Heritability

Concept of heritability

- Heritability is the proportion of the observed variation in a progeny that is inherited.
- Heritability measures this degree of correspondence.
- **Genetic determination** is a matter of what causes a characteristic or trait; heritability, by contrast, is a scientific concept of what causes differences in a characteristic or trait.
- Heritability is, therefore, defined as a fraction: it is **the ratio of genetically caused variation to total variation**.

Heritability Continued…

- Consider a dairy farmer who owns several hundred milk cows.
- The farmer notices that some cows consistently produce more milk than others.
- **If the differences in milk production are largely genetic in origin, then the farmer may be able to boost milk production by selectively breeding the cows that produce the most milk.**
- If the differences are largely environmental in origin, selective breeding will have little effect on milk production, and the farmer might better boost milk production by adjusting the environmental factors associated with higher milk production.
- To determine the extent of genetic and environmental influences on variation in a characteristic, phenotypic variation in the characteristic must be partitioned into components attributable to different factors.

Phenotypic Variance

- Consider a population of wild plants that differ in size.
- Collect a representative sample of plants from the population, weigh each plant in the sample, and calculate the mean and variance of plant weight.
- This **phenotypic variance** is represented by V_P.

Components of phenotypic variance

- Differences in phenotype may be due to differences in genotypes among individual members of the population.
- These differences are termed the **genetic variance and are represented by V_G.**
- Differences in phenotype may be due to environmental differences among the plants.
- these differences are termed the **environmental variance,** V_E.

Genetic-environmental interaction variance (*VGE)*

- *arises when the effect of a gene depends on the specific* environment in which it is found.

Components of genetic variance

1. A**dditive genetic variance** (V_A) *comprises the additive effects of genes on the phenotype*, which can be summed to determine the overall effect on the phenotype.
2. D**ominance genetic variance** (***V_D***) when some genes have a dominance component.
3. **Epistasis genetic variance** (***V_I***) genes at different loci may interact in the same way that alleles at the same locus interact.

$$V_G = V_A + V_D + V_I$$

$$V_P = V_A + V_D + V_I + V_E + V_{GE}$$

Table 9.1 Symbols commonly used to refer to categories or causes of variation in quantitative traits. Variation is indicated by V while the specific cause of that variation is indicated by a subscript capital letter (with one exception). Total genetic variation (V_G) in phenotype can be divided into three subcategories.

Symbol	Definition
V_P	Total variance in a quantitative trait or phenotype
V_G	Variance in phenotype due to all genetic causes
V_A	Variance in phenotype caused by additive genetic variance or the effects of alleles
V_D	Variance in phenotype caused by dominance genetic variance or deviations from additive values due to dominance
V_I	Variance in phenotype caused by interaction genetic variance (epistasis between and among loci)
V_E	Variance in phenotype caused by environmental variation
$V_{G\times E}$	Variance in phenotype caused by genotype-by-environment interaction
V_{Ec}	Variance in phenotype caused by environmental variation shared in common by parents and offspring or by relatives

Additive genetic variance (V_A) The proportion of the total genotypic variance (V_G) caused by the sum of phenotypic effects of alleles when they are assembled into genotypes.

Dominance genetic variance (V_D) The proportion of the total genotypic variance (V_G) caused by the deviation of genotypic values from their values under additive gene action caused by the combination of alleles assembled into a single-locus genotype.

Epistasis or interaction genetic variance (V_I) The proportion of the total genotypic variance (V_G) due to the deviation of genotypic values from their values under additive gene action caused by interactions between and among loci.

Types of heritability

Broad sense heritability.

- ✓ Heritability estimated using the total genetic variance (V_G) *is called broad sense* heritability.
- ✓ It is expressed mathematically as:

$$H^2 = V_G/V_P$$

- ➢ Can potentially range from 0 to 1.
- ➢ H^2 0 all of the differences in phenotype result from environmental variation.
- ➢ A value of 1 indicates that all of the phenotypic variance results from differences in genotype.
- ➢ A heritability value between 0 and 1 indicates that both genetic and environmental factors influence the phenotypic variance.

Narrow sense heritability

- Because the additive component of genetic variance determines the response to selection, the narrow sense heritability estimate is more useful to plant breeders than the broad sense estimate. It is estimated as:

$$h^2 = V_A/V_P$$

Genotype-by-environment interaction ($V_{G\times E}$) The contribution to total phenotypic variation caused by genotypes that vary in their sensitivity to different environments. Also known as phenotypic plasticity.

Exercise

Phenotypic variation is analyzed for milk production in a herd of dairy cattle and the following variance components are obtained.

Additive genetic variance (V_A)	= .4
Dominance genetic variance (V_D)	= .1
Genic interaction variance (V_I)	= .2
Environmental variance (V_E)	= .5
Genetic-environmental interaction variance (V_{GE})	= .0

(a) What is the narrow-sense heritability of milk production?

(b) What is the broad-sense heritability of milk production?

