

Beef Cattle Handbook



BCH-1400

Product of Extension Beef Cattle Resource Committee

The Genetic Principles of Crossbreeding

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Crossbreeding is the mating of two individuals with different breed makeups. It is widely used in commercial beef production because of the benefits it has to offer cow-calf producers. Improvements in efficiency can be dramatic if appropriate breed combinations are used. Crossbreeding does not eliminate the need for outstanding purebred cattle since efficient systems require well characterized, superior purebred cattle. Crossbreeding in beef cattle did not receive widespread approval until the last few decades; however, a large percentage of commercial cattle today are crossbred.

Crossbreeding is one type of a larger class of mating systems called outbreeding. Outbreeding has the opposite effect of inbreeding and is defined as the mating of relatively unrelated individuals. Other forms of outbreeding include: 1) linecrossing, which is the mating of members of different families within a breed, 2) grading-up, which is mating the sires of a given breed to females of a particular breed and their female progeny each generation, in order to propagate the breed of interest, and 3) hybridization, which is the mating of individuals of different species.

Crossbreeding is beneficial for two primary reasons. First, a well-designed crossbreeding system allows the producer to combine the desirable characteristics of the breeds involved in the cross while masking some of the disadvantages of the breeds. This is frequently referred to as breed complementarity. The second benefit arises from heterosis, which often is referred to as hybrid vigor. In addition to these primary benefits, crossbreeding also enables a producer to change a herd rapidly with the introduction of new breeds.

Heterosis Defined

Heterosis is a measure of the superior performance of the crossbred relative to the average of the purebreds involved in the cross. The probable cause of most heterosis is due to combining genes from different breeds, concealing the effects of inferior genes. Heterosis may result in the crossbred being better than either parental breed or simply better than the average of the two. For example, an Angus x Hereford crossbred calf may generally grow faster than either Angus or Hereford purebreds. However, a Charolais x Angus crossbred calf may not grow as fast as a purebred Charolais or have the ability to marble similar to purebred Angus but will likely be better than the average of the purebreds for both traits.

This difference is usually expressed as a percentage of the average performance of the purebreds. The general formula for calculating percent heterosis is given below:

$$\% \text{ heterosis} = \frac{\text{crossbred avg.} - \text{purebred avg.}}{\text{purebred avg.}} \times 100$$

Example 1 illustrates the calculation of the percentage of heterosis. Average breed performance for weaning weight is given for two arbitrary breeds. In this example, the heterosis value of 4.4% means that the crossbred progeny performance is 4.4% greater than the average parental breed performance.

Example 1. Heterosis for Weaning Weight

Breed A: 455 lb.

Breed B: 445 lb.

Purebred Average = $(455+445)/2 = 450$ lb.

Crossbred Average = 470 lb.

$$\% \text{ heterosis} = \frac{470-450}{450} \times 100 = 4.4\%$$

Types of Heterosis

Heterosis arises from three mating situations. Individual heterosis is the advantage of the crossbred individual relative to the average of the purebred individuals. For example, a Limousin x Hereford calf may grow faster than the average of purebred Limousin and Hereford. Maternal heterosis is the advantage of the crossbred mother over the average of purebred mothers. For example a Hereford x Angus cow is generally a better mother (higher weaning %, milk production, etc.) than the average of purebred Hereford and Angus dams. Paternal heterosis is the advantage of a crossbred sire over the average of purebred sires. Paternal heterosis generally has an effect only on conception rate and aspects of male reproduction. The male parent does not have any direct environmental effect on the survival of the calf, so the benefits are more limited than those for maternal heterosis. However, the benefit in added conception rate can be substantial, particularly if young males are being used.

Numerous experiments have been conducted to investigate the effects of crossbreeding in cattle. These experiments yielded estimates of heterosis as well as comparisons among the breeds involved. Table 1 summarizes results on the percentage of heterosis for various traits based on research from several locations. Heterosis may be a positive or negative value. Also, heterosis may be positive even when one of the parent breeds outperforms the crossbred average.

Heterosis values (Table 1) have been derived largely from experiments involving British and/or European breeds. Note that British crosses with Brahman and other Bos Indicus breed types may result in more heterosis due to less genetic similarity between breeds.

