

Chapter 3

ANIMAL GENETICS AND BREEDING

Fundamental Principles of Genetics

Genetics studies how living [organisms](#) inherit features from their ancestors. Genetics tries to identify which features are inherited, and work out the details of how these features are passed from generation to generation.

Genetics may be conveniently divided into 3 areas of study: **transmission genetics**, **molecular genetics** and **population genetics**.

Transmission Genetics

*Transmission genetics is concerned with identifying the **genes** that affect a particular characteristic, and also the patterns by which these genes are transmitted from generation to generation, or from cell to cell.*

The total genetic complement of a cell or organism is called **genome**. The particular version of a genome carried by an individual is called the **genotype**, which is a set of **genes**. A **gene** is defined as *the smallest unit of inheritance*. Therefore, genes are the determiners of **heridity**.

The outward manifestation of the expression of the genotype is called the **phenotype**. Genes may express themselves in the **phenotype** in two general ways, known as additive and nonadditive phenotypic expressions. Individual genes can be identified through phenotypic inheritance patterns, but only if some variation is present in the phenotype. Some phenotypic variation is discontinuous, e.g, yellow versus green pea seeds. Discontinuous variation often can be explained genetically by different forms of a gene called **alleles**: in an example from peas, **Y** is the allele for the yellow phenotype, and **y** for green. Plants and animals carry a pair of each gene, so in the pea example, an individual pea can be YY, Yy or yy. Because the Y allele is dominant (written as a capital) the Yy individual is yellow phenotype.

Some phenotypic variation takes the form of a continuous range of values (eg, very short through all intermediate values to very tall). Continuous variation often can be explained

by a number of interacting genes (polygenes); the greater the number of genes involved, the greater the possible range of variation. Environmental variation also contributes to continuous variation, so one of the analytical problems in studying such phenotypes is trying to partition continuous variation into genetic variation from environmental variation.

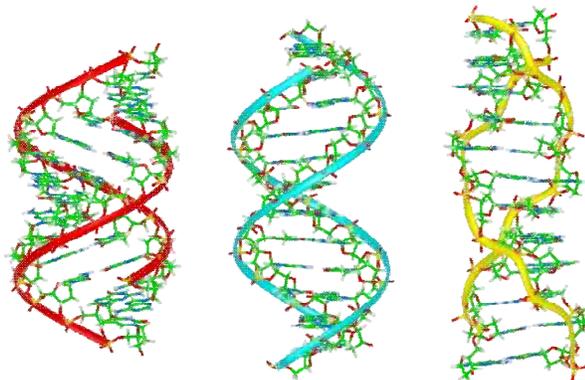
Transmission genetics has found widespread use in traditional agricultural practices, especially in plant and animal breeding. Many plants and animals used in commerce have been developed by breeding procedures. Furthermore, many diseases are known to be genetic in origin, resulting from a mutation to produce a disease-causing allele.

Molecular Genetics

Molecular genetics focuses on the structure and function of the genetic units, ie, the chemical composition of genes and their expression in determining the structure of proteins, the most important functional components of cells.

All animals (and plants as well) are made of small building blocks called **cells**. The main parts of the cell include the **nucleus** and the cytoplasm. The nucleus is the heart and brain of the cell and contains the **chromosomes**. Each species of animals possesses a characteristic number of chromosomes for that species (humans have 2 sets of 23 chromosomes, each parent contributing a set, for a total of 46).

Genes, the determiners of **heredity**, are carried on chromosomes. Each chromosome contains a 50 mm length of a threadlike chemical called **DNA** (deoxyribonucleic acid); however, as each chromosome is less than 0.005 mm long, the DNA must be very efficiently packed through coiling and supercoiling. A **gene** is simply a functional segment on the DNA thread. It embodies a coded message, in the form of a sequence of chemical units called **nucleotides**.



The sequence of most genes dictates the sequence of amino acids that make up a specific protein molecule. Proteins are crucial in phenotypic expression because when you look at an organism what you see is either a protein or something that has been made by a protein. Some proteins (called enzymes) control chemical reactions taking place in cells, and some are important structural components of cells, such as microtubules or muscle myofilaments.

DNA has the unique property of being able to make copies of itself (ie, replicate). That is, the gene as a portion of a DNA molecule has the ability to replicate itself when new cells are formed. Bacteria consist of single cells without a membrane-bound **nucleus**; each cell carries a single circular DNA chromosome that replicates before the cell divides by binary fission, producing daughter cells that are an exact genetic copy of the original cell. Plants, animals and fungi are composed of one or more cells having membrane-bound nuclei. The body cells of plants and animals contain two sets of linear chromosomes per nucleus, and fungal cells one set per nucleus. These chromosomes replicate before body cell division, and the chromosome copies are partitioned equally into daughter cells during an orderly nuclear division process called **mitosis**.

