factsheet
Pork Information Gateway

Multiple Trait Selection for Pork Improvement

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Originally published as a National Swine Improvement Federation Factsheet.

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Introduction

One of the most important decisions breeders make is choosing which traits to improve in their herds. Breeders must decide among numerous traits of economic importance and determine whether to improve performance a small amount in several traits or make larger amounts of improvement in fewer traits.

Background

Selection is similar to developing a financial budget when one has a limited amount of money to spend each month. One can buy one or two large items or smaller quantities of more items. Just as monthly income is limited, selection intensity is also limited. The breeder must decide how many traits to attempt to improve and how much selection pressure to budget to each trait. One trait might be greatly improved by applying all the selection pressure to it, or several traits might be improved to a lesser degree each by "spreading" the selection intensity around. Similar to compounding interest, genetic improvements accumulate over generations and hence affect the performance of the herd in subsequent generations. And like investment opportunities, returns resulting from selection are not the same for all traits. Expected response to selection is proportional to the heritability and selection differential of that trait. Traits with higher heritabilities have a greater response with a given selection intensity than traits with lower heritabilities; however, not all traits have the same economic value. So, while progress may be more rapid in a trait with a high heritability, the value of the progress may be greater for a trait with a lower heritability. The challenge to breeders is to determine which traits to improve based on the heritability and the economic values among them. To make the task a bit harder, remember genetic improvement is cumulative over generations. The typical generation interval in pigs is about three years. So, when identifying the list of traits and their relative values, it's their importance and value in six to nine years, not today, that is the real challenge. This fact sheet focuses on the concepts of developing a selection objective and the selection criterion used to obtain that objective. The selection objective is a description of the traits you wish to improve and their relative importance to herd profitability. The selection criterion is the method of evaluating each animal, relative to the selection objective, for use in deciding which animals to retainfor breeding. Ideally, the selection criterion accurately identities those breeding animals that advance a herd toward the desired objective most rapidly. Frequently mentioned traits of higheconomic importance to include in selection objectives are litter size, 21-day litter weight, days to market, feed efficiency, and backfat thickness. Other traits of interest include carcass lean percent, meat quality, libido, rebreeding interval, longevity, structural soundness, and disease resistance. It is not practical to attempt to improve all these traits simultaneously. A breeder must prioritize traits to include in selection objectives and decide which are the most important to improve. As the number of traits chosen for selection increases, the genetic change in each individual trait decreases. As a result, it is critical to identify those traits, that when improved, result in the greatest economic gain.

Once the selection objective is chosen, breeders should apply the appropriate selection criteria over a period of years to achieve a positive change in herd performance. The selection criterion may include any number of traits and methods of selection. Develop the criterion to maximize the rate of genetic improvement in the selection objective, which results in maximal economic gain.

It is important to keep in mind that the objective and criterion are not the same. The objective is the goal of the program, whereas the criterion is the traits measured on animals and/or their relatives and used as the basis for selection to achieve the objective. The objective and criterion may even include different traits. For example, the objective might be to improve pork quality of the carcass by increasing percentage lean, color, and flavor. The criterion used to select breeding animals might be ultrasonic backfat depth and loin area (as estimators of percent lean) measured directly on the selection candidates plus color and marbling score (as an indicator of flavor) measured on sibs or progeny. The selection criterion is developed to maximize the genetic improvement of the selection objective, as constrained by the cost and or ability to gather data on selection candidates and their relatives to use for the selection criterion.

The Selection Objective

$$\text{Genetic Change per Year} = \frac{\text{(Accuracy x Variability x Selection Intensity)}}{\text{(Generation Interval)}}$$

Equation 1.

In developing a selection objective, there are several underlying principles to keep in mind. Annual response to selection is dependent on the accuracy of selection (heritability and amount of information), variance of a trait, selection intensity, and generation interval. Heritability and variation are biologically determined by the genetic mechanisms controlling a trait. The accuracy of selection is dependent on the heritability. The more the expression of a trait (phenotype) is controlled by these genetic mechanisms, the more confidence one has that the individual contains the desired genes to achieve the selection objective. For a given trait, the amount of response achieved by a breeder is determined by the amount of recorded information (affects accuracy), \the intensity of selection applied in a generation, and the length of time taken to produce the next generation (Equation 1). To increase the rate of genetic progress, a breeder must increase the accuracy and intensity of selection while decreasing the generation interval.

