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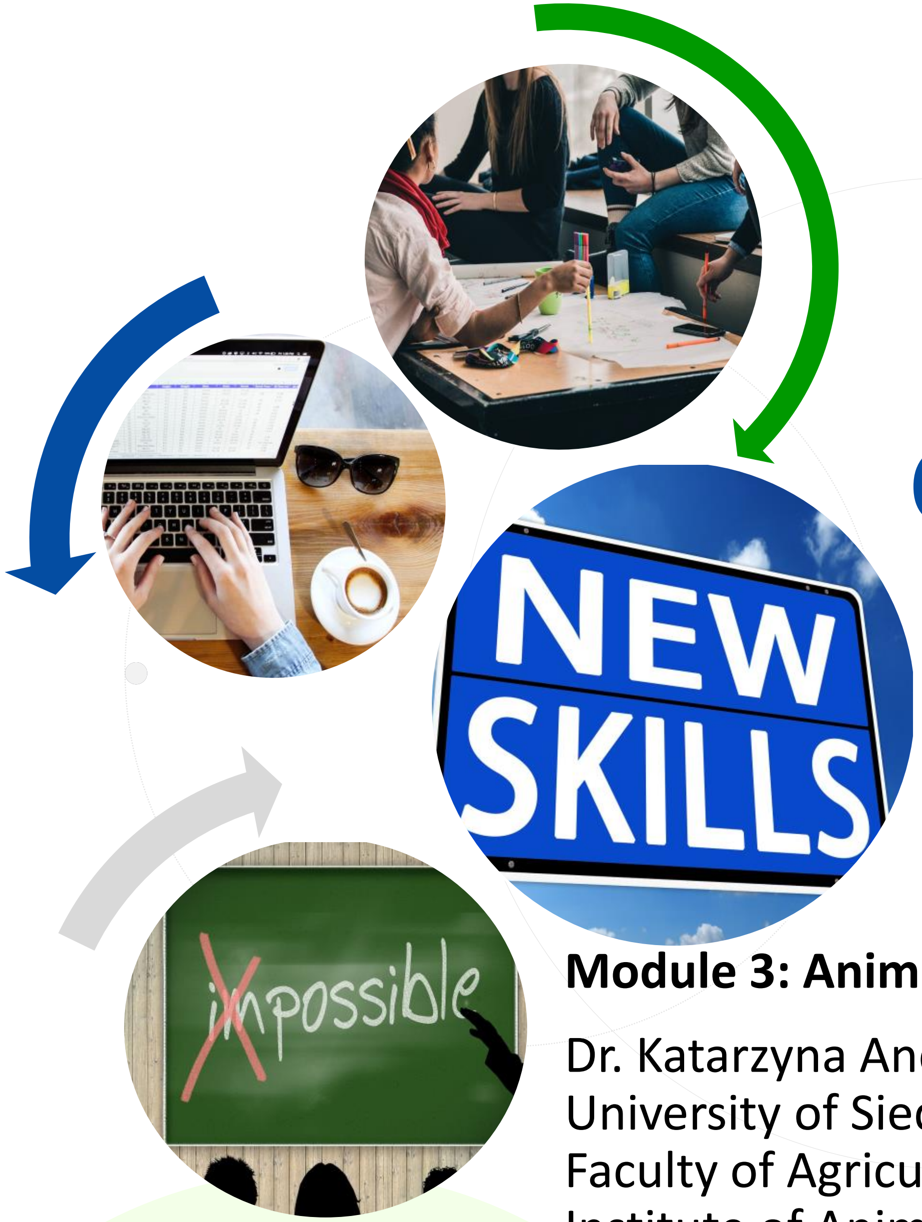

Crossbreeding effects

Module 3: Animal Breeding

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Crossbreeding is a system of mating involving the pairing of animals representing two (or more) genetically dissimilar groups. It is the opposite of inbreeding; however, in certain cases, inbreeding and crossbreeding can overlap and complement one another. The aims that can be achieved through crossbreeding are highly varied, and these are the basis for the division of this mating system into a whole range of different methods.

