Heterosis, inbreeding depression

Modul no. 3: Animal Breeding

Katarzyna Andraszek, Ph.D. University Professor

Siedlce University of Natural Sciences and Humanities,
Faculty of Agrobioengineering and Animal Husbandry
Institute of Animal Science and Fisheries

Erasmus+ project 2021-1-SK01-KA220-HED-000032068

Co-funded by the European Union

Heterosis means hybrid vigour – increased viability and vigour of animals and plants derived by crossbreeding genetically different forms.

Heterosis is the opposite of **inbreeding depression** and is manifested as an increase in fertility, body size, growth rate, and other traits caused by higher heterozygosity in F1 individuals obtained by crossing two different homozygous lines.

The phenomenon of heterosis is widely exploited in plant and animal breeding.

ISAGREED
Co-funded by the European Union

ISAGREED

To obtain heterozygous individuals and the effect of heterosis, it is necessary to mate individuals from lines that are as homozygous as possible and therefore at high risk of inbreeding depression.

The effect of heterosis is best seen when inbreeding depression previously occurs but is not so severe that it greatly reduces the viability or fertility of animals.

ISAGREED

Co-funded by the European Union

ISAGREED

Individuals of the F_1 generation will have values of traits (including productivity) at a level represented by the pure parent line with the higher value for the trait.

The effect of heterosis will occur only in the first generation obtained by crossing the parent lines.

The successive F_2, F_3, ... F_n generations will have normal parameters of traits and will not exhibit the hybrid vigour effect.

ISAGREED

The genetic background of heterosis is explained by two hypotheses.

ISAGREED
Co-funded by the European Union

The **overdominance hypothesis** assumes that the combination of two opposing alleles at a given locus in the heterozygote has a greater, more beneficial effect than the two identical alleles in the homozygote; for example, heterozygous individuals (Aa) are resistant to more parasites than homozygous individuals (AA or aa). In heterozygous individuals, both allelic forms (dominant and recessive) of the gene are expressed, so that the effects of their expression overlap, ultimately resulting in a higher value for the trait.

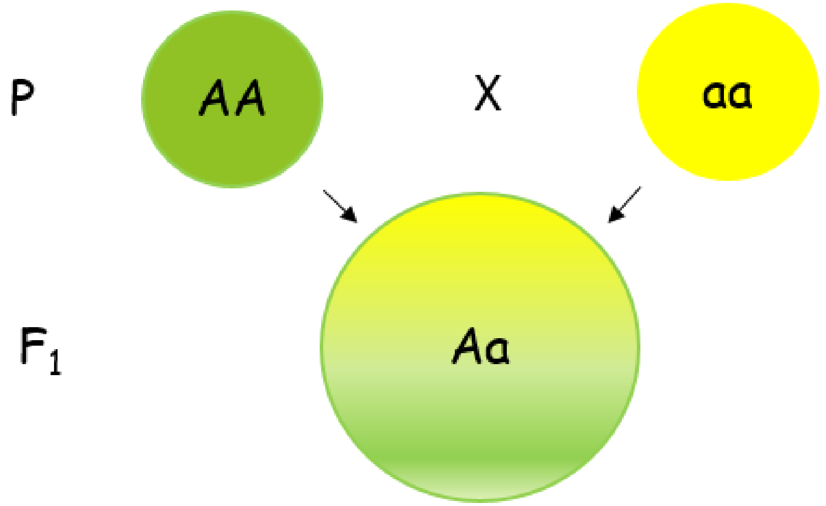

Fig. 1. Effect of enhanced gene expression in individuals of the F1 generation.
The size of the oval illustrates the value of the trait in individuals of a given group.

The **dominance hypothesis** assumes that the deleterious effect of recessive alleles is manifested to a lesser extent in heterozygous individuals than in recessive homozygotes.

