Chapter 4

- Extensions to Mendelian Genetics
- Allele Interactions
INTRODUCTION

• **Mendelian inheritance** describes inheritance patterns that obey two laws
  – Law of segregation
  – Law of independent assortment

• **Simple Mendelian inheritance** involves
  – A single gene with two different alleles
  – Alleles display a simple dominant/recessive relationship
INTRODUCTION

• In this chapter we will examine traits that deviate from the simple dominant/recessive relationship

• The inheritance patterns of these traits still obey Mendelian laws
  – However, they are more complex and interesting than Mendel had realized
Variations of Mendelian Phenotypic Ratios

- alleles can interact with each other in complex ways
  - incomplete dominance
  - codominance
  - pleiotropic alleles
- many traits are controlled by more than one gene
  - epistasis
  - redundancy
  - complementation
  - penetrance
  - expressivity
- interactions of genes with the environment
But nature is usually more complicated than this.

Mendel was successful because he chose simple examples to start with (and he had some luck).
Dominance is not always complete

• Crosses between true-breeding strains can produce hybrids with phenotypes different from both parents
  – Incomplete dominance
    • Looks like neither parent
  – Codominance
    • Looks like both parents
Incomplete Dominance: the phenotype of the heterozygous hybrid is usually an intermediate between the homozygous parents.

- Segregation of both genotype and phenotype is 1:2:1.
- Alleles contribute different amounts of functional protein; total amount determines phenotype.
- The amount of red pigment present is dependent on the amount of enzymes present, which is dependent on the number of wildtype copies of the gene. This is a dosage effect.

<table>
<thead>
<tr>
<th>Phenotype</th>
<th>Genotype</th>
<th>Amount of gene product</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red</td>
<td>AA</td>
<td>2x</td>
</tr>
<tr>
<td>Pink</td>
<td>Aa</td>
<td>x</td>
</tr>
<tr>
<td>White</td>
<td>aa</td>
<td>0</td>
</tr>
</tbody>
</table>
Incomplete Dominance

- Example: blooming time in peas.

- Example: Flower color.
  - A cross of pure breeding red lowered plants and pure breeding white flowered plants yields plants with pink flowers.
  - Is this blending?
  - Check F2 generation ratios.

- Biochemical basis of incomplete dominance.

- *Incomplete dominance is when neither of the two traits are seen in the F1 of a cross of two pure breeding traits.*
Incomplete dominance in snapdragons

(b) A Punnett square for incomplete dominance

P

Gametes

F₁ (all identical)

F₂

1 AA (red) : 2 Aa (pink) : 1 aa (white)
Incomplete Dominance

• What is the phenotypic and genotypic ratio?
  – Genotype:
    • 1 AA: 2 Aa : 1 aa
  – Phenotype
    • 1 red : 2 pink : 1 white
  – Notice anything?
    • They are the same

• Usually use R and R’ or A and A’ because neither is dominant
Question

• In cattle, roan coloring is the result of crossing red with white cattle. What crosses would result in a pure line of roan cattle?
  – 1. Red x Red
  – 2. Red x White
  – 3. White x White
  – 4. Roan x Roan
  – 5. None
Codominance

• Both alternative traits can be visualized in the F1.

• Example: spotted lentil plant crossed to a dotted lentil plant.

• F1 hybrids look like both parents.

• Check phenotypic and genotypic ratios of F2.

• **Codominance is when both alternative traits are expressed in the F1 of a cross of two pure breeding parents.**
Codominant lentil coat patterns

Fig. 3.4a
Co-Dominance

• What is the phenotypic and genotypic ratio?
  – Genotype:
    • 1 CsCs: 2 CsCd : 1 CdCd
  – Phenotype
    • 1 spotted : 2 spotted and dotted : 1 dotted
  – Again, notice anything?
    • They are the same
• In this case both alleles expressed
Do variations on dominance relations negate Mendel’s law of segregation?