- Solution

- Solution

To determine the heritabilities, we first need to calculate V_P and V_G.

$$\begin{aligned} V_P &= V_A + V_D + V_I + V_E + V_{GE} \\ &= .4 + .1 + .2 + .5 + .5 \\ &= 1.2 \end{aligned}$$

$$\begin{aligned} V_G &= V_A + V_D + V_I \\ &= .7 \end{aligned}$$

(a) The narrow sense heritability is:

$$h^2 = \frac{V_A}{V_P} = \frac{0.4}{1.2} = .33$$

(b) The broad sense heritability is:

$$H^2 = \frac{V_G}{V_P} = \frac{0.7}{1.2} = .58$$

The Limitations of Heritability

1. Heritability does not indicate the degree to which a characteristic is genetically determined.
2. An individual does not have heritability.
3. There is no universal heritability for a characteristic.
4. Even when heritability is high, environmental factors may influence a characteristic.
5. Heritabilities indicate nothing about the nature of population differences in a characteristic

Applications of heritability

1. To determine whether a trait would benefit from breeding.
2. To determine the most effective selection strategy to use in a breeding program.
3. To predict gain from selection. Response to selection depends on heritability.

Response to selection in breeding

- Selection, in essence, entails discriminating among genetic variation to identify and choose a number of individuals to establish the next generation.
- The **response to selection** (***R***) is the difference between the mean phenotypic value of the offspring of the selected parents and the whole of the parental generation before selection.
- The response to selection is simply the change of population mean between generations following selection.
- S**election differential** (***S***) is the mean phenotypic value of the individuals selected as parents expressed as a deviation from the population mean .
- Response to selection is related to heritability by the following equation:

$$R = h^2S$$

Breeder's Equation

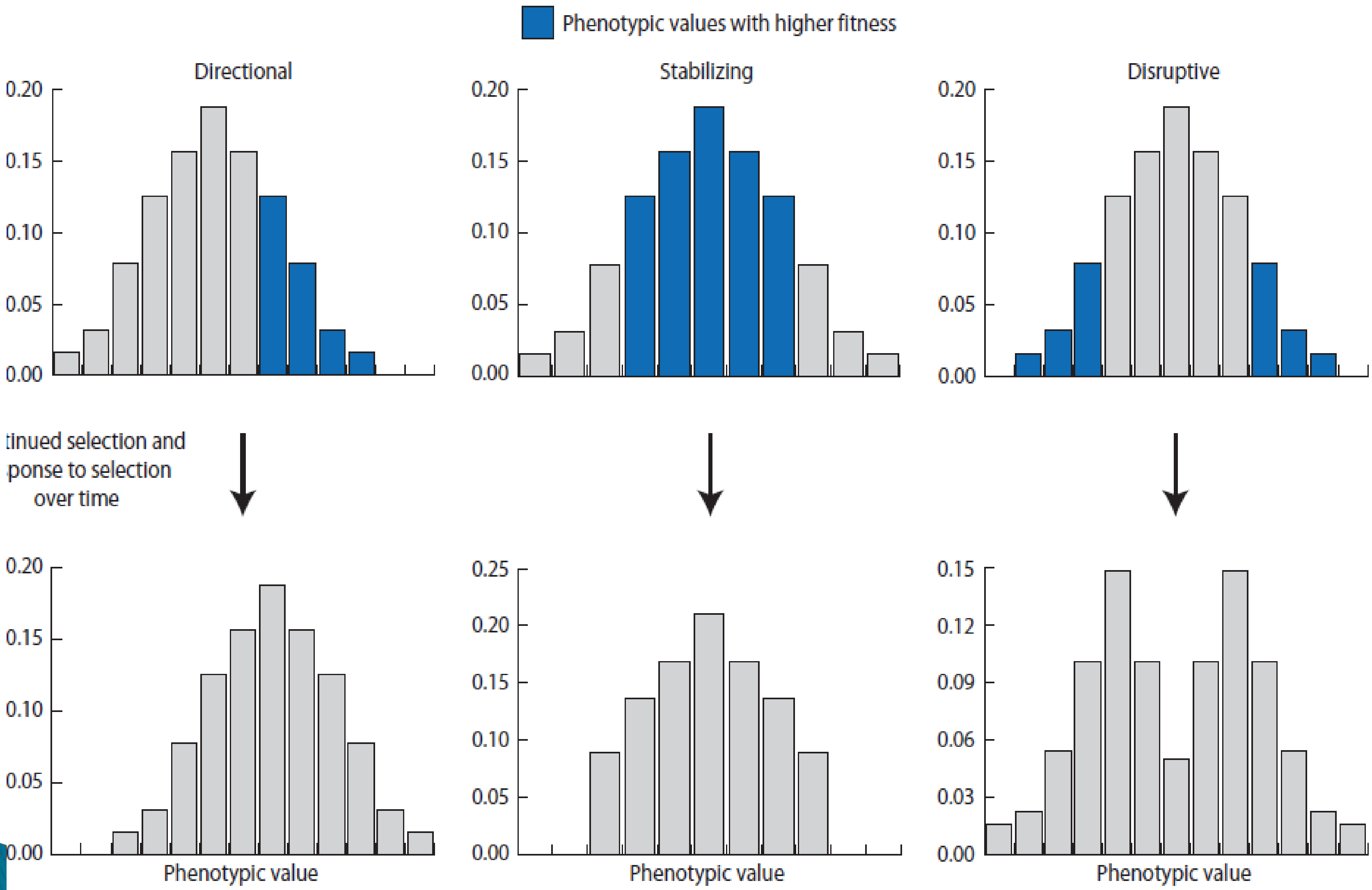
Genetic correlation Non-independence of inherited values for two traits. A correlation between the breeding values of two quantitative traits.