Animals also undergo a specialized nuclear division (**meiosis**) during the sexual cycle. In animals, meiotic division results in **sperms** and **eggs** (or **ovum**), which contain only one chromosome set per cell. When sperm and egg unite, the resulting cell (the **zygote**) is the progenitor cell of the body of a new individual, and contains the usual two chromosome sets. During meiosis different allele pairs can assort into new combinations, so zygotes are of many different genotypes, all differing from the two parents.

Infrequently, DNA undergoes a sequence change, termed a **mutation**, that alters both genotype and phenotype. This is the ultimate source of all genetic variation. Mutations without obvious cause are referred to as spontaneous mutations; induced mutations result mainly from damage to genes caused by environmental chemicals and radiation. Mutations are the material on which the environment acts to result in evolution; thus, a mutation that gives an organism an advantage may permit it to produce more offspring which, in turn, contain the mutated gene. Over time, an entire population may change.

A revolution in molecular genetics occurred upon the invention of recombinant DNA technology. This technology allowed genes to be isolated by cloning, characterized in detail by DNA sequencing, and manipulated experimentally in a test tube (in vitro mutagenesis). Improvements of recombinant DNA technology have led to the ability to characterize whole genomes. Recombinant DNA technology also allows genes to be removed from their original organism and spliced into the chromosomes of other organisms, to create transgenic organisms.

Population Genetics

Population genetics analyses the pattern of distribution of genes in populations of organisms, and changes in the genetic structure of populations.

Different populations of organisms show different frequencies of various alleles. Population genetics attempts to measure these allele frequencies in order to compare the

genetic compositions of different populations. The purpose of these measurements can be for ecological studies, or to study evolutionary changes in the population. One fundamental tool is the Hardy-Weinberg formula, which states that under conditions of random mating and with no change of allele frequency, the structure of a very large population can be described as p^2 of genotype AA, $2pq$ of Aa and q^2 of aa, where p and q are the frequencies (proportions) of alleles A and a in that population. This will give a stable population structure. The Hardy-Weinberg proportions can be changed by mutation, selection, random changes in allele frequency (genetic drift), and migration, all of which can be considered to be evolutionary forces.

In other words, **population genetics** is the study of the [allele frequency](#) distribution and change under the influence of the four evolutionary processes: [natural selection](#), [genetic drift](#), [mutation](#) and [gene flow](#). It also takes account of population subdivision and population structure in space. As such, it attempts to explain such phenomena as [adaptation](#) and [speciation](#). Population genetics was a vital ingredient in the [modern evolutionary synthesis](#) its primary founders were [Sewall Wright](#), [J. B. S. Haldane](#) and [R. A. Fisher](#), who also laid the foundations for the related discipline of [quantitative genetics](#).

Quantitative genetics is the study of continuous traits (such as height or weight) and its underlying mechanisms. It is effectively an extension of simple [Mendelian inheritance](#) in that the combined effect of the many underlying genes results in a [continuous distribution](#) of [phenotypic](#) values.

The phenotypic value (P) of an [individual](#) is the combined effect of the genotypic value (G) and the environmental deviation (E):

$$P = G + E$$

The genotypic value is the combined effect of all the genetic effects, including [nuclear genes](#), [mitochondrial](#) genes and interactions between the genes. It is therefore often subdivided in an additive (A) and a dominance component (D). The additive effect described the cumulative effect of the individual genes, while the dominance effect is the result of interactions between those genes. The environmental deviation can be subdivided in a pure environmental component (E) and an interaction factor (I) describing the [interaction between genes and the environment](#) This can be described as:

$$P = A + D + E + I$$

The contribution of those components cannot be determined in a single individual, but they can be estimated for whole populations by estimating the [variances](#) for those components, denoted as:

$$V_P = V_A + V_D + V_E + V_I$$

The **heritability** of a trait is the proportion of the total (i.e. phenotypic) variation (V_P) that is explained by the **genetic variation**. This is the total genetic variation (V_G) in broad sense heritabilities (H^2), while only the additive genetic variation (V_A) is used for narrow sense heritabilities (h^2), often simply called heritability. The latter gives an indication how a trait will respond to **natural** or **artificial selection**

Animal Selection

Purpose of animal selection

The purpose of animal selection is to identify and select superior breeding animals which possess a large proportion of superior genes for a desirable trait, or traits.

Methods of animal selection

Types of selection are within and between **family selection** individual or **mass selection**, sibling selection, and progeny testing, with many variations.

Within family selection uses the best individual from each family for breeding.

Between family selection uses the whole family for selection.