Not all traits express the same degree of heterosis. Heterosis levels can be grouped into three major classes. Reproductive traits generally show fairly high levels of heterosis. Growth traits generally have moderate levels of heterosis while carcass traits infrequently display much heterosis. There are exceptions to these generalities but the three classes work as a general rule of thumb. It should be pointed out that this is exactly the reverse of the general levels of heritability for these classes of traits. For example, carcass traits show low levels of heterosis; however, these traits tend to be high-

Table 1. Heterosis in Beef Cattle

Trait	Heterosis (%)	
	Individual	Maternal
Calving %	3.4	6.6
Calf survival	1.7	2.0
Birth weight	2.7	1.6
Calving difficulty	2.0 ^a	0 ^a
Milk production	-	9.0 ^a
Cow lifetime productivity	-	25.0 ^a
Weaning weight	4.7	4.2
Postweaning ADG (feedlot)	3.9	-1.4
Postweaning ADG (pasture)	6.4	-
Yearling weight (feedlot)	3.8	2.9
Yearling weight (pasture)	4.5	-
Loin eye area	2.8	-
Fat thickness	2.3	-
Quality grade	.7	-
Dressing %	.6	-
Cutability %	.6	-

Long, C.R. 1980. Crossbreeding for beef production. *J. Anim. Sci.* 51:1197

^a Kress, D.D. and T.C. Nelson. 1988. Crossbreeding beef cattle for western range environments. *Nev Agri Exp Sta.* TB-88-1

ly heritable. Also, traits that express the higher levels of heterosis tend to be those traits that are more highly influenced by inbreeding. This should make sense as heritability depends upon additive types of gene action while heterosis and inbreeding depression depend upon non-additive gene action such as dominance and epistasis. Heterosis also requires genetic differences among individuals involved in the crosses.

Genetic Basis of Heterosis

The genetic basis of heterosis is the opposite of the origin of inbreeding depression. Inbreeding tends to cause more gene pairs in an individual to be homozygous (the offspring receives an identical gene from each parent). In contrast, crossbreeding tends to cause more gene pairs to be heterozygous (the offspring receives different genes from its parents). This arises from the fact that different breeds tend to have high frequencies of different genes. Breeds that are genetically very different would tend to cause more heterozygosity and, as a result, more heterosis when crossed. Heterozygosity will result in better performance if there is non-additive gene action (dominance and epistasis) and the recessive allele results in inferior performance. Dominance is present if the heterozygous individual is not exactly intermediate between the two homozygotes. This would be analogous to the dominance relationship that results in the offspring of a mating between a black bull and a red cow being black, with the red masked. Various types of dominance are illustrated in Figure 1. Epistasis may also play a part in heterosis. Epistasis is the interaction between different loci. A qualitative example of epistasis would be

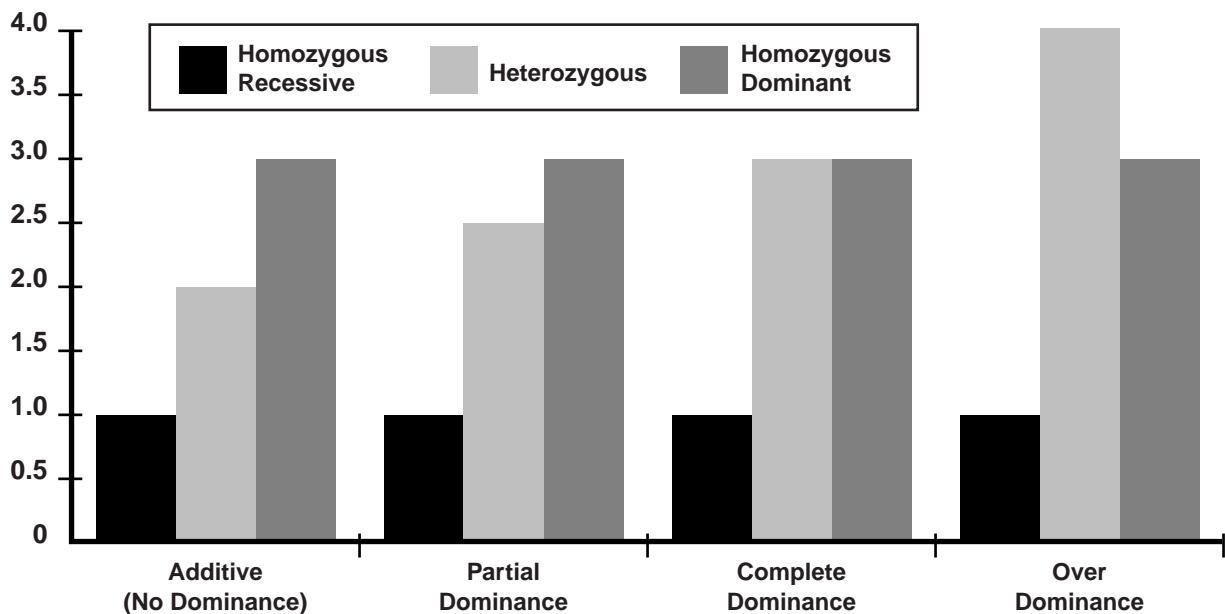


Figure 1. Types of Dominance

the relationship between scurs and horns. If an individual is homozygous for the horned condition, it is horned, regardless of any presence or absence of the scur gene. The gene location (locus) that affects scurs can only express itself in an individual that has at least one polled gene at the locus that affects horns.