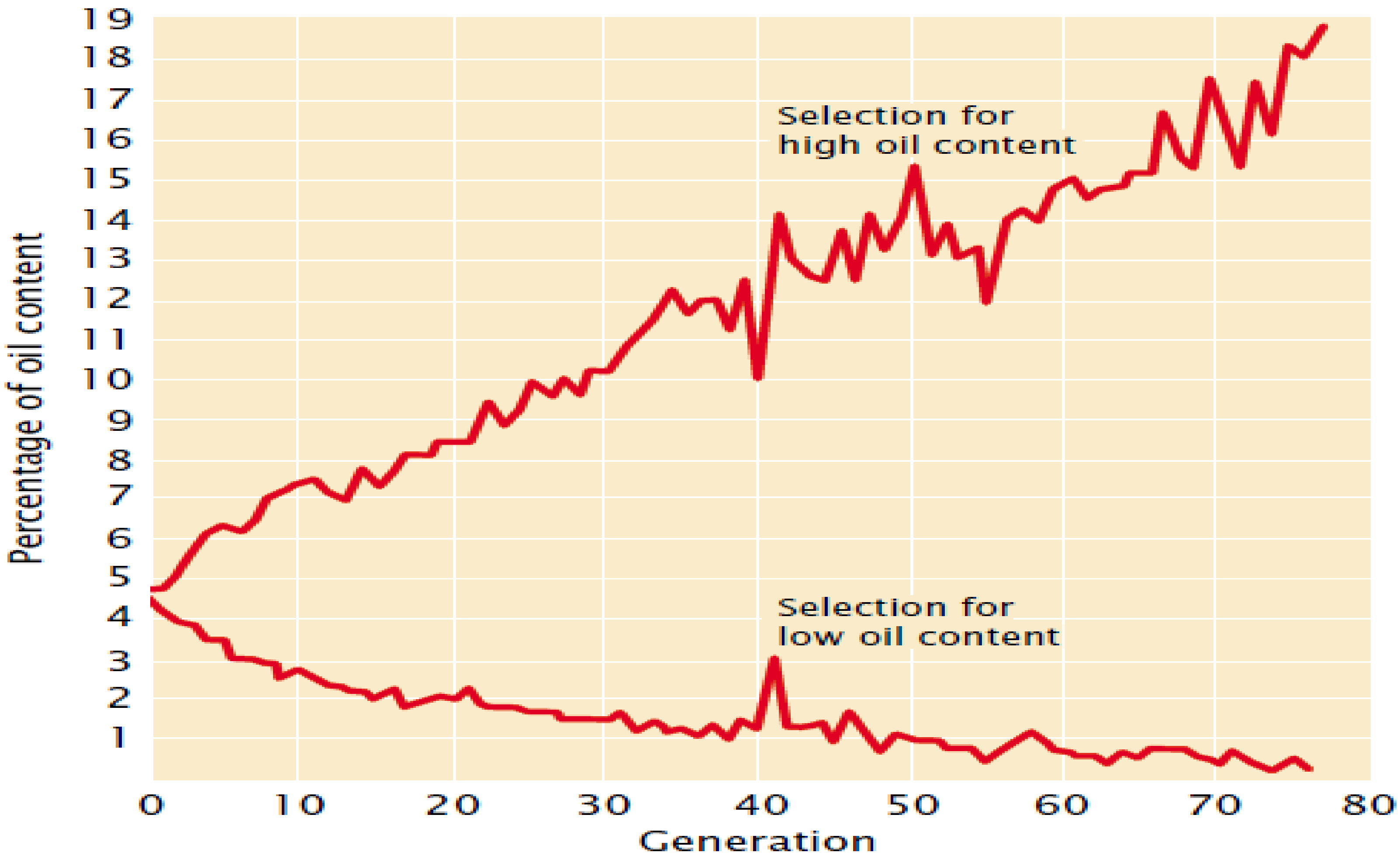
Phenotypic correlation Non-independence of the values of two or more quantitative traits within individuals.

