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Heritability and Its Use in Animal Breeding

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How much advantage for a particular trait do superior animals transmit to their offspring? Heritability estimates help us answer this important question. This publication explains the meaning of heritability estimates, how they are calculated and their influence in changing livestock performance.

What is a heritability estimate?

Heritability is the single most important consideration in determining appropriate animal evaluation methods, selection methods and mating systems. Heritability measures the relative importance of hereditary and environmental influences on the development of a specific quantitative trait. More specifically, it measures that part of the total variability of the trait caused by genetic differences among the animals on which the measurements were taken. Heritability, then, is a ratio of genetic variance (V_g) to total variance (V_p) (i.e., $h^2 = V_g/V_p$). Total variance (or phenotypic variance) includes variance caused by genetic and environmental factors (i.e., $V_p = V_g + V_E$).

The numerical value of the heritability estimate is given as a percentage or a decimal and should, of course, lie between 0 and 1. In some instances, the value falls outside this range. This is a chance occurrence caused by statistical manipulation.

A heritability estimate is a partial description of one trait in one group of animals at some particular time. It may vary (for each trait) during one time period from herd to herd, or it may vary in the same herd from time to time. This is natural because herds differ in genetic makeup and because there are many different environmental circumstances from herd to herd or within a herd from year to year. These genetic and environmental differences influence the size of the numerical value of the terms (i.e., genetic variance,V_g and total variance, V_p) used in the estimation of heritability.

The numerical value of a heritability estimate can be increased or decreased by changes in either of its component parts. An increase results from a reduction in the environmental variance or from an increase in genetic variance. Conversely, a decrease results from an increase in environmental variance or from a reduction in genetic variance.

A number of factors affect genetic variance. Introduction of new and unrelated animals into the herd may increase the genetic variance. Effective selection within a group of animals over a number of generations decreases the genetic variance. The use of inbreeding as a system of mating also reduces the genetic variance.

Any management practice that ensures uniform treatment of animals reduces environmental variance. For example, if you give each animal the same amount and quality of feed, you reduce environmental variance. When you make adjustments for any environmental differences, your objective is to remove performance differences that result because animals are "treated" differently.

Weaning weight provides an example. To get accurate figures, you make adjustments for the dam's age or the calf's season of birth to remove their effects on weaning weight. Effective adjustment also reduces total variance of weaning weight within individual herds. This reduction makes recognizing genetic differences among animals in the herd easier. When you adjust records and treat animals uniformly, you are attempting to reduce environmental variance so you can more easily recognize genetic differences.

Calculation of heritability estimates

The heritability estimates in Tables 1, 2 and 3 are average values based on many studies conducted at USDA research centers and college of agriculture experiment stations in many states.

Table 1
Heritability estimates of some important traits in beef cattle.[1]

Trait	Number of estimates	Average estimates
Reproduction		
Calving interval	3	0.08
Fertility		0.10
Growth		
Birth weight	75	0.45
Gain, birth to weaning	62	0.30
Weaning weight	83	0.24
Feedlot gain	43	0.34
Pasture gain	14	0.30
Final feedlot weight	36	0.46
Final yearling pasture weight	19	0.44

Conformation		
Weaning score	52	0.38
Final feedlot score	16	0.36
Yearling pasture score	12	0.30
Efficiency		
Feed efficiency	20	0.45
Height		
Weaning, shoulder, creep fed	6	0.82
Weaning, shoulder, non-creep fed	6	0.88
Weaning, hip, creep fed	6	0.82
Weaning, hip, non-creep fed	6	0.95
Carcass		
Grade		0.50
Dressing percent		0.45
Ribeye area per hundredweight		0.70
Fat thickness per hundredweight		0.45
Tenderness		0.60
Retail product, percent		0.30
Retail product, pounds		0.60

[1]From (in part): A summary of genetic and environmental statistics for growth and conformation characters of young beef cattle. Departmental Tech. Rpt., number 103, second edition, Texas Ag. Exp. Station, Texas A&M University, College Station, Texas.

Table 2

Heritability estimates of some important traits in sheep.[1]

Trait	Average estimate
Reproduction	

Gestation length	0.45
Multiple birth	0.15
Growth	
Birth weight	0.30
Rate of gain	0.30
Weaning weight (at 60 days)	0.10
Weaning weight (100+ days)	0.30
Mature body weight	0.40
Conformation	
Weaning type score	0.10
Yearling type score	0.40
Fleece	
Face cover	0.56
Neck folds (at weaning)	0.39
Skin folds	0.40
Fleece weight, grease	0.38
Fleece weight, clean	0.40
Staple length (at weaning)	0.39
Staple length (at yearling)	0.47
Grade	0.35
Carcass	
Loineye area	0.53
Fat thickness over loineye	0.23
Weight per day of age	0.22
Length	0.31
Fat weight	0.57

Bone weight	0.30
Lean weight	0.39
Grade	0.12
Retail cut weight	0.50
Dressing percent	0.10

[1]From SID, The Sheepman's Handbook, June 1983.

Table 3
Heritability estimates of some important traits in swine.[1]

Trait	Average estimate
Reproduction	
Number farrowed	0.10
Number weaned	0.10
Growth	
Birth weight	0.10
Weaning weight	0.15
Growth rate	0.30
Efficiency	
Feed efficiency	0.35
Carcass	
Meat tenderness	0.30
Meat color	0.30
Marbling (in loin)	0.30
Meat firmness	0.30
Backfat thickness	0.50
Loineye area	0.50

Length	0.60
Percent ham, chilled carcass weight	0.60
Percent fat cuts, chilled carcass weight	0.60
Percent lean cuts, chilled carcass weight	0.50

[1]**From: Pork Industry Handbook, PIH-9, 1976.**

In general, each estimate of heritability is based on the degree of resemblance among related individuals vs. non-related individuals in some animal population. Family units most often used to evaluate degree of resemblance include parent and offspring; parents and offspring; full sibs (i.e., full brothers and/or sisters); and paternal half sibs (i.e., half brothers and/or sisters).