Generation Interval

Traits with higher heritability have a greater response to selection than traits with lower heritabilities. This does not mean one should only select for those traits with high heritabilities. Some economically important traits have lower heritabilities. Selection response is also dependent on the variation exhibited in a trait. The greater the variation, the greater the potential response to selection due to potentially larger selection intensity. Knowledge of the heritability and variance of traits is useful in determining the potential for improving a trait by selection and therefore helpful in deciding which traits to include in a selection objective.

The proportion of the population selected to produce the next generation determines selection intensity. To maintain herd size, parents that are culled must be replaced by an equal number from among the offspring. Therefore, the number of offspring produced by each parent in part determines selection intensity. The more offspring produced, the smaller proportion of those offspring that must be retained as replacements, i.e., a higher selection intensity.

A breeder must decide which traits to apply selection pressure towards and in what proportion. As the number of traits increases, the improvement in any individual trait decreases because the selection intensity applied to each individual trait decreases.

Table 1 illustrates the relative response to selection when equal emphasis and heritabilities are considered for multiple traits, assuming no correlation among the traits. As shown, the response in each individual trait decreases quite rapidly as more traits are added to the objective.

However, the net worth of the total change in all traits is greater than the value of improving any single trait, even though the response in that one trait is large.

# of Traits	Relative Response[1]
1	1.0
2	.71
3	.58
4	.50
5	.44
10	.31
20	.22

Table 1. Relative response in one trait from selection for multiple traits(F_Z) [1]Relative Response /√n where n=number of traits.

Careful consideration is needed to decide which traits to include in a selection objective. Including traits that are of little value in the selection objective reduces the overall rate of herd improvement by wasting selection pressure. Not all traits are worth the same amount. To compare traits, we need a common scale of measurement. A scale that is universally understood is economic value ($). Changes in levels of performance of different traits have different economic values. For example, increasing average litter size by one pig may be worth considerably more than decreasing days to market by one day, even though growth rate may be changed more rapidly because of its higher heritability.

Traits in Objective	Value/unit[1]	Response[2]	Value of Response
Days to market	-$.175/day	4.25 days	$.74
Backfat	-$15/1 in.	-.002 in.	$.03
$.77/pig			
Days to market	-$.175/day	-3.75 days	$.66
Backfat	-$15/.1 in.	-.001 in.	$.02
# Born Alive	$13.50/pig/litter	.29 pigs/litter	$.453

Table 2. Relative response in one trait from selection for multiple traits(F_Z)

Table 2 shows a comparison of a two trait objective of days to market and backfat thickness with a three-trait objective adding number born alive. By adding litter size to the objective, the value of the response in days to market and backfat thickness decreases from $.77/pig to $.68/pig. But the increase in value associated with including litter size ($.51/pig) more than offsets the $.09/pig reduction in the growth traits. Therefore, with the economic values illustrated, it is more profitable to include the third trait, litter size, in the objective, even though response in each individual trait is reduced. As economic values change, the traits included in the selection objective may change.

When considering multiple trait improvement, the correlation among traits is important. Genetic correlations are caused by two mechanisms, linkage, and pleiotropy. Linkage occurs when the controlling genes of two traits are located near each other on the same chromosome and therefore are transmitted from parent to offspring together.

Pleiotropy is a situation where one gene, or group of genes, controls more than one trait. Pleiotropy is most obvious for growth traits. Genes controlling growth tend to do so throughout the entire growth period. Genes affecting growth early in the growing period also affect later growth. Therefore, weights at different ages are positively correlated. Genetic correlations may be positive, which means as you select to change one trait, the second trait moves in the same direction (both increase or both decrease). Or, genetic correlations may be negative, which means the traits respond in opposite directions (one increases as the other decreases). Correlations among traits must be considered in assessing the total impact of selection for a trait. As a trait is altered, performance for all correlated traits change as well. The net effect of changing a trait is the summation of the changes in the trait itself and all correlated traits.