Table 22.3 Genetic correlations in various organisms

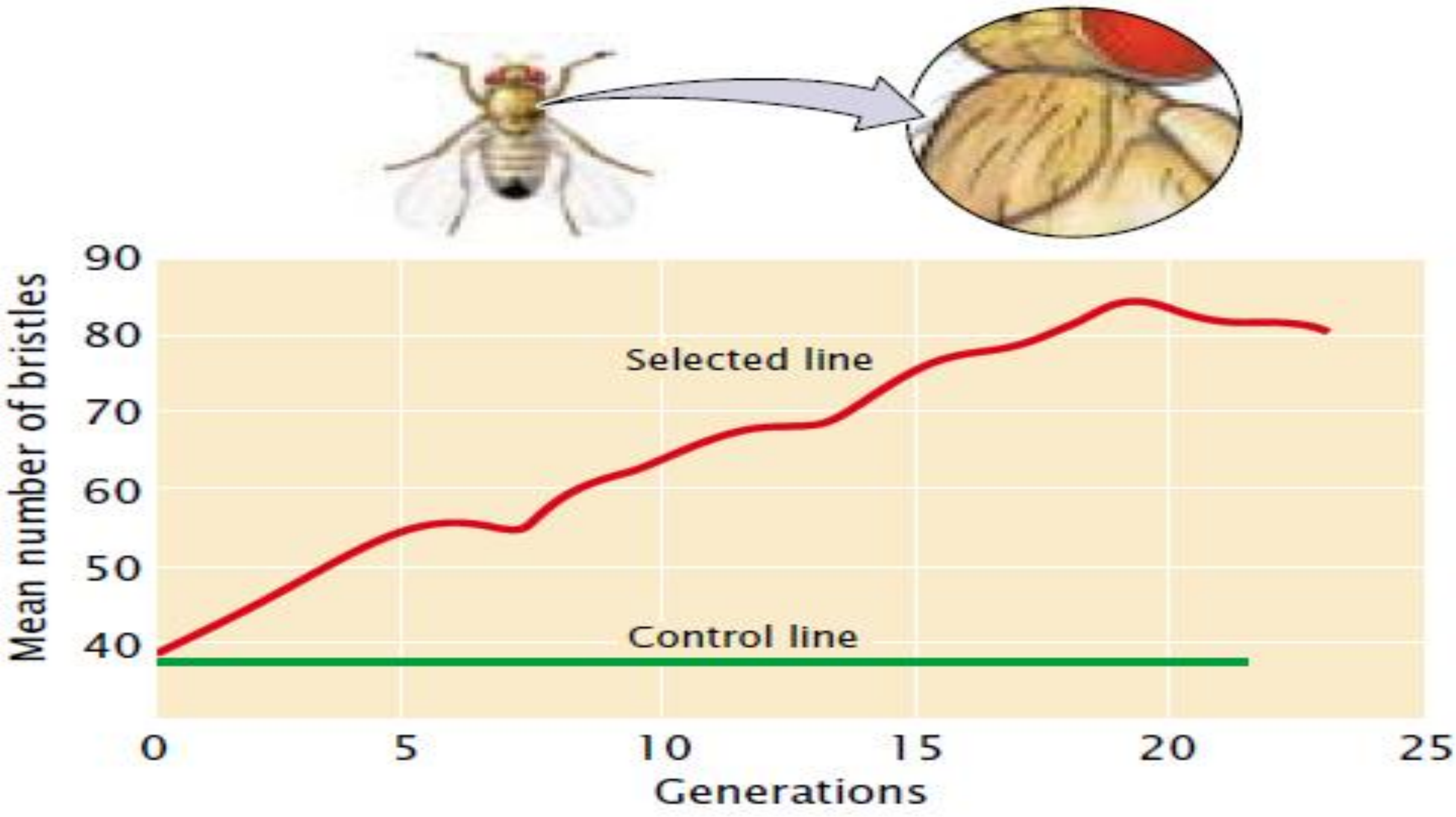
Organism	Characteristics	Genetic Correlation
Cattle	Milk yield and percentage of butterfat	−.38
Pig	Weight gain and back-fat thickness	.13
	Weight gain and efficiency	.69
Chicken	Body weight and egg weight	.42
	Body weight and egg production	−.17
	Egg weight and egg production	−.31
Mouse	Body weight and tail length	.29
Fruit fly	Abdominal bristle number and sternopleural bristle number	.41