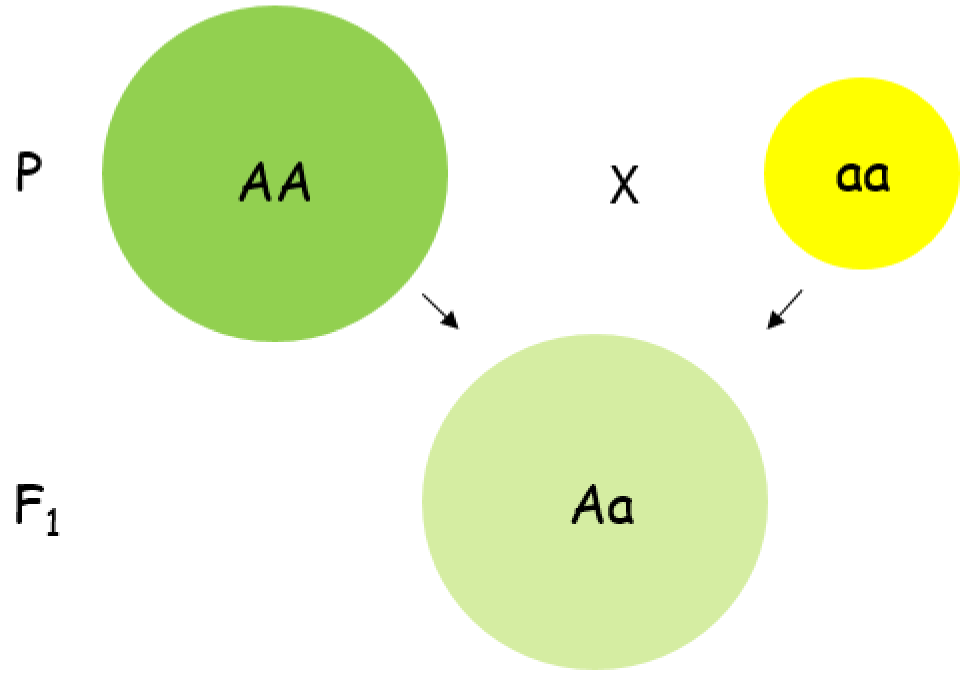

Fig 2. The deleterious effect of the recessive allele.
The size of the oval illustrates the value of the trait in individuals of a given group.

Erasmus+ project 2021-1-SK01-KA220-HED-000032068
ISAGREED
Co-funded by the European Union

The two hypotheses have different consequences in gene expression.

If the main cause of heterosis is overdominance, then certain genes should be overexpressed in the offspring relative to the parents, due to the overlapping of the effects of the two alleles.

In contrast, if it is the other hypothesis that explains the better condition of crossbreds, then fewer genes with low expression should be manifested in the offspring in comparison with the parents, which are recessive homozygotes. In addition, for each allele the expression should be comparable to that observed in the superior parent.

ISAGREED

The heterosis effect is often exploited in plant breeding. Special parent lines are often bred in order to obtain hybrids that will be more productive. An example of exploitation of heterosis which is very widespread in plant breeding is maize grown for grain.

ISAGREED
Co-funded by the European Union

ISAGREED

Examples of the effects of heterosis in animal breeding

ISAGREED
Co-funded by the European Union

ISAGREED

In cattle, Aberdeen Angus x Hereford crossbreds, known as „Black Baldy”, which are very popular in North America, Australia and New Zealand, have higher values for meat traits. In addition, this cross is used in heifers in order to obtain calves of smaller size and thus reduce the risk of complications during delivery, which are characteristic of Herefords. „Black Baldy” cows also have very good maternal characteristics.

Co-funded by the European Union

ISAGREED

In pigs, an example is Hampshire x Yorkshire crossbreds, known as „Blue Butts".

In poultry, the two breeds White Rocks x White Cornish are crossed to obtain commercial broilers. The crossbreds inherit greater body size from the White Cornish breed, and greater daily weight gains from White Rocks.

ISAGREED

Estimation of the effects of heterosis

The effect of heterosis and its magnitude can be defined as:

- the percentage increase in the value of a trait relative to the parent population with the better value for the trait,
- the percentage increase in the value of heterozygotes relative to the average for one parent population or the average value for both parent populations,
- the percentage increase in the value of a trait in the F1 generation relative to the best value observed in commercial cultivation in a given region (used for plants).

ISAGREED
Co-funded by the European Union

The effect of heterosis can be estimated by comparing the values of the parent populations and the populations resulting from crossbreeding.

If the value of the trait in parent line A (μ_A) is

$$\mu_A = \mu + a_A + m_A$$

where: μ – average value of the trait in the population; a_A – effect of direct genetic factors (breeding value); m_A – maternal genetic effect,

and the value of the trait in parent population B (μ_B) is

$$\mu_B = \mu + a_B + m_B$$

where: μ - average value of the trait in the population; a_B – effect of direct genetic factors (breeding value); m_B – paternal genetic effect,

ISAGREED

Co-funded by the European Union

then the value of the trait in the F_1 generation obtained by mating line A females with line B males will be:

$$\mu_{AB} = \mu + \frac{(a_A + a_B)}{2} + m_A + h_{AB}$$

whereas the value obtained by mating of males from line B with females from line A will be:

$$\mu_{BA} = \mu + \frac{(a_A + a_B)}{2} + m_B + h_{AB}$$

where: h_{AB} – effect of heterosis (expressed in the units used for a given trait).

