6.2: Inheritance of Linked Genes pg. 251

Independent assortment states that during gamete formation, the two alleles for one gene segregate or assort independently of the alleles for other genes. (BbTt) (FOIL Method) (BT, Bt, bT, bt)

But if two genes are found on the same chromosome, they will not assort independently, and do not follow Mendelian inheritance patterns. Genes that are inherited together are said to be “linked.” (Chromosome 1 BT and its Homologue bt)

Linked Genes

Linked genes are genes that are on the same chromosome and that tend to be inherited together.

William Bateson and Reginald Punnett completed a study in 1905 that determined the movement of alleles found on the same chromosome. The study used sweet peas, particularly flower colour and pollen shape, they followed the inheritance pattern.

For flower colour, purple is dominant over red, and for pollen shape long is dominant over round.

A cross was performed using a true breeding purple/long and red/round.

The F₁ generation was 100% purple/long.

Crossing two individuals from the F₁ generation resulted in a F₂ generation with four different phenotypes. (purple/long, purple/round, red/long and red/round).
The alleles that created these combinations did not follow the 9:3:3:1 pattern, but supported the idea that these alleles did not assort independently and therefore must be linked.

**Figure 6.10**: A dihybrid cross between two sweet pea plants does not produce the expected phenotypic ratio of 9:3:3:1. These results support the theory that alleles on the same chromosome do not assort independently.

### Crossing Over and the Inheritance of Linked Genes

Linked genes don’t always stay linked. These linkage groups can be separated by crossing over during **prophase I** of meiosis.

When crossing over occurs, the genes that were previously linked become unlinked, creating four different types of chromosomes (**gametes**). The proportions are not equal because crossing over does not occur in every cell during meiosis.
Figure 6.11: In most of the gametes formed, there is no crossing over – they maintain the linkage of the alleles. In a small minority of gametes, crossing over occurs and alleles of previously linked genes become unlinked.

Using Gene Linkage for Chromosome Mapping

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Sex-linked Inheritance

*Sex-linked trait* is a trait controlled by genes on the X or the Y chromosomes.

Thomas Hunt Morgan studied the fruit fly, *Drosophila melanogaster*. His results supported Sutton’s theory; that the distribution of chromosomes into developing gametes follows the pattern for two alleles of a gene, according to Mendel’s *law of segregation* and *independent assortment*. *Chromosome theory of Inheritance* states that traits determined by genes are inherited through the movement of chromosomes during meiosis.
While studying the fruit fly he discovered a white eyed male fruit fly. He crossed the white eyed male with a red eyed female. The $F_1$ generation was all red eyed (males and females). Conclusion was the red eye allele was dominant and the white eye was a mutation.

Morgan crossed a male from the $F_1$ generation with a female from the same generation.

In the $F_2$ generation all females were red eyed, but the males showed a 50/50 split red/white eyed. Conclusion was that the eye colour for males was determined by the sex chromosome $X$. flies have sex chromosomes similar to humans, males are $XY$, and females are $XX$.

The gene for eye colour must be controlled by the sex chromosomes, therefore is called a sex-linked trait.

**Sex-linked Genes**

In humans the $X$ and $Y$ chromosomes only have a few genes in common. The $X$ chromosome has 2000 genes, while the $Y$ chromosome has 100 genes. Genes found on the $X$ chromosome are called $X$-linked, while genes found of the $Y$ chromosomes are called $Y$-linked.

All alleles on the sex chromosomes are expressed *superscripted* to an $X$ or a $Y$. 
The Red and White Eyes of Fruit Flies

Males can either be red or white eyed, based on a dominant; $X^R$ allele and the recessive $X^r$ allele. Two genotypes create two phenotypes.

Females have three genotypes, creating two phenotypes. $X^R X^R$, $X^R X^r$, for red eyes and $X^r X^r$ for white eyes.

<table>
<thead>
<tr>
<th>Genotype</th>
<th>Phenotype</th>
</tr>
</thead>
<tbody>
<tr>
<td>$X^R X^R$</td>
<td>Female with red eyes (homozygous dominant)</td>
</tr>
<tr>
<td>$X^R X^r$</td>
<td>Female with red eyes (heterozygous, carrier for the white-eyed allele)</td>
</tr>
<tr>
<td>$X^r X^r$</td>
<td>Female with white eyes (homozygous recessive)</td>
</tr>
<tr>
<td>$X^r Y$</td>
<td>Male with red eyes</td>
</tr>
<tr>
<td>$X^r Y$</td>
<td>Male with white eyes</td>
</tr>
</tbody>
</table>

Table 6.1: Possible Genotypes and Phenotypes for Drosophila Eye Colour

Figure 6.13: In Morgan’s experiment on tracking the inheritance pattern of a sex-linked trait, the white-eye phenotype was passes from the father in the P generation through the daughter in the F$_1$ generation.
Sex-linked Traits in Humans

**X-linked dominant** disorders, affected males will always pass on the genetic disorder \(X^D\text{Y}\) to a female who will be affected. A female can pass the disorder equally to either the male or the female offspring. Most **X-linked** traits are recessive. Therefore the male only requires one allele to be affected, the female requires two alleles. The **X-linked recessive** trait affects more males than females.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Inheritance Pattern</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duchenne muscular dystrophy</td>
<td>X-linked recessive</td>
<td>Progressive weakening of muscles and loss of coordination</td>
</tr>
<tr>
<td>Hemophilia</td>
<td>X-linked recessive</td>
<td>Cannot produce a necessary blood clotting factor</td>
</tr>
<tr>
<td>X-linked hypophosphatemia</td>
<td>X-linked dominant</td>
<td>Softening of bone, which leads to bone deformity</td>
</tr>
<tr>
<td>Hairy ears</td>
<td>Y-linked</td>
<td>Hair grows on the outside of the ears</td>
</tr>
</tbody>
</table>

Table 6.2: Sex-linked Traits in Humans

**Colour Vision Deficiency: An X-linked Recessive Trait**

**CVD** or **Colour Vision Deficiency** affected individuals varying degrees, between colours or shades of colours.

Red-green colour blindness is an **X-linked recessive** disorder. Individuals have a difficult time distinguishing between shades of red and green. To tract this pattern of inheritance, **pedigree** can be used.

![Pedigree Diagram](image_url)

**Figure 6.14:** An X-linked recessive trait like CVD will affect more males than females in a family.
Hemophilia: A Common Sex-linked Trait in Humans

Hemophilia is a genetic disorder that affects the body’s ability to produce a protein involved in blood clotting. Hemophilia is an X-linked recessive trait.

This disease is known the royal disease because it spread among the royal families of Europe; Britain, Spain, Russia, and Prussia. Arranged marriages were common, and the disease can be traced back through the centuries using a pedigree chart.

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