Types of Selection



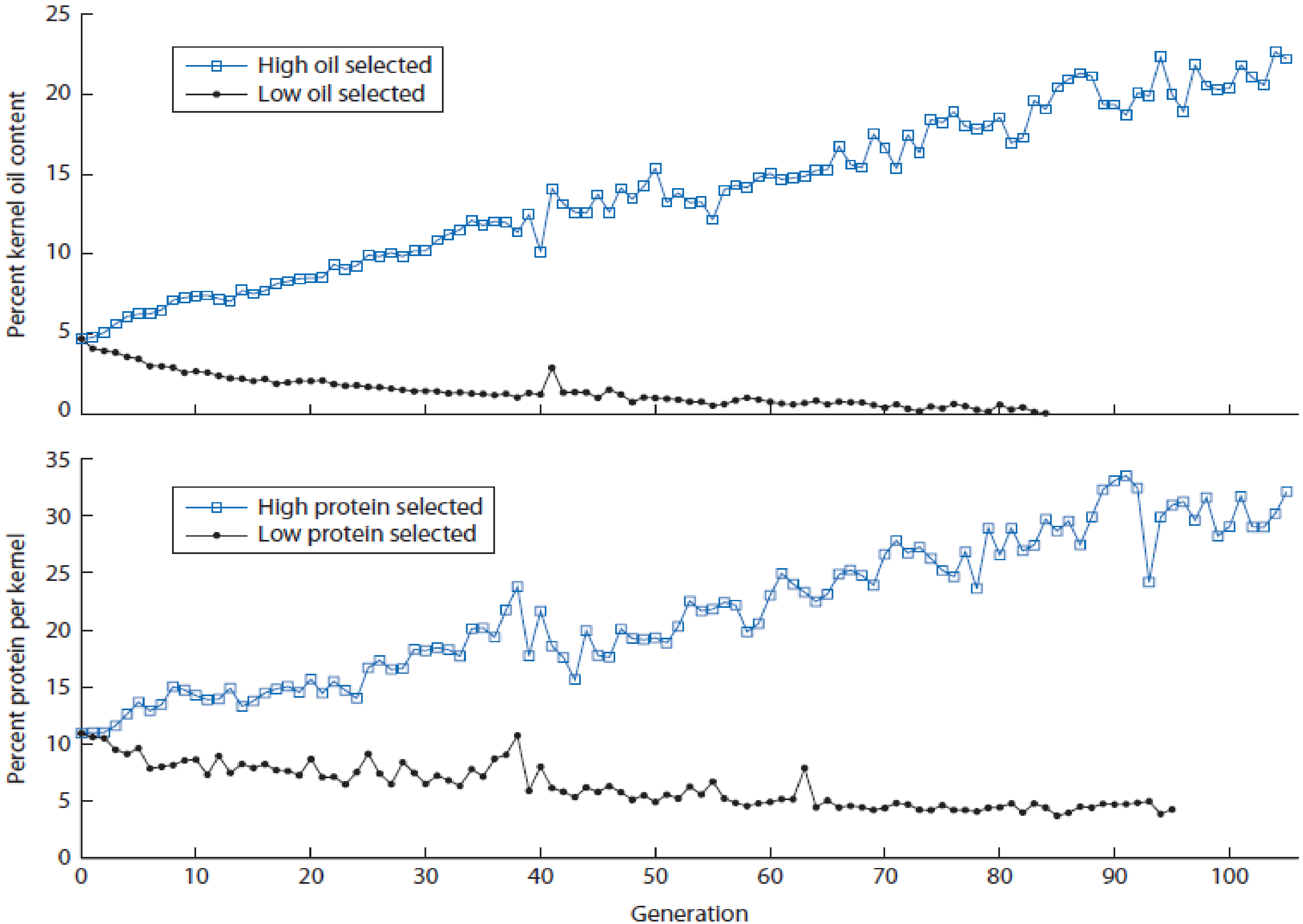


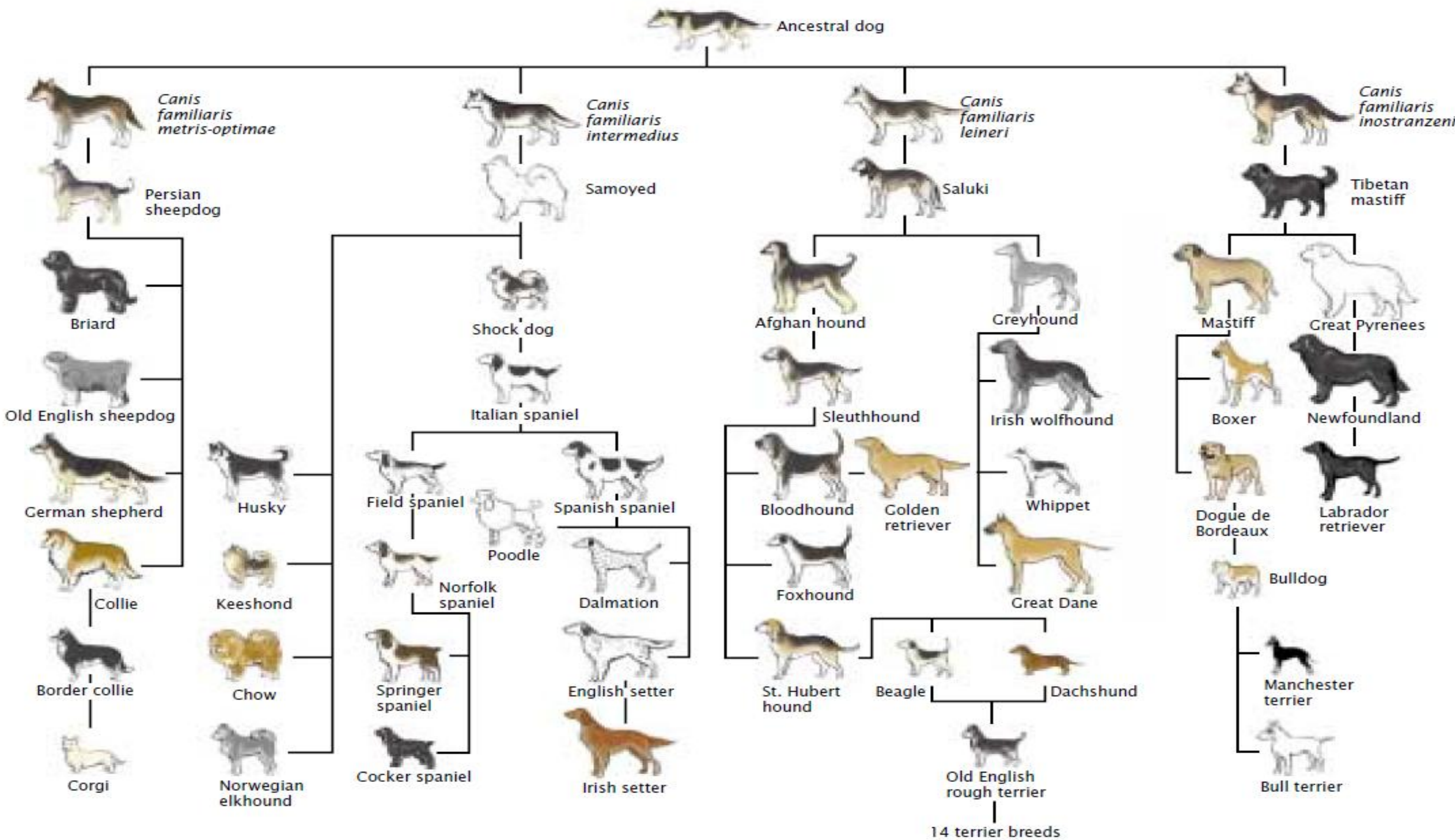
In a long-term response-to-selection experiment, selection for oil content in corn increased oil content in one line to about 20%, while almost eliminating it altogether in another line.