Mass selection uses records of only the candidates for selection. Mass selection is most effective when heritability is high and the trait is expressed early in life, in which case all that is required is observation and selection based on phenotypes.

When mass selection is not appropriate, other methods of selection, which make use of **relatives** or **progeny**, can be used singularly or in combination.

Modern selection technologies allow use of all these types of selection at the same time, which results in greater accuracy.

Breeding schemes

Once superior animals are identified and selected, it is necessary to devise breeding schemes (mating systems) which will give the most genetic improvement. The different breeding schemes may be grouped into purebreeding and crossbreeding.

Purebreeding

Purebreeding is the mating of males and females of the same breed. Purebred breeding aims to establish and maintain stable traits, that animals will pass to the next generation. By "breeding the best to the best," employing a certain degree of [inbreeding](#), considerable [culling](#) and selection for "superior" qualities, one could develop a bloodline or "breed" superior in certain respects to the original base stock. Such animals can be recorded with a [breed registry](#), the organisation that maintains [pedigrees](#) and/or [stud books](#). The goal of purebreeding should be to supply genetics (seedstock) to the commercial production. Seedstock are marketed as sire and replacement dams to other seedstock producers or to commercial operations.

In purebreeding, there may be also special schemes called inbreeding and linebreeding.

Inbreeding/Closebreeding

Inbreeding or closebreeding may be defined as the production of progeny by parents that are more closely related than the average of the population from which they came. Inbreeding is often described as "narrowing the genetic base" because the mating of related animals results in offspring that have more genes in common. Inbreeding is used to concentrate desirable traits. Mild inbreeding has been used in some breeds of dogs and has been extensively used in laboratory [mice](#) and rats. For example, mice have been bred to be highly sensitive to compounds that might be detrimental or useful to humans. These mice are highly inbred so that researchers can obtain the same response with replicated treatments.

Inbreeding is generally detrimental in domestic animals. **Inbreeding depression** is reduced [fitness](#) in a given [population](#) as a result of inbreeding. Increased inbreeding is accompanied by reduced fertility, slower growth rates, greater susceptibility to disease, and higher mortality rates. As a result, producers try to avoid mating related animals. This is not always possible, though, when long-continued selection for the same traits is practiced within a small population, because parents of future generations are the best candidates from the last generation, and some inbreeding tends to accumulate. The rate of inbreeding can be reduced, but, if inbreeding depression becomes evident, some method

of introducing more diverse genes will be needed. The most common method is some form of crossbreeding.

Linebreeding

Line breeding is the most conservative form of inbreeding, is usually associated with slower improvement and limited risk of producing undesirable individuals. It can involve matings between closely or distantly related animals, but it does not emphasize continuous sire-daughter, dam-son, or brother-sister matings.

The main purpose of linebreeding is to transmit a large percentage of one outstanding ancestor's genes from generation to generation without causing an increase in the frequency of undesirable traits often associated with inbreeding.

Because linebreeding is not based strictly on mating closely related individuals (with very similar gene types), it does not necessarily cause a rapid increase in homozygous gene pairs. Consequently, it will not expose undesirable recessive genes as extensively as closebreeding. For this reason, linebreeding is generally a safer inbreeding program for most breeders.

Intensive inbreeding (and resulting increased homozygosity) is often directly related to an increase in the expression of many undesirable traits. Therefore, the linebreeder should carefully study pedigrees for each prospective mating and determine if, and how closely, the male and female are related. By following certain guidelines, the breeder can limit inbreeding (and, therefore, homozygosity) within their herd. At the same time, they may increase the influence of a common ancestor upon the entire strain or family.

Outbreeding/Outcrossing

Outbreeding or **outcrossing** is the mating of males and females from unrelated families in the same breed. **Outcrossing** is the practice of introducing unrelated genetic material into a breeding line. It increases [genetic diversity](#), thus reducing the probability of all individuals being subject to disease or reducing genetic abnormalities (only within the first generation).

It is used in line-breeding to restore vigor or size and fertility to a breeding line. "Line-breeding", is where animals carry a common ancestor in their pedigrees and are bred together, should be considered distinct from the term "in-breeding" which is the production of offspring by parents more closely related than the average

Crossbreeding

Crossbreeding involves the mating of animals from *different* breeds. Crossbreeding offers two primary advantages: the opportunity for **breed complementarity** and **heterosis** (also called hybrid vigor). Normally, breeds are chosen that have complementary traits that will enhance the offspring's economic value. An example is the crossbreeding of [Yorkshire](#) and [Duroc](#) breeds of pigs. Yorkshires have acceptable rates of gain in muscle mass and produce large litters, and Durocs are very muscular and have other acceptable traits, so these breeds are complementary. Another example is [Angus](#) and [Charolais](#) beef cattle. Angus produce high-quality beef and Charolais are especially large, so crossbreeding produces an animal with acceptable quality and size.

