbody>
</table>

a. What were the genotypes of the two parental mice in the cross?
b. Draw the chromosomes of the parents.
c. If you deduced linkage, state the map unit value or values and show how they were obtained.
Answer: There are three patterns of possible outcomes from a testcross of a triply heterozygous parent. If all genes are linked, you expect pairs of roughly equal numbers of progeny in four different frequencies (for example, see problem 20 of this chapter). If all genes are unlinked, the expectation is eight classes of progeny in roughly equal numbers due to the independent assortment of all genes. The last possibility is that two of the genes are linked, but the third is unlinked. In that case, the expectation is two groups of four of two different frequencies. This final pattern is observed in the data of this problem.

In reviewing the data, the four most common classes are either waltzing bent or nonwaltzing straight with gray or albino segregating equally among those two groups. This observation tells you that the $W/w$ and $B/b$ genes are linked and both are unlinked to the $G/g$ gene.

a. $W/w \cdot G/G \cdot A/A \times w/w \cdot g/g \cdot a/a$

b. 

\[
\begin{array}{c|c|c}
W & B & G \\
\hline
w & & w \\
\hline
& b & g
\end{array}
\times

\begin{array}{c|c|c}
W & B & G \\
\hline
w & & w \\
\hline
& b & g
\end{array}
\]

c. For this cross, $W B$ and $w b$ begin linked to each other so any progeny of the testcross that are $W b$ or $w B$ are recombinant.

\[
\text{map distance} = (4 + 5 + 5 + 6)/100 \times 100\% = 20 \text{ map units}
\]
61. In a certain diploid plant, the three loci $A$, $B$, and $C$ are linked as follows:

\[ \begin{array}{c}
A \\
\hline
\downarrow \quad \downarrow \\
B \\
\hline
\downarrow \quad \downarrow \\
C \\
\end{array} \]

$\quad 20 \text{ m.u.} \quad \rightarrow \quad 30 \text{ m.u.}$

One plant is available to you (call it the parental plant). It has the constitution $A\ b\ c/a\ B\ C$.

a. With the assumption of no interference, if the plant is selfed, what proportion of the progeny will be of the genotype $a\ b\ c/a\ b\ c$?

b. Again, with the assumption of no interference, if the parental plant is crossed with the $a\ b\ c/a\ b\ c$ plant, what genotypic classes will be found in the progeny? What will be their frequencies if there are 1000 progeny?

c. Repeat part b, this time assuming 20 percent interference between the regions.

Answer:

a. To obtain a plant that is $a\ b\ c/a\ b\ c$ from selfing of $A\ b\ c/a\ B\ C$, both gametes must be derived from a crossover between $A$ and $B$. The frequency of the $a\ b\ c$ gamete is:

\[ \frac{1}{2} p(\text{CO} \ A-B) \times p(\text{no CO} \ B-C) = \frac{1}{2}(0.20)(0.70) = 0.07 \]

Therefore, the frequency of the homozygous plant will be $(0.07)^2 = 0.0049$
b. The cross is $A b c/a B C \times a b c/a b c$.

To calculate the progeny frequencies, note that the parentals are equal to all those that did not experience a crossover. Mathematically this can be stated as:

$$\text{parentals} = p(\text{no CO } A-B) \times p(\text{no CO } B-C) = (0.80)(0.70) = 0.56$$

Because each parental should be represented equally:

$$A b c = 1/2(0.56) = 0.28$$
$$a B C = 1/2(0.56) = 0.28$$

As calculated above, the frequency of the $a b c$ gamete is:

$$1/2 \times p(\text{CO } A-B) \times p(\text{no CO } B-C) = 1/2(0.20)(0.70) = 0.07$$

as is the frequency of $A B C$.

The frequency of the $A b C$ gamete is:

$$1/2 \times p(\text{CO } B-C) \times p(\text{no CO } A-B) = 1/2(0.30)(0.80) = 0.12$$

as is the frequency of $a B c$.

Finally, the frequency of the $A B c$ gamete is:

$$1/2 \times p(\text{CO } A-B) \times p(\text{CO } B-C) = 1/2(0.20)(0.30) = 0.03$$

as is the frequency of $a b C$.

So for 1,000 progeny, the expected results are

| $A b c$ | 280 |
| $a B C$ | 280 |
| $A B C$ | 70  |
| $a b c$ | 70  |
| $A b C$ | 120 |
| $a B c$ | 120 |
| $A B c$ | 30  |
| $a b C$ | 30  |
c. Interference $= 1 - \text{observed DCO/expected DCO}$

$0.2 = 1 - \text{observed DCO}/(0.20)(0.30)$

\[
\text{observed DCO} = (0.20)(0.30) - (0.20)(0.20)(0.30) = 0.048
\]

The $A-B$ distance $= 20\% = 100\% [p(\text{CO }A-B) + p(\text{DCO})]$

Therefore, $p(\text{CO }A-B) = 0.20 - 0.048 = 0.152$

Similarly, the $B-C$ distance $= 30\% = 100\% [p(\text{CO }B-C) + p(\text{DCO})]$

Therefore, $p(\text{CO }B-C) = 0.30 - 0.048 = 0.252$

The $p(\text{parental}) = 1 - p(\text{CO }A-B) - p(\text{CO }B-C) - p(\text{observed DCO})$

$= 1 - 0.152 - 0.252 - 0.048 = 0.548$

So for 1,000 progeny, the expected results are:

\[
\begin{align*}
A & \ b & \ c & & 274 \\
 a & \ B & \ C & & 274 \\
A & \ B & \ C & & 76 \\
a & \ b & \ c & & 76 \\
A & \ b & \ C & & 126 \\
a & \ B & \ c & & 126 \\
A & \ B & \ c & & 24 \\
a & \ b & \ C & & 24
\end{align*}
\]