The response of a population to selection often levels off at some point in time. In a response-to-selection experiment for increased abdominal chaetae bristle number in female fruit flies, the number of bristles increased steadily for about 20 generations and then leveled off.

Selection for oil and protein content





Artificial selection has produced the tremendous diversity of shape, size, color, and behavior seen today among breeds of domestic dogs.

Exercise

* 1. How does a quantitative characteristic differ from a discontinuous characteristic?
2. Briefly explain why the relation between genotype and phenotype is frequently complex for quantitative characteristics.
* 3. Why do polygenic characteristics have many phenotypes?
* 4. Explain the relation between a population and a sample. What characteristics should a sample have to be representative of the population?
5. What information do the mean and variance provide about a distribution?
6. How is the standard deviation related to the variance?
* 7. What information does the correlation coefficient provide about the association between two variables?
8. What is regression? How is it used?

Exercise continued...

*10. List all the components that contribute to the phenotypic variance and define each component.

*11. How do the broad-sense and narrow-sense heritabilities differ?

12. Briefly outline some of the ways that heritability can be calculated.

13. Briefly discuss common misunderstandings or misapplications of the concept of heritability.

14. Briefly explain how genes affecting a polygenic characteristic are located with the use of QTL mapping.

*15. How is the response to selection related to the narrow-sense heritability and the selection differential? What information does the response to selection provide?

16. Why does the response to selection often level off after many generations of selection?

*17. What is the difference between phenotypic and genetic correlations?

Mating designs

Mating in breeding has two primary purposes:

1. To generate information for the breeder to understand the genetic control or behavior of the trait of interest.
2. To generate a base population to initiate a breeding program.

Hybrid crosses

- These are reviewed here to give the student a basis for comparison with the random mating schemes to be presented.

1. Single cross = A × B →F1 (AB)
2. Three–way cross = (A × B) →F1 × C →(ABC)
3. Backcross = (A × B) →F1 × A →(BC1)
4. Double cross = (A × B) →FAB; (C × D) → FCD; FAB × FCD→(ABCD)