The evidence for the relative importance of dominance and epistasis in beef cattle heterosis is not conclusive, but studies have shown dominance to be the major factor for many traits.

Use of Heterosis Figures

Heterosis levels are presented as percentage values so they can be used to calculate the expected performance of the crossbred individuals. The first step calculates the average expected performance of the purebreds. This can be accomplished, simplistically, by multiplying each breed value by the proportion it contributes to the cross:

Two-Breed Cross: Hereford x Angus

$$\text{Expected crossbred performance} = \frac{1}{2} H + \frac{1}{2} A + \text{heterosis}$$

The heterosis to be added into a two-breed cross is individual heterosis. This is accomplished by multiplying the purebred average by the % heterosis and adding it to the average of the breeds. If the dam is also crossbred, the maternal heterosis would have to be included, in the same manner as the individual heterosis. Example 2 shows the procedures involved.

Example 2. Calculating Expected Weaning Weight of Crossbred Calves

Individual Heterosis: 4.7 %
Maternal Heterosis: 4.2 %

Two Breed Cross (purebred A sire x purebred B dam)

Breed A: 460 lb
Breed B: 480 lb
Purebred Average = $\frac{1}{2} (460) + \frac{1}{2} (480) = 470$ lb
Individual Heterosis = $.047(470) = 22.09$ lb

Expected Crossbred Average = Purebred Average + Individual Heterosis

$$\text{Expected Crossbred Performance} = 470 + 22.09 = 492.09 \text{ lb.}$$

Three-Breed Cross (purebred C sire x crossbred AB dam)

Breed C: 500 lb.
Purebred Avg. = $\frac{1}{2} (500) + \frac{1}{2} (460) + \frac{1}{2} (480) = 485$ lb.
Expected Crossbred Avg = Purebred Avg + Individual Heterosis + Maternal Heterosis

$$\text{Individual Heterosis} = .047 (485) = 22.80 \text{ lb.}$$

$$485 + 22.80 = 507.80 \text{ lb.}$$

$$\text{Maternal Heterosis} = .042 (507.80) = 21.33 \text{ lb.}$$

$$\text{Expected Crossbred Performance} = 507.8 + 21.33 = 529.13 \text{ lb.}$$

This simple example assumed that cattle from the three breeds perform equally well as sires or dams. In other words, this case assumed no breed complementarity. This assumption makes the calculations simple but is not very useful in practical situations. For example, it is well established that a Charolais sire x Angus dam cross will perform differently than an Angus sire x Charolais dam cross. It is necessary to calculate expected performance such that the relative merit of the breeds as dams is taken into account. Substantial differences exist between breeds in reproductive performance and in mothering ability.

To include maternal differences between breeds, each breed will be assigned two values. The first value will be for its contribution of genes to the offspring (direct breed value). The second value will be for any superiority or inferiority as a dam (maternal breed value). The expected performance will then take on the following general form (with the general purebred mean representing the average performance of all the considered breeds when used as purebreds):

- Expected performance = General Purebred Mean
- + ½ sire breed direct value
- + ½ dam breed direct value
- + dam breed maternal value
- + individual heterosis
- + maternal heterosis

The heterosis values will still be added on as increases after the breed values are added together. The direct values are multiplied by ½ because each parent contributes half the genes to the offspring.

Example 3. Weaning Weight in Cattle

Breed	Direct Value (lb.)	Maternal Value (lb.)
A	-50	+10
B	-40	-15
C	+30	+30
D	+60	-25

General Mean = 500 lb.

Individual Heterosis = 4.7 %

Maternal Heterosis = 4.2 %

Purebred D

500 + 60 - 25 = 535 lb.

Two-Breed Cross (purebred B sire x purebred A dam)

Calculate performance with the direct and maternal breed values

500 + ½ (-40) + ½ (-50) + 10 = 465

Second, add on the individual heterosis

465 + .047 (465) = 486.86 lb.

Three-Breed Cross (purebred D sire x crossbred AC dam)

Calculate performance with the direct and maternal breed values:

$$500 + \frac{1}{2} (60) + \frac{1}{2} (-50) + \frac{1}{2} (30) + \frac{1}{2} (10) + \frac{1}{2} (30) = 545 \text{ lb.}$$

Add on the individual heterosis:

$$545 + .047 (545) = 570.62 \text{ lb.}$$

Add on the maternal heterosis to calculate the predicted performance:

$$570.62 + .042 (570.62) = 594.59 \text{ lb.}$$

The relative values of the direct and maternal effects will depend upon the biological mechanism for the traits. Some traits, such as postweaning average daily gain, are largely determined by the genotype of the individual. These traits will have relatively small contributions from maternal effects. Other traits, such as calving percentage, are essentially determined by the dam so they will have very large maternal effects relative to the direct effects. A trait like weaning weight has large direct components as well as maternal components so both values may be large in magnitude.