The other consideration in crossbreeding is [heterosis](#), or [hybrid vigour](#), which is displayed when the offspring performance exceeds the average performance of the parent breeds. This is a common phenomenon in which increased size, growth rate, and fertility are displayed by crossbred offspring, especially when the breeds are more genetically dissimilar. Such increases generally do not increase in successive generations of crossbred stock, so purebred lines must be retained for crossbreeding and for continual improvement in the parent breeds. In general, there is more heterosis for traits with low heritability. In particular, heterosis is thought to be associated with the collective action of many genes having small effects individually but large effects cumulatively. Because of hybrid vigour, a high proportion of commercial pork and beef come from crossbred animals.

There are unlimited crossbreeding schemes. The most commonly utilized crossbreeding schemes include:

1. Two-Breed Cross
2. Two-Breed Rotational Cross
3. Three-Breed Rotational Cross
4. Static Terminal Sire
5. Rotational Terminal Sire

These schemes are listed in order from least to most demanding in terms of facilities and labor. The same ranking applies to the realized benefits; the two-breed cross is the easiest to manage but results in the least heterosis and little opportunity for breed complementarity. Use of artificial insemination (A.I.) or multiple breeding pastures is required for use of complex systems. Following is a brief description of each system for cattle crossbreeding:

Two-Breed Cross

Use of a two-breed cross involves maintaining purebred/straightbred cows of a single breed and mating all females to a bull of another breed. This is a simple system that requires only one breeding pasture, but realizes less than half of the possible heterosis. Use of a two-breed cross allows realization of direct heterosis (advantages of a crossbred calf), but not maternal heterosis (advantages of a crossbred cow). All other systems result in both direct and maternal heterosis. A further drawback is that straightbred females must be purchased as replacements to continue the breeding program. A possible use of this system is for generation of F1 (purebred x purebred) replacements for sale to producers who are using more complex systems. This would be a means for owners of small cowherds to "add value" to their cattle.

Two-Breed Rotational Cross

In this scheme, bulls of two breeds are used. Females sired by a bull of a particular breed are mated to a bull of the other breed. Thus, after several generations, approximately two-thirds of the genetics of each calf result from breed it was sired by, one-third from the other breed. The two breeds will be equally represented within the cowherd if the number of each breed culled each year is equal. If natural service is used, this system requires at least two breeding pastures and requires that both breeds used be approximately equal in terms of size, nutritional requirements and maternal potential.

Three-Breed Rotational Cross

Nearly all of the possible heterosis is realized with proper management of a three-breed rotational crossbreeding system. This system is similar to the two-breed rotational cross except that three breeds are used. As in the two-breed rotational cross, females are mated to a bull of the breed that is least related to them (the sire breed of their maternal grandam). Benefits include a high degree of heterosis and potential for outstanding breed complementarity. However, this system is more difficult to maintain than the two previously described and at least three breeding pastures are required if A.I. is not used. In herds of less than 100 cows, the cost to maintain adequate bull power in each of three breeds may be prohibitive. Furthermore, inclusion of three breeds may make it difficult to maintain a uniform cowherd.

Static Terminal Sire

In this scheme the cowherd consists entirely of F1 females that are mated to bulls of a third, terminal sire breed. All calves are marketed. Only one breeding pasture is required

and heterosis and breed complementarity can be nearly maximized. However, F1 replacement females must be purchased. Locating a steady supply of economical, high-quality replacements can be difficult in most areas.

Rotational Terminal Sire

This scheme, which is used in many swine herds, is similar to the static terminal sire system except that a portion of the herd (typically 20 to 30 percent) is designated for production of replacement females. These females are maintained separately from the rest of the herd and mated to bulls of a maternal breed, possibly in a two-breed rotational system. The majority of the cows in the herd are mated to a terminal sire and all calves marketed. This can be a demanding scheme to maintain but will produce excellent results.

A more feasible variant may be to mate all heifers to maternal breed bulls and keep replacements from them while the mature cowherd produces only terminal-sired calves. The logic behind this is that heifers should be managed separately from mature cows anyway and that most (but by no means all) maternal breed bulls are easier calving than terminal breed bulls. This may make A.I. of heifers to high-quality maternal bulls a practical way to upgrade the maternal performance of the herd over time.

Review exercises

1. What is genetics and its areas of study?
2. Elaborate on transmission genetics.
3. Elaborate on molecular genetics.
4. Elaborate on population genetics.
5. How does animal breeding utilize trait variations?
6. Describe the role and different methods of animal selection.
7. Describe the different breeding schemes.

8. Determine what breeding schemes the two following figures represent?