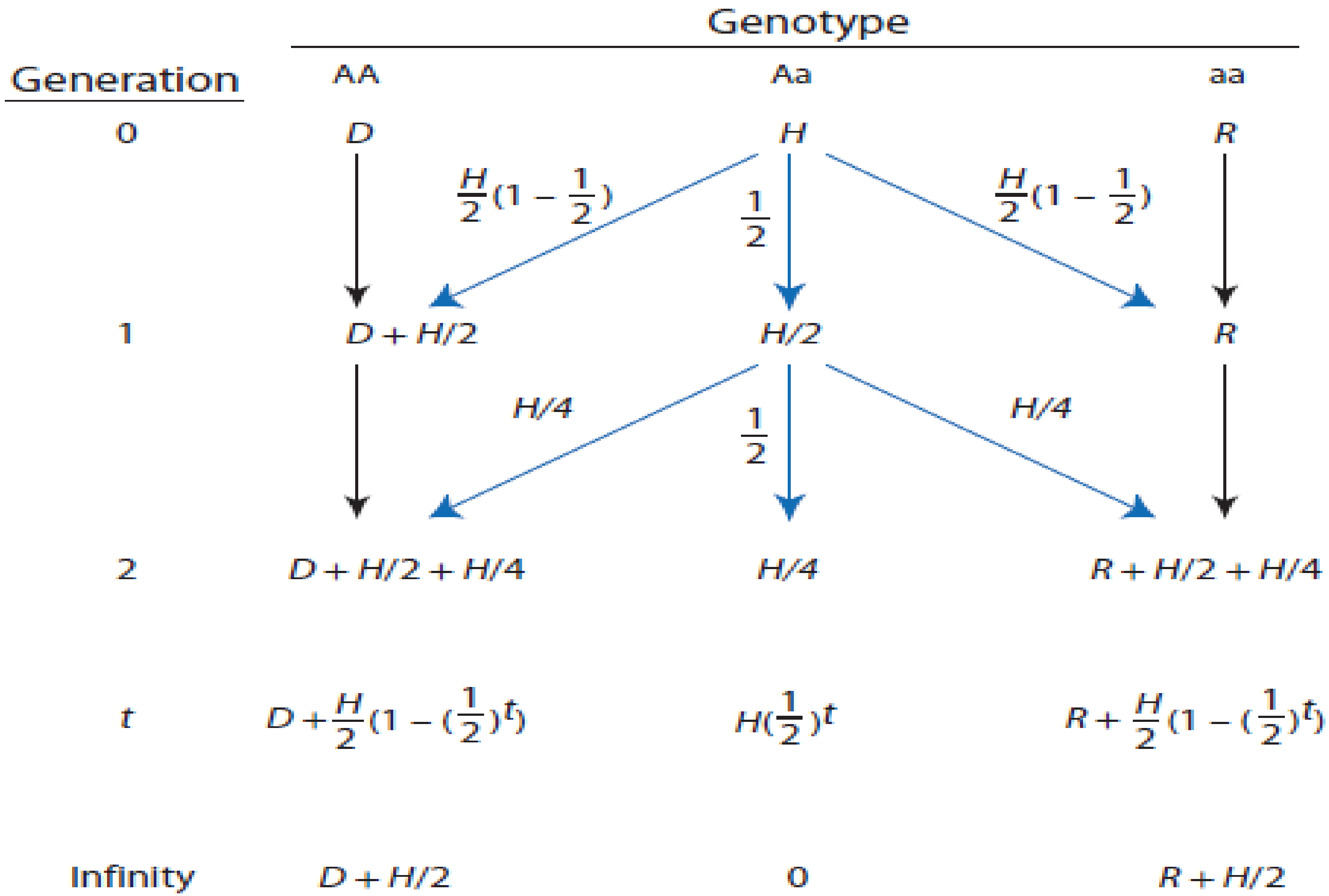
Inbreeding

This comes about in two ways:-

1) The systematic choice of relatives as mates and
2) Subdivision of the population where individuals have a narrower choice of mates and thus are forced to mate with relatives.

- ✓ An inbred individual is one whose parents are related, meaning that there is a common ancestry in the family tree.
- ✓ The most obvious effect of inbreeding is the expression of hidden recessives.
- ✓ Inbreeding often results in spontaneous abortions, fetal death, & congenital deformities.
- ✓ The inbreeding coefficient (F) can be defined as the probability that any two alleles at a locus are identical by descent.
- ✓ As the inbreeding coefficient increases, the heterozygosity (proportion of heterozygotes) decreases.

Impacts of repeated Selfing



Impact of Selfing Continued…

- The impact of complete positive genotypic assortative mating or self-fertilization on genotype frequencies.
- The initial genotype frequencies are represented by *D, H, and R.*
- *When either of the homozygotes* mates with an individual with the same genotype, all progeny bear their parent's homozygous genotype.
- When two heterozygote individuals mate, the expected genotype frequencies among the progeny are one half heterozygous genotypes and one quarter of each homozygous genotype.
- Every generation the frequency of the heterozygotes declines by one-half while one-quarter of the heterozygote frequency is added to the frequencies of each homozygote (diagonal arrows).
- Eventually, the population will lose all heterozygosity although allele frequencies will remain constant.
- Therefore, assortative mating or self-fertilization changes the packing of alleles in genotypes but not the allele frequencies themselves.

Table 2.11 A summary of the Mendelian basis of inbreeding depression under the dominance and overdominance hypotheses along with predicted patterns of inbreeding depression with continued consanguineous mating.

Hypothesis	Mendelian basis	Low-fitness genotypes	Changes in inbreeding depression with continued consanguineous mating
Dominance	Recessive and partly recessive deleterious alleles	Only homozygotes for deleterious recessive alleles	Purging of deleterious alleles that is increasingly effective as degree of recessiveness increases
Overdominance	Heterozygote advantage or heterosis	All homozygotes	No changes as long as consanguineous mating keeps heterozygosity low

Hybrid Vigor/Hetrosis

- Hybrid vigor may be defined as the increase in size, vigor, fertility, and overall productivity of a hybrid plant, over the midparent value (average performance of the two parents).
- It is calculated as the difference between the crossbred and inbred means.
- The *practical definition of* heterosis is hybrid vigor that greatly exceeds the better or higher parent in a cross.
- Heterosis occurs when two inbred lines of outbred species are crossed, as much as when crosses are made between pure lines of inbreeders.
- More frequently among cross-pollinated species than self-pollinated species

Genetic basis of heterosis

1. Dominance theory
2. Overdominance theory
3. Biometrics of heterosis

Heterosis The increase in performance, survival, and ability to reproduce of individuals possessing heterozygous loci (hybrid vigor); increase in the population average phenotype associated with increased heterozygosity.

Inbreeding depression The reduction in performance, survival, and ability to reproduce of individuals possessing homozygous loci; decrease in population average phenotype associated with consanguineous mating that increases homozygosity.

Mating designs for random mating populations

1. *Biparental mating (or paired crosses)*
2. *North Carolina Design I*
3. *North Carolina Design II*
4. *North Carolina Design III*
5. *Diallel cross*

Breeding vegetatively (clonally) propagated species

Clones, inbred lines, and pure lines

1 Pure lines.

- **Developed as cultivars** of self-pollinated crops for direct use by farmers.
- As products of repeated selfing of single plants, pure lines are homogeneous and homozygous and can be naturally maintained by selfing.