They can be broadly divided into two main groups, with these breeding goals as the criterion:

a) crossbreeding aimed at exploiting and adapting foreign genes in a herd or population

b) crossbreeding aimed at exploiting the phenomenon of heterosis, i.e. hybrid vigour

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- Crossbreeding
  - To exploit the heterosis effect
    - Crossbreeding of non-inbred individuals
      - Interbreeding
      - Crisscross
      - Rotational
    - Crossbreeding of inbred lines
      - Top crossing
      - Incrossbreeding
      - Incrossing
      - Recurrent selection
      - Reciprocal recurrent selection
  - To adapt foreign genes
    - Breed improvement
    - Upgrading
    - Breed creation

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Crossbreeding can increase production levels in two ways. Crossbreeding allows the breeder to combine the desired traits of two or more breeds to achieve higher overall performance of these traits in the crossbred animals than could be achieved within a given breed. This is often called the complementarity of breeds and refers to the strengths of one breed that complement or cover up the weaknesses of the other breed. The other way crossbreeding increases productivity involves improving the performance level of the desired traits through heterosis. Increased productivity may result from heterosis exhibited in the offspring of the crossbred animal.

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Breeders have long known that in the case of many traits, including performance traits, the value of crossbred animals surpasses that of both parent forms. This phenomenon, known as hybrid vigour, was later called ‘heterosis’ by the American geneticist Shull, expressing its association with the heterozygous state of the genotype.

Heterosis is manifested not only in increased levels of most economically important performance traits, such as milk yield in cattle, laying capacity in hens, and body weight in many species, but above all in an increase in the overall viability of crossbreds in comparison with the parent forms. This is the reason for the other name for heterosis — hybrid vigour.

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Crossbreeding methods aimed at exploiting and adapting foreign genes in a population

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This type of crossbreeding is not intended to obtain immediate, temporary heterosis effects, but to obtain a permanent effect in the form of improvement or correction of certain shortcomings in one breed by the other, to make a previously primitive breed more similar to another which is at a higher breeding level, or finally to create a new breed based on existing breeds.

It should be remembered that these actions must be accompanied by constant concern for improving environmental conditions. This is an essential condition for obtaining the intended breeding results.

Depending on these specific goals, we can distinguish several methods of crossbreeding animals of different breeds.

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Crossbreeding for breed improvement

This type of crossbreeding is used when a breed essentially meets the breeding and production requirements set for it, but has certain flaws that should be corrected. In this situation they can be corrected using individuals of another breed in which this trait is particularly well expressed. Since polygamy is commonly used in breeding, males from the improving breed, in which the target traits are well expressed, are usually selected.

Crossbreeding is usually performed once, using the 'halfbred' offspring for further mating and thus moving gradually further from the breed undergoing improvement.

Crossbreeding should be accompanied by rigorous selection because the point is not to change the previous breed type, but only to improve a specific trait using genes from a different population.

Crossbreeding for breed improvement is not necessarily done in primitive breeds, although that is its most common application, e.g. improvement of Polish Red cattle with Danish Red cattle. Breeds with a high level of breeding culture are also often forced to use the genes of other breeds. For example, many Western European dairy cattle breeds have had an 'infusion of blood' from Shorthorns to improve meat performance.

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Upgrading

Upgrading is used to make one breed more similar to another with higher performance value. A breed can be successfully improved if its performance level represents a certain value. If we are dealing with a primitive breed, a one-time 'infusion of blood' will be of little use. Upgrading will then be more effective. For this purpose, male breeders are eliminated from the breed and replaced with male breeders of the higher-value breed. The female crossbred animals obtained will again mate with males of that breed, and this will be repeated for several generations. After six generations of upgrading, the herd has 98.3% of the 'blood' of the upgrading breed and becomes similar to it. Subsequent breeding is usually carried out without further crossing, with selection for the most desired utility type.

This type of crossbreeding is the fastest and most efficient means of transforming low-performance breeds. Its success largely depends on the choice of upgrading breed, which must be well adapted to the local natural and environmental conditions.

Crossbreeding for breed creation

If none of the existing breeds is suited to the conditions of a given geographic and economic region, and the performance level of the local primitive breeds is unsatisfactory, we must resort to attempts to create a new breed, which will satisfy economic requirements and at the same time be well adapted to the existing environmental conditions.