Correlations among traits may be exploited to reduce testing costs. An example is the relationship among growth rate, backfat, and feed efficiency. These three traits are correlated such that fast-growing lean animals are more efficient. It is expensive and difficult to accurately measure feed efficiency directly on individual animals, but growth rate and backfat can be economically measured. Therefore, a selection objective of improving feed efficiency can be achieved by using both growth rate and backfat thickness as selection criteria. The response due to direct selection for feed efficiency is greater, but the costs of measurement are also greater. Use of the correlated information is one method of reducing testing costs while improving the feed efficiency.

Multiple Trait Selection Criterion

There are three general methods of multi-trait improvement.

Tandem Selection. Tandem Selection is a method by which a single trait is used as the selection criterion for one or more generations. The trait used as the selection criterion in each generation is rotated among all traits of the selection criteria in successive generations. Each trait follows in a tandem fashion until all traits have been used as the selection criterion. For example, a breeder may have an objective of increasing growth rate, decreasing backfat, and increasing litter size. In the first generation, selection would be for the fastest growing hogs. This is followed in tandem in the second generation by selecting the leanest hogs (lowest backfat). In the third generation, hogs from the largest litters are selected. Then a new round of rotation is started.

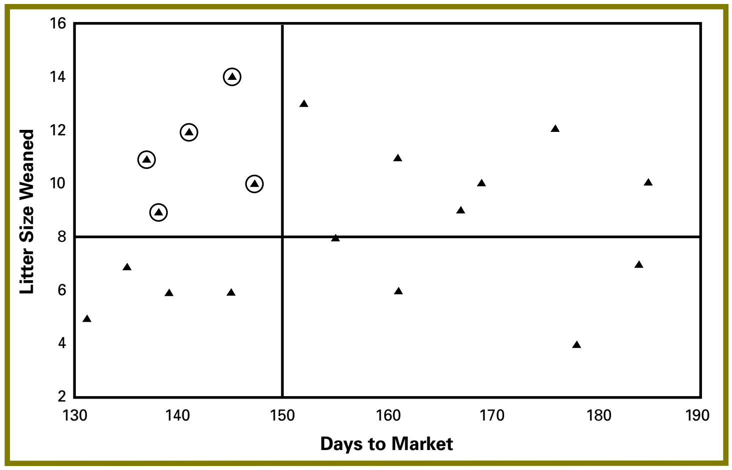

Figure 1. Independent Culling Levels with equal emphasis between traits.

Tandem selection is frequently described as a simple method of selection because only one trait must be evaluated in any generation. The drawback with this method is that some animals with a greater total number of desirable genes (more closely aligned with the overall breeding objective) may not be selected because it may be inferior to other animals in the trait currently being used as the selection criterion. Also, the greatest response for any trait occurs during those generations when it is the criterion, hence response is sporadic. In addition, if there are negative correlations among traits, improvements achieved by selection for one trait in earlier generations may be cancelled out by correlated losses in subsequent generations. Tandem selection is not a recommended method of achieving maximum response to selection.

Independent Culling Levels. Independent culling levels is a method where minimum standards of performance are established for each trait in the criteria. Any animal not satisfying the minimum standard for all traits is culled.

Independent culling levels is a frequently used method of improvement. It allows simultaneous improvement of traits and varying emphasis to be placed on traits (Figure 1). Animals in the figures whose data points are circled are the animals that would be selected. The relative selection pressure applied to each trait is altered by changing the culling levels. Figure 2 demonstrates a higher selection intensity for days to market with a corresponding reduction in pressure applied to litter size, relative to the selection pressures depicted in Figure 1. The total number of animals selected by either set of culling levels is the same. The percent of animals selected by each trait is defined such that the product of multiplying the percent saved by each criterion is equal to the final percentage of the herd needed for breeding.