Based on these assumptions, the effect of heterosis can be estimated according to the following formula:

$$h_{AB} = \frac{(\mu_{AB} + \mu_{BA})}{2} - \frac{(\mu_A + \mu_B)}{2}$$

ISAGREED

ISAGREED

Co-funded by the European Union

Sometimes, however, crossing of inbred parent lines does not result in heterosis, and the crossbred offspring has the same trait values as the parents, or inferior values.

This phenomenon is called outbreeding depression. It affects wild animal populations more often than farmed animals and is most likely linked to the fact that the parent populations are better adapted as a result of long-term selection for specific environmental conditions, manifesting the best values of the traits.

Heterozygous offspring, on the other hand, lose these abilities through 'mixing' of the effects of the alleles. This may also be linked to insufficient genetic distance between the parent populations, so that heterosis does not appear in the offspring.

Erasmus+ project 2021-1-SK01-KA220-HED-000032068
Co-funded by the European Union

Inbreeding depression is one of the main factors reducing the adaptive capacity of inbred organisms and their viability in comparison to non-inbred individuals, significantly increasing the risk of, or ultimately causing, the extinction of a population, especially a small one. Inbreeding depression may appear in a population in which inbreeding takes place as a consequence of the increased homozygosity resulting from this type of mating.

Erasmus+ project 2021-1-SK01-KA220-HED-000032068

ISAGREED

Co-funded by the European Union

ISAGREED

Different alleles have effects of varying strength on the body – on traits determining adaptation to environmental conditions, which are crucial for the functioning of the body and its survival. Deleterious alleles are eliminated from the population by natural selection.

The problem of inbreeding depression rarely affects large populations because the effects of deleterious genes are seldom manifested, especially when mating is random.

However, it plays an important role in small populations, in which there is a high probability of inbreeding and of two copies of the same deleterious allele being passed on to the offspring, in which its effect is manifested.

Co-funded by the European Union

ISAGREED

If the frequency of recessive homozygotes in a population in which random mating takes place is q^2, then in an inbred population the frequency will be q^2+pqF, where F is the inbreeding coefficient. This has a significant impact on the incidence of diseases or deleterious traits in the population.

In the case of random mating, if the frequency of a recessive allele is 0.01, then the frequency of a homozygous recessive genotype, e.g. associated with a genetic disease, will be 0.0001.

However, if mating takes place between individuals with an inbreeding coefficient of 0.0625 (i.e. their parents were siblings, so they are first cousins), then the frequency increases more than sevenfold to 0.00072.

ISAGREED

Co-funded by the European Union

ISAGREED

Inbreeding depression is estimated for various populations of farm animals because it affects productivity traits (usually unfavourably).

Inbreeding depression is mainly expressed in the form of a regression coefficient defining by how much, on average, the value of the trait will change when the inbreeding coefficient changes by 1% (or 10%).

The change can also be expressed as a percentage of the average value for the trait in the analysed population.

The value of the inbreeding coefficient at which the value of the trait changes drastically is determined as well.

Co-funded by the European Union

ISAGREED

Heterosis

Caused by multiple mutations with small effects; due to chance (genetic drift), many such mutations may have high frequencies.

Inbreeding depression

Caused by single, rare mutations with large effects.

Co-funded by the European Union

I S A G R E E D

Partners:

Slovak University of Agriculture Nitra

Mendel University in Brno

Siedlce University of Natural Sciences and Humanities

Czech University of Life Sciences Prague

Thank you for your attention!

This presentation has been supported by the Erasmus+ KA2 Cooperation Partnerships grant no. ***2021-1-SK01-KA220-HED-000032068 "Innovation of the structure and content of study programs in the field of animal genetic and food resources management with the use of digitalisation - Inovácia obsahu a štruktúry študijných programov v oblasti manažmentu živočíšnych genetických a potravinových zdrojov s využitím digitalizácie"****. The European Commission support for the production of this presentation does not constitute an endorsement of the contents which reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.*

Katarzyna Andraszek

katarzyna.andraszek@uph.edu.pl

ISAGREED

Co-funded by the European Union