The starting material for breed creation can be not only two breeds but very often more, depending on the required utility type and in some cases the general biological properties required of the future breed. The roles of individual breeds in the creation of a new one are not identical. Their use is dependent on the traits we wish to take from them. Thus there also cannot be any exact recipe for the formation of a new breed. Each instance is highly individual and depends on our ultimate goal and the conditions accompanying the process. An example of crossbreeding for breed creation is breeding work conducted in Poland on mountain sheep or longwool sheep. The Puławska pig breed and the autosexing chicken breed Polbar were also obtained in this manner.

The breed creation method must be accompanied by rigorous selection, in which individuals of the type most similar to the desired one are kept for further breeding. Following the crossbreeding period, there is often a need for inbreeding to more quickly establish favourable properties in the group of animals meant to constitute the start of the new breed.

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Crossbreeding methods aimed at exploiting the phenomenon of heterosis

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Crossbreeding of animals of different breeds aimed at achieving the heterosis effect in the first generation has been broadly termed commercial crossbreeding. The offspring of animals of different breeds has usually had better expressed performance traits than both parent forms. Heterosis is a temporary phenomenon which cannot be maintained due to segregation in the next generation. Thus in order to obtain a heterotic F_x generation, the initial parent forms must always be kept in pure breeding. Heterosis is not absolutely certain to appear in every case. Sometimes crossbreds manifest an intermediate phenotype, or less often, an even less favourable phenotype than that of the parents in terms of the traits that most interest the breeder. The search for the most efficient ways of mating has given rise to numerous commercial crossbreeding methods.

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Interbreeding of non-inbred individuals

This method involves mating of individuals belonging to two different breeds. Because this method was the first used to obtain heterotic commercial crossbreds, it is often referred to as commercial crossbreeding.

A serious disadvantage of this method is that the heterotic F1 generation cannot be used for further breeding, because heterosis is not manifested in subsequent generations, and the offspring, due to segregation of traits, becomes highly uneven. In the case of animals of naturally low prolificacy, practical application of the method is difficult, due to the need to maintain large herds of the parent breeds. Commercial crossbreeding is always easier to carry out in species that leave numerous offspring. These may include chickens or even pigs. However, this does not mean that this method cannot be used at all in cattle, which on average produce one offspring a year. Due to the increasing importance of meat performance in cattle and the generally low capacity for rapid growth and fattening in dairy breeds, cows of these breeds are increasingly mated with bulls of typical meat breeds. This type of mating is of course carried out only with females whose offspring is not expected to be reared for restocking of the herd. The benefits of this type of crossbreeding are obvious; the cows can continue to be used for milk, while their offspring, which as crossbreds sired by a male of a meat breed have good growth properties, are used for rapid fattening.

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Crisscross

Crossbreeding in which the crossbred animals must continually be obtained from "pure" parent breeds is difficult in practice and moreover not always profitable, because these animals are not used for breeding to obtain offspring for restocking the herd. Crisscrossing involves continual backcrossing of crossbred animals with one parent breed and then the other. This method is not limited to the maintenance of crossbreds for production purposes. The females are also used for breeding, which to some extent eliminates the shortcomings of the previous method.

The heterozygosity of crossbred animals obtained from backcrossing changes slightly from generation to generation and never attains a value for the trait as high as that of the F_1 generation obtained from the crossing of two breeds. Theoretically, heterosis of subsequent generations should be about 2/3 of the heterosis of the first generation. This is approximately confirmed by practical results, achieved mainly in pig breeding.

This method in practice may be somewhat less efficient in terms of the performance of the crossbred animals, but in the end is highly profitable, as there is no need to maintain two herds of pure breeds. For this purpose it is sufficient to have an adequate number of males of both parent breeds, while the female material will be selected crossbreds.

Rotational crossbreeding

Rotational crossbreeding differs from crisscross in the number of starting breeds. It is usually three instead of two, but theoretically four or five breeds could be used in rotational crossbreeding. As in crisscross breeding, once the first-generation crossbreds have been obtained from two breeds, they become the female material for further breeding, to be mated successively with purebred males.