- Dominance relations affect phenotype and have no bearing on the segregation of alleles
- Alleles still segregate randomly
- Gene products control expression of phenotypes differently
- Mendel’s law of segregation still applies
- Interpretation of phenotype/genotype relation is more complex
Codominant blood group alleles

(b) Codominant blood group alleles

Blood type

Red blood cell

A sugar

B sugar

A and B sugars

P $\ 
\ 
$ $^{\text{A}}_{\text{A}}$ $^{\text{B}}_{\text{B}}$

$\times$

$^{\text{A}}_{\text{A}}$ $^{\text{B}}_{\text{B}}$

$^{\text{A}}_{\text{B}}$

$F_1$

$^{\text{A}}_{\text{A}}$ $^{\text{B}}_{\text{B}}$

$^{\text{A}}_{\text{B}}$
Multiple Alleles

• A gene can have more than two alleles
  – How many do we inherit?
    • Just two…..but can pull from more than two in the gene pool

• Back to blood type
  – How many are there?
  – Three alleles
    • IA
    • IB
    • i
ABO Blood Types in Humans

• Three different alleles: $I^A$, $I^B$ and $i$.
• There are 4 different blood group phenotypes: A, B, AB and O.
• Each pair has a different dominance relationship.
• Biochemical Basis:
  – Complex membrane anchored molecules that cause a variation in the structure of the sugar polymer on the cell surface.
  – Three possibilities: Sugar type A, B or none.
### ABO Blood Types

**Blood Type**

- **A**
  - Genotype: \( I^A I^A \) or \( I^A i \)
  - Corresponding Phenotype: A

- **B**
  - Genotype: \( I^B I^B \) or \( I^B i \)
  - Corresponding Phenotype: B

- **AB**
  - Genotype: \( I^A I^B \)
  - Corresponding Phenotype: AB

- **O**
  - Genotype: \( ii \)
  - Corresponding Phenotype: O
ABO Antigens

- **Type A** individuals have the A antigen on their RBCs, and anti-B antibodies in their blood.
  - Their genotype is $I^A/I^A$ or $I^A/i$.

- **Type B** individuals have the B antigen
  - on their RBCs, and anti-A antibodies in their blood. Their genotype is $I^B/I^B$ or $I^B/i$.

- **Type AB** individuals have both the A and the B antigen on their RBCs, and neither anti-A nor anti-B antibodies in their blood.
  - Their genotype is $I^A/I^B$.

- **Type O** individuals have neither the A nor the B antigen on their RBCs, and both anti-A and anti-B antibodies in their blood.
  - Their genotype is $i/i$. 
Question

• Which blood type is the universal donor?
  – 1) A
  – 2) B
  – 3) AB
  – 4) O
Question

• Which blood type is the universal acceptor?
  – 1) A
  – 2) B
  – 3) AB
  – 4) O
Question

• In a paternity suit, the child in question has blood type A and the mother is type AB, which of the following men could not possibly be the child’s father? A father with type _______ blood.
  – 1. A
  – 2. B
  – 3. AB
  – 4. O
  – 5. All of the above could possibly be the father.
Dominance series

• Alleles are listed in order of most dominant to most recessive

• Establishes dominance relationships between multiple alleles

• Crosses between breeding lines allow arrangements

• Interbreeding F1 hybrids results in 3:1 ratios
  – Says alleles are in fact alleles of the same gene
(a) *Mus musculus* (house mouse) coat colors

![Mice](image)

(b) Alleles of the *agouti* gene

<table>
<thead>
<tr>
<th>Genotype</th>
<th>Phenotype</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-</td>
<td>agouti</td>
</tr>
<tr>
<td>a_IA</td>
<td>black/yellow</td>
</tr>
<tr>
<td>aa</td>
<td>black</td>
</tr>
</tbody>
</table>

(c) Evidence for a dominance series

![Mice diagram](image)

Dominance series: $A > a_I > a$
There are multiple alleles for the gene that codes for coat color in mice.