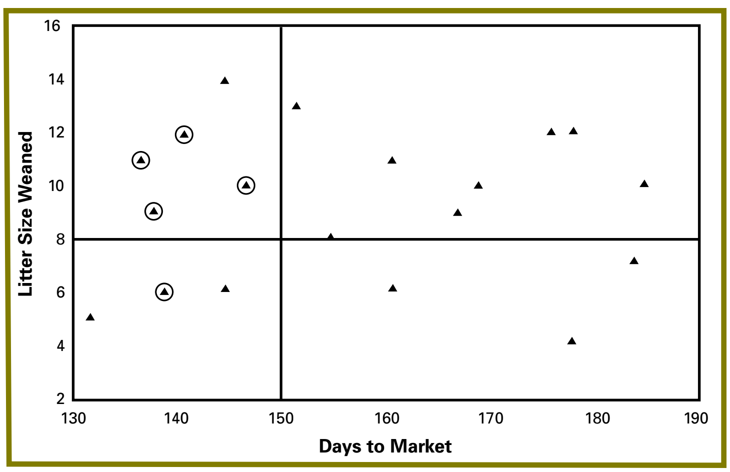

Figure 2. Independent Culling Levels with twice the emphasis on days to market.

For example, if selection is based on two traits weighted equally and 25% of the herd is retained for breeding, the culling level for each trait will select 50% of the animals (50% x 50% = 25%). If a 2 to 1 emphasis were placed on the traits, 35% of the animals could be selected on the first trait, but the upper 70% of the animals ranked on the second trait must be selected to retain 25% of the herd (.35 x .70 = .25).

One problem with independent culling levels occurs if the culling rules are applied rigidly. Exceptional performance in one trait may not offset a minor deficiency in another trait. An animal that has superior performance for one trait but only average performance for another may be culled. Many breeders "break the rules" to allow for this type of situation. The problem is that the breeder must spend considerable time and effort monitoring the selection system. Independent culling levels are frequently used in combination with other forms of multi-trait selection. Physical abnormalities that restrict an animal's ability to perform as breeding stock are used as a basis for culling prior to final selection decisions being made on other criteria such as an index of growth and maternal traits. Care should be taken to insure that only those traits that affect the economic status of a herd are used as culling criteria.

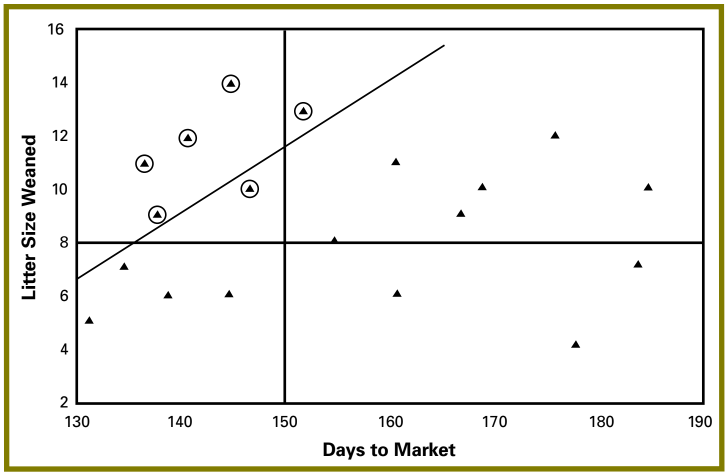

Figure 3. Index Selection, NSIF maternal line index.

Index Selection. Index Selection is a method where the net values of all traits of the selection criteria are combined into a single index value. The index is derived utilizing the heritabilities of the traits, correlation among traits, and economic value of each trait. An index value is calculated for each animal based on its performance (performance of relatives may also be included) for each trait. Selection is then based on the ranking of individuals according to index value.

The index value is an estimate of the cumulative value, usually dollar ($) value, of each animal's genetic potential of all traits in the objective. Index selection has advantages over independent culling levels in that all traits are improved simultaneously and differential emphasis can be placed on each trait.