The statistical technique used in calculating heritability is chiefly dependent upon available records. One practical consideration is the kind of family units represented in the data. This may dictate the technique used. If you have a choice of techniques (for example, if more than one kind of family unit is represented in the data set), then you must consider which technique gives the least amount of bias from a variety of sources.

Complications in any technique arise most often when you try to account for the effects of environmental factors. You must equalize environmental factors as much as possible and adjust for other non-genetic factors that influence animal performance. For example, if you are evaluating resemblance between weaning hip heights of cows and their calves, you might make adjustments for differences in age at the time of measurement, age of dam, sex of calf, season of birth, and so forth.

If you fail to adequately account for environmental contributions, you will reduce the estimate of heritability. From a practical standpoint, this means you will be less able to recognize genetic differences among animals you are considering for breeding purposes.

One of the most common estimation techniques, and the one described here, is the paternal half-sib analysis of variance. With this method, the total variance is divided into two parts. In one, variation is attributed to differences among progeny of different sires. In the other, the variance is attributed to differences among offspring of the same sire. The analysis of variance is generally put into tabular form as follows:

Source of variance	Degrees of freedom	Mean squares	Expected mean squares
Total	N - 1		
Among sires	S - 1	M_1	$V_w + kV_s$
Within sires	N - S	M_2	V_w

Degrees of freedom is an awkward concept. In general, it is related to number of observations minus number of constraints. For example, N - 1 is the total number of measurements (observations) of a specific trait, such as hip height, minus 1.

Mean squares, M_1 and M_2, represent estimates of variances associated with "among sires" and "within sires" sources of variance.

Expected mean squares are theoretical components of their respective mean squares.

k is the weighted number of progeny per sire.
$\mathbf{V_S}$ is a measure of the resemblance among half sibs and is interpreted to be one-fourth of the genetic variance for the trait concerned.
$\mathbf{V_W}$ is interpreted to be three-fourths of the genetic variance and all of the environmental variance.
$\mathbf{V_S}$ is calculated from the mean squares (i.e., variances) associated with the "among sires" and "within sires" sources of variance as $(M_1 - M_2)/k$.
Heritability, h^2, is then calculated as:

$$h^2 = \frac{4V_s}{V_s + V_w}$$

Usefulness of heritability estimates

You can use heritability estimates to estimate progress and setbacks in different traits that you can expect from different matings. For example, a particular mating may bring improvement in rate of gain if the parents are genetically superior. If they are inferior, however, they may cause a decline in rate of gain in their offspring.

To illustrate how to figure expected progress from particular matings, assume you have a herd with an average daily gain in the feedlot of 2.40 pounds per day. From that herd, you kept bulls that gained 3.20 pounds and heifers that gained 2.80 pounds per day for breeding purposes.

How much gain in genetic improvement could you expect in the progeny of these selected parents?

To answer this question, first calculate just how superior these parents were to the average in the herd.

Calculate the superiority of the breeding animals as follows:

- Superiority of dams = 2.80 - 2.40 or 0.40 pounds per day.
- Superiority of sires = 3.20 - 2.40 or 0.80 pounds per day.
- Superiority of parents = (0.40 + 0.80) ÷ 2 = 0.60 pounds per day.

The next question is, "How much of this 0.60 pound advantage is transmitted to the offspring?" To answer, you must know the heritability of feedlot average daily gain. The average estimate for this trait is 0.34 (Table 1).

Expected genetic gain, then, is equal to the average superiority of the parents multiplied by the heritability (i.e., 0.60 x 0.34 or 0.20 pounds per day).

The herd average was 2.40 pounds feedlot gain per day. With all other things equal, you would expect the offspring of the selected parents to gain an average of 2.40 + 0.20 = 2.60 pounds per day. This is the average of the herd plus the genetic advantage transmitted by the parents.

The calculations above illustrate two important points. First, if the selected parents had not been superior in rate of gain over the average of the herd, there would have been no genetic improvement in rate of gain of their offspring, regardless of the degree of heritability of the trait.

Second, the amount of genetic progress is also dependent on how highly heritable a trait is. Though the parents had an advantage over the herd average of 0.60 pounds per day in gain, they would not have transmitted any of this advantage to their offspring if the trait had a herd heritability.

The general conclusion, then, is that the greater the superiority of the individuals selected for breeding purposes and the higher the heritability of the trait, the more progress will be made in selection.

A knowledge of the size of the heritability estimate is also important in deciding which animal evaluation method should be used. When heritability of the trait is medium to high (above about 0.30), selection based upon the individual's own level of performance allows a relatively rapid rate of improvement. When the trait has a low heritability, you should use other methods to identify genetically superior individuals. The "other" methods involve various schemes for including the level of performance of related individuals such as siblings or progeny.

You can make more improvement in low heritability traits by using mating systems that take advantage of heterosis (hybrid vigor). As a general rule, the lower the heritability of a trait, the greater the heterotic response from various outbreeding mating systems.

Low-heritable traits, such as those associated with reproductive efficiency, show the greatest benefit from using outbreeding mating systems. Highly heritable traits, such as carcass quality traits, show very little if any heterotic response from outbreeding mating systems.

An important difference lies between these two avenues of trait improvement. Improvement from selection schemes is cumulative over the generations. But improvement that comes from exploitation of heterosis is maximized in one generation and must be recreated each generation thereafter.

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