Using pair wise crosses of mice homozygous for each of the sixteen agouti alleles one, can construct a dominance series.

The dominance series describes a hierarchical relationship between the various alleles of a single gene.
Pleiotropy

- One gene may contribute towards several visible characteristics.
  - E.g: coat color in mice

- In addition to coat color, a specific allele at this locus also causes lethality.

- *The phenomenon of a single gene determining multiple distinct traits is known as pleiotropy.*

- Pleiotropy may be the result of a single gene product (protein) giving rise to multiple functional characteristics.
  - Examples:
    - Recessive lethal alleles
    - Sickle Cell Syndrome
The $A_Y$ Allele Is Pleiotropic

**Pleiotropic**: multiple physical effects (phenotypes) caused by a single altered gene or pair of altered genes.

$A_Y$: mutation, yellow coat

$A_Y/A$ mice are yellow, obese, and develop tumors and type 2 diabetes

$A/A$: wild-type agouti (brown)

$A_Y/A_Y$ die *in utero* always get 2 yellow : 1 wild-type

pure breeding yellow mice can never be obtained
Genetic Explanation

- Homozygous $A^Y/A^Y$ mice die in utero and are never observed; it is a lethal phenotype.
- Yellow mice are heterozygotes.
- Homozygous recessive (wild type) mice are agouti.

- $A^Y$ allele is dominant over the A normal allele for coat color
- but is recessive for lethality.
- Dominance depends on what trait you look at.
Another example: White coat color and blue eyes in dogs and cats is often co-inherited with deafness. Pleiotropic genes have mutant phenotypes that disrupt more than one process, even seemingly unrelated ones, such as pigment formation and ear development.

**Pleiotropy**
• Hereditary congenital deafness in dogs (and cats) is associated with defects in neural crest cells, which are precursors for both melanocytes required for pigmentation of the coat and eyes and structures of the inner ear.
Conclusions:

• Alleles of a single gene can interact with other alleles of the same gene or with the environment.

• When heterozygous offspring look like one parent but not the other -
  • complete dominance, dominance series.

• When heterozygotes show a phenotype unlike that of either parent -
  • incomplete dominance.

• When heterozygotes show characteristics of both parents
  • co-dominance.
Question

- When the same gene is related to respiratory problems and sterility, it can be described as:
  - 1. pleiotropy
  - 2. co-dominance
  - 3. Incomplete dominance
  - 4. Complete dominance
**Summary**

**TABLE 3.1** For Traits Determined by One Gene: Extensions to Mendel’s Analysis Explain Alterations of the 3:1 Monohybrid Ratio

<table>
<thead>
<tr>
<th>What Mendel Described</th>
<th>Extension</th>
<th>Extension’s Effect on Heterozygous Phenotype</th>
<th>Extension’s Effect on Ratios Resulting from an $F_1 \times F_1$ Cross</th>
</tr>
</thead>
<tbody>
<tr>
<td>Complete dominance</td>
<td>Incomplete dominance</td>
<td>Unlike either homozygote</td>
<td>Phenotypes coincide with genotypes in a ratio of 1:2:1</td>
</tr>
<tr>
<td></td>
<td>Codominance</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Two alleles</td>
<td>Multiple alleles</td>
<td>Multiplicity of phenotypes</td>
<td>A series of 3:1 ratios</td>
</tr>
<tr>
<td>All alleles are equally viable</td>
<td>Recessive lethal alleles</td>
<td>No effect</td>
<td>2:1 instead of 3:1</td>
</tr>
<tr>
<td>One gene determines one trait</td>
<td>Pleiotropy: one gene influences several traits</td>
<td>Several traits affected in different ways, depending on dominance relations</td>
<td>Different ratios, depending on dominance relations for each affected trait</td>
</tr>
</tbody>
</table>
Homework Problems

– Chapter 4

– # 1, 4, 6, 7, 8, 9, 10, 11, 12, 13, 14

• DON’T forget to submit the online iActivity
  – “Charlie Chaplin”