In addition, index selection allows for a superior level of performance in one trait to compensate for deficiencies in other traits. Typically, indexes use the relative economic values of traits to define the selection emphasis applied to each trait. Traits with higher economic value receive higher emphasis. In Figure 3, a maternal index, based on the NSIF recommendations1 is presented, Index = 100 + 7 x (Litter Size) - 1.4 x (Days to Market) where litter size and days to market are expressed as deviations from the mean. A sow with +2 pigs per litter and -7 days to market would have an index value of 100 + 7 x (2 pigs) - 1.4 x (-7 days to market) = 123.8 index units. Sows with the highest index values are selected. Index Selection is the most efficient of the three methods for multiple trait improvement.

Determining the Selection Objective

The selection objective includes all traits of economic importance to the production system where the pigs are used. For example, if the animals are to be used only to sire market hogs (paternal line), then those traits (growth rate, leanness, and feed efficiency) involved in performance of market hogs are most important. However, if their primary role is to produce replacement females for commercial production, then maternal traits are of primary importance. However, since replacement females contribute 1/2 the genetic potential for growth and leanness of their market hogs, growth traits should not be ignored in maternal lines. A herd producing stock for use in a rotational breeding program should have an objective that is intermediate between the paternal and maternal line. The relative emphasis among traits is shown in Table 3.

When industry-wide selection objectives are developed, more precise estimates of the economic importance of traits should be used. A profit function accounting for all inputs and outputs of the production system in terms of measurable traits is needed to determine the economic values. Major costs to the production system such as housing and labor can be represented as a daily charge for each type of facility in the production system and can be determined as a function of growth rates for pigs or conception rates for the breeding herd. Other costs, such as feed, can be based on feed consumption of growing pigs and maintenance requirements of the breeding herd.

Equation 2 is a profit function appropriate for the growing-finishing phase of pork production. Line 1 of Equation 2 is the income from the sale of a market pig. Income is determined by the base market price adjusted for premiums (or discounts) associated with a leaner (or fatter) carcass. Line 2 of Equation 1 represents the costs of rearing the pig in the growing and finishing phase. Costs are determined by multiplying the time it takes for the pig to reach market weight (growth rate) by the daily cost of facilities and labor and the feed consumed in attaining the gain (feed efficiency) by the cost of feed. Line 3 is the value of the weaned pig. Elements that are biological traits subject to genetic change are represented by upper case letters. Elements that are management constraints or represent costs and/or values are represented by lower case letters. Economic estimates are for a midwestern U.S. farrow-to-finish market hog production system.

Selection Objective	Relative Weighting on	
	Maternal Traits	Growth Traits
Paternal Line	0	1
Maternal Line	2/3	1/3
General Purpose Line	1/2	1/2

Table 3. Relative emphasis between growth and maternal traits for alternative selection objectives. Determining the proper weightings to be used for individual traits the selection index should be done using an economic analysis of the pork production system where the selected animals will be used. Gross market values are frequently used as initial estimates of relative values.

Determining the Selection Criterion

(1)	GFO = slwt x bmp x [1-vlu x (BF-1.0)]	
(2)	-(slwt-aww) x (cFF x FUGGF+CFDxDUGGF)	
(3)	-vPW	
aww	Average weaning weight	15 lb.
BF	Backfat thickness in.	
bmp	Base market price	$.45/lb.
c_{FD}	Daily cost per head to maintain	$.17/day
c_{FF}	Cost of feed in growing-finishing	$.075/lb.
DUG_{GF}	Days per unit gain post weaning	days
FUG_{GF}	Feed per unit gain post weaning	lb./lb.
slwt	Target slaughter weight	250 lb.
vlu	Value of reduce backfat pig in growing-finishing facilities	10.5%/in.
v	Value of weaned pig	$22.45/pig

Equation 2. Growing-Finishing Objective (GFO)

Ideally, the traits described in the selection objective are included in the selection criterion. However, traits in the selection criterion must be measured on each animal or its relatives. Realistically, the cost of measuring some traits, either in terms of money