Loss of Heterosis

The examples presented thus far were for situations where individual and maternal heterosis were either completely absent or completely present. This is not always the case. Heterosis (from dominance) is dependent upon gene pairs having members from two different breeds. In backcrosses, rotational crossbreeding and composite breeds, not all gene pairs will have genes from different breeds. The proportion of available heterosis (arising from dominance) can be easily predicted by examining the degree of heterozygosity. In a typical two breed cross, all gene pairs will be crossbred (one gene from each parental breed) and will be more likely to be heterozygous or become of different breed sources:

Hereford x Angus cross (with 8 pairs of genes)

Hereford	x	Angus	=	Crossbred
[H] [H]		[A] [A]		[H] [A]
[H] [H]		[A] [A]		[H] [A]
[H] [H]		[A] [A]		[H] [A]
[H] [H]	x	[A] [A]	=	[H] [A]
[H] [H]		[A] [A]		[H] [A]
[H] [H]		[A] [A]		[H] [A]
[H] [H]		[A] [A]		[H] [A]

This example illustrates one pair of chromosomes, (with eight genes on each chromosome) for each animal. The Hereford has only Hereford genes, and the Angus has only Angus genes. The crossbred has Hereford genes on one chromosome and Angus genes on the other chromosome so that each gene pair has

one gene from each breed. This calf is completely crossbred. If the crossbred calf is mated back to a Hereford bull (shown below), there will be crossing over and random segregation so that the egg cell produced by the crossbred heifer will have half Hereford genes and half Angus genes. The result of this backcross will have the following genetic makeup:

Hereford	x	HA	=	Backcross
H H		H A		H H
H H		H A		H H
H H		H A		H H
H H	x	H A	=	H H
H H		H A		H A
H H		H A		H A
H H		H A		H A
H H		H A		H A

This calf's gene pairs are half H x A and half H x H. We might say that only half of the gene pairs are crossbred. As a result, only half of the individual heterosis is present. The dam is the result of a Hereford x Angus mating so all of the maternal heterosis is present.

The amount of heterosis that can be utilized can be calculated by considering the proportion of gene pairs of an individual which are crossbred. The H x HA backcross had half crossbred gene pairs so 50 percent of the individual heterosis was used. The dam was completely crossbred, so 100 percent of the maternal heterosis was used. If heifers from the backcross were mated to a Charolais bull, there would be 100 percent individual heterosis since all gene pairs in the offspring would have one Charolais gene and one gene which is either Hereford or Angus. Any mating system that results in the sire breed(s) and dam breed(s) having some commonality will lose some heterosis.

One point of confusion for many producers is the loss of heterosis when a composite breed is formed.

There would be a loss of heterosis, as described in this section, because of backcross matings. However, once the breed is established and matings are among individuals with similar genetic makeup, the level of heterozygosity and the resulting heterosis should be constant. For example, if a two-breed composite is formed with equal representation of both breeds, the level of heterozygosity stabilizes at 50 percent. This would remain true until selection and inbreeding began to move the genetic makeup of the composite breed toward more homozygosity.

The loss of heterosis described in this section is that part due to dominance. Epistasis may lead to increased loss of heterosis or decreased loss of heterosis depending upon the nature of the epistasis. Experimental reports of epistatic effects in beef cattle are not numerous, but the existing evidence suggests that it is of some importance. The practical effect of these epistatic effects is that prediction of heterosis level due to heterozygosity will be biased.

Use of the Genetic Principles of Crossbreeding

Effective crossbreeding systems will be those that take best advantage of available breed resources and maintain high levels of heterosis. Producers should choose breeds for the cow herd that match the environment and sire breeds that will produce the most marketable offspring from the cows while minimizing dystocia. The choice of breeds and proper use of heterosis are critical issues as programs are developed. Experimental evidence indicates that total pounds of calf produced per cow in the breeding herd can be increased by 20 - 25 percent with effective crossing systems. The cost of a good breeding program is not that different than that of a poor breeding program. Producers should choose breeds wisely, maximize use of heterosis, and follow organized crossbreeding systems if they wish to remain competitive.

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This publication was prepared in cooperation with the Extension Beef Cattle Resource Committee and its member states and produced in an electronic format by the University of Wisconsin-Extension, Cooperative Extension. Issued in furtherance of Cooperative Extension work, ACTS of May 8 and June 30, 1914.