However, as with all crossbreeding, here too it must be borne in mind that heterosis may not be manifested in every case. Therefore before implementing this method in systematic mating, trial crossbreeding should be carried out to determine whether the crossing of specific breeds will have the intended results. If the results are encouraging, crossbreeding can be initiated in the entire population, preferably involving cooperation among breeders of several herds. This enables a rotational exchange of males between herds, and thus reduces maintenance costs and contributes to better use of these males.

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Crossing of inbred lines within and between breeds

The phenomenon of heterosis is the result of heterozygosity of the genotype. Signs of hybrid vigour in crossbreds were recognized before the theoretical explanation for the phenomenon was found. However, when it was concluded from a great number of observations that heterosis appears as a consequence of heterozygosity in crossbred animals, the search began for the most effective mating methods for maximizing heterozygosity.

Inbreeding makes the lines it is used in genetically uniform, and at the same time makes unrelated lines more distant from one another. This realization led to the development of many new mating methods aimed at achieving heterosis. The common feature of these methods is crossbreeding of inbred animals.

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Top crossing

Top crossing involves crossbreeding of inbred individuals (usually males) with non-inbred animals. Top crossing can also be carried out between breeds (top-crossbreeding) when the males of one of the breeds used for mating are inbred, while the females of the other breed are not. This type of mating may also be used in the crisscross and rotational crossbreeding methods. Top crossing based on inbred male material can be applied in all livestock species. The results depend on the right choice of inbred line from which the male for crossbreeding is taken.

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Crossing of inbred lines of different breeds (incrossbreeding)

This type of crossbreeding involves mating individuals of different breeds in which the animals used for crossbreeding come from inbred lines. This system is most popular in chicken breeding. Many experiments have shown that this method is highly efficient. In addition to one-time crossbreeding of two breeds or lines, crossbreeding can also be applied twice, when the starting material consists of four breeds. If we designate them A, B, C and D, to obtain heterotic Fx crossbreds we initially mate animals from breeds or lines A and B and from breeds or lines C and D. To maintain hybrid vigour in the next generation of crossbreds, crosses between A and B and between C and D can be crossed with one another, to obtain four-breed (or four-line) crosses.

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Crossing of inbred lines within a breed (incrossing)

This is a variant of the previous method. The difference is that it involves crossing of inbred individuals from inbred lines which may differ significantly genetically due to inbreeding. The choice of lines for crossbreeding may be preceded by trial mating in order to find those best suited to one another in terms of the heterosis obtained in the generation of crossbreds.

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Recurrent selection for the heterosis effect

Crossbreeding of inbred lines is costly, and moreover there is always a risk that it will not achieve its aims, i.e. a degree of heterosis that would more than cover the costs of breeding inbred lines. The search for new methods of obtaining heterotic crossbred animals with smaller expenditures and lower risk led to the method of recurrent selection.

In this method the initial heterozygous herd is crossed in a trial with a strongly inbred line. A thorough evaluation of the offspring is carried out to identify the pairings that have yielded the best results, i.e. the highest heterosis in the offspring. The animals from the heterozygous herd that produced the best results in crossbreeding with inbred individuals are now used for breeding within their own herd.

Selection for the heterosis effect is carried out from generation to generation until the most favourable results of crossbreeding with the inbred line are obtained. This line, which can be referred to as the test herd, serves the purpose of evaluation of both female and male material in mating with the heterozygous herd, as the crossbreds in this method are not breeding material but serve only as a test for their father or mother from the herd under evaluation.

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Reciprocal recurrent selection for the heterosis effect

This is a modification of the previous method. Through trial pairings resulting in a selection criterion within herds, it also aims to at obtain herds that are optimally suited for the production of heterotic crossbreds. In contrast to rotational selection, this method involves trial crossbreeding not of one inbred test herd, but of two outbred herds, which are thus highly heterozygous.

This method is very interesting because of its genetic consequences. Selection for the suitability of both herds for the production of heterotic crossbreds results in gradual uniformity within each of them. This limitation of variation has a positive effect on the genotype of the individual from the other herd. If we accept the theory of superdominanse as a correct explanation of the heterosis phenomenon, then theoretically the genotypes of both herds should best complement one another when all genetic loci in which superdominance is manifested are homozygous.