2 Inbred lines.

- These are genotypes that are developed to be used as parents in the production of hybrid cultivars and synthetic cultivars in the breeding of cross-pollinated species.
- They are not meant for direct release for use by farmers.
- They are homogenous and homozygous, just like pure lines.
- However, unlike pure lines, they need to be artificially maintained because they are produced by forced selfing (not natural selfing) of naturally cross-pollinated species.

3. Clones.

- Clones are identical copies of a genotype.
- Are phenotypically homogeneous.
- However, individually, they are highly heterozygous.
- Asexually or clonally propagated plants produce genetically identical progeny.

Concept of totipotency

- Each cell in a multicelluar organism is **totipotent (i.e., endowed with the full complement** of genes to direct the development of the cell into afull organism).

In vitro culture medium

Table 11.1 Murashige and Skoog (MS) medium salts.

Nutrient	Source
Nitrate	NH_4NO_3 KNO_3
Sulfate	$MgSO_4.7H_2O$ $MnSO_4.H_2O$ $ZnSO_4.7H_2O$ $CuSO_4.5H_2O$
Halide	$CaCl_2.H_2O$ KI $CoCl_2.6H_2O$
P, B, Mo	KH_2PO_4 H_3BO_3 Na_2MoO_4
NaFeEDTA	$FeSO_4.7H_2O$ NaEDTA

Micropropation

Is the *in vitro clonal propagation of plants.*

Micropropagation can be summarized in five general steps:

1. Selection of explant.
2. Initiation and aseptic culture establishment.
3. Proliferation of axillary shoots.
4. Rooting.
5. Transfer to the natural environment.

Other tissue culture applications

1. Synthetic seed
2. Production of virus-free plants

Production of haploids

Haploids may be produced by one of several methods:

1 Anther culture to induce androgenesis.

2 Ovary culture to induce gynogenesis.

3 Embryo rescue from wide crosses.

Breeding implications, advantages, and limitations of clonal propagation

Advantages

1 Sterility is not a factor in clonal propagation because seed is not involved.

2 Because clonal plants are homogeneous, the commercial product is uniform.

3 Micropropagation can be used to rapidly multiply planting material.

4 Heterozygosity and heterosis are fixed in clonal populations.

Disadvantages

1 Clonal propagules are often bulky to handle (e.g., stems, bulbs).

2 Clones are susceptible to devastation by an epidemic.

- Because all plants in the clonal population are identical, they are susceptible to the same strain of pathogen.

3 Clonal propagules are difficult to store for a long time because they are generally fresh and succulent materials.

Animal Breeding

What is Animal Breeding?

Animal breeding is the scientific application of genetic principles to the improvement of livestock populations.

It answers two fundamental questions:

1) What are the best animals?

2) How can we genetically improve populations?

- Best animal is a relative term– there is no best animal for all situation.
- We need to determine what *traits* are of primary importance and *phenotypes* and *genotypes* are most desirable for those traits.

The importance of traits depends on:

the physical environment under which animals are kept

- the management system
- the economic factors.
- E.g., Best preventive health program (management) depends on the kinds of pathogens in the area (physical environment) and the costs of vaccines, dewormers (economics)
- Knowledge of the function of the animal and the interactions between the genotype and other components of the system is necessary if we want to develop sensible goals for breeding programs (**breeding objectives**).

Population structure and breeding objective

- In the process of determining the best animal, you might ask, "Best for whom?" The answer to this question depends on
- the function of the animal
- the structure of the population

The role of the breeder within that structure

Populations have a pyramidal structure including:

a. **Breeders** (a relatively small number)
b. **Multipliers** (a larger number than breeders)
c. **End users** (the largest group in the pyramid) – on the base of the pyramid

How are animal populations improved?

- ***The purpose of animal breeding is not to genetically improve individual animals but to improve animal populations, to improve further generations of animals***.
- To achieve this, there are two basic tools.
- Selection is the first of basic tool to make genetic selection.
- The second tool is mating.
- **Selection** is the process of choosing parents to produce the next generation of animals.
- Selection process determines the genetic make-up of the population in the future.
- This process determines *which individuals become parents*, *how many offspring they may produce* and *how long they remain in the breeding population*.
- Two kinds of selection exist: *Artificial selection* and *Natural selection*

1. ***Natural Selection*** is a great natural evolutionary force that fuels genetic change in all living organisms.
2. ***Artificial Selection*** is the primary interest in animal breeding. During selection both individual performance and information on relatives is used.

Mating

- Is the process that determines which selected males are bred to which selected females.
- It is distinctly different from selection.
- In selection, you choose the group of animals you want to be parents; in mating, you match males and females from the selected group.

Technology and animal breeding

Over the years the face of animal breeding has changed from being controlled by few individuals to being run by large companies. Such changes have been catalyzed by major advances listed below.

1. The adoption of scientific principles to the breeding industry. Introduction of phenotypic measurements
2. Major developments from introduction of biotechnology. Introduction of reproductive and molecular technology. E.g., Artificial insemination, *in vitro* fertilization, embryo transfer, cloning of individuals and marker-assisted selection.
3. Rapid development in computer and information technology.Better data collection and genetic evaluation

Exercise

Briefly define the following terms or phrases.

1. Artificial insemination
2. *In vitro* fertilization
3. Embryo transfer
4. Cloning of individuals
5. Marker-assisted selection
6. *Mating*
7. *Selection*