This means that this method leads to an increase in homozygosity in the herd. While in the case of inbreeding the homozygosity of individual genetic loci is established randomly, in the case of reciprocal recurrent selection, homozygosity is established for genes whose effect is most beneficial in crossbreeding with a given herd.

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Genetic consequences of crossbreeding

The genetic consequences of crossbreeding are the opposite of the genetic consequences of inbreeding. Inbreeding causes depression, with a reduced reproduction rate, reduced viability of offspring, a reduced growth rate, and delayed sexual maturity. Generally speaking, the traits that exhibit the greatest inbreeding depression are the same traits that exhibit the greatest heterosis in crossbreeding.

There are two fundamental genetic requirements for a trait to show heterosis: there must be genetic diversity between the breeds that are crossed, and certain non-additive gene effects must occur for a given trait. If either of these conditions is not met for a given trait in a given cross, the trait will not exhibit heterosis. In this case, the expected results in the offspring will simply be the average of the performance levels of each of the purebred parents. In the case of traits expressing heterosis, the level of heterosis will depend on the degree of genetic diversity between the two parent breeds.

Genetic diversity refers to the degree of genetic similarity or difference between two breeds. Breeds of similar origin and subjected to similar selection pressure during their development are expected to be genetically much more similar than breeds having completely different origins and selected for different purposes during their development.

Non-additive gene effects refer to the effect of genes belonging to different pairs of alleles involved in the expression of a given trait. These effects can be divided into two categories: non-additive gene effects which are expressed in individual pairs of genes (due to the level of dominance) and non-additive gene effects which occur as the result of interactions between genes belonging to different pairs of alleles (epistasis).

The epistatic effect of genes involves combinations of genes at one locus interacting with the effects of combinations of genes at other loci. There are many different types of epistatic effects, but their relative influence is very difficult to measure due to their complexity. It seems doubtful that these epistatic effects are the main reason for heterosis in the case of most traits.

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Crossbreeding is conducted in order to achieve certain goals. These include obtaining the heterosis effect, the ability to rapidly incorporate desired genetic material in breeding, and the possibility of combining several beneficial traits in animal breeding. Heterosis (hybrid vigour), is associated with maximum heterozygosity of the genotype. A wide variety of methods for obtaining heterotic crossbreds have been created. Many of them are based on initial inbreeding followed by crossbreeding of inbred animals with one another. The potential applications of various crossbreeding methods largely depend on the prolificacy of the species.

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The combination of complementarity between the strains or breeds crossed and the added impact of heterosis makes crossbreeding a very important breeding system for commercial production systems.

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Examples

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Example 1

Assume two inbred lines with the following genotypes are crossed:

Line A – aaBBccDDEE

Line B – AAbbCCddee

Will heterosis then appear in the F1 generation, if we assume that every dominant gene has a more beneficial effect than the alternative recessive gene?

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Line 1 Line 2

aaBBccDDEE x AAbbCCddee

AaBbCcDdEe

The value of the trait in the F1 generation will exceed that of the parents from both line 1 and line 2.

The phenomenon of heterosis occurred.

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Example 2

Give an example of rotational crossbreeding using three chicken breeds. Describe the share of each genotype in the fourth generation.

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100% 100%
A x B

F1
50% 50% 100%
A B x C

F2
25% 25% 50% 100%
A B C x A

F3
12,5% 12,5% 25% 50% 100%
A B C A x B

F4
6,25% 6,25% 12,5% 25% 50%
A B C A B

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Example 3

The average weight of the litter at the age of 21 days was 45 kg for breed A and 47.5 kg for breed B, whereas for the F1 generation obtained by crossing breeds A and B, it was 51 kg. Calculate the effect of heterosis.

$$EH = \frac{(F-R)}{R} * 100$$

EH – effect of heterosis

F – average phenotypic value of trait in crossbreds

R – average phenotypic value of trait in parents

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$$EH = \frac{(F-R)}{R} * 100$$

F = 51

R = (45 + 47,5)/2 = 46,25

$$EH = \frac{(51-46,25)}{46,25} * 100 = 0,103 * 100 = 10,27$$

The heterosis value is approximately 10%.

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Thank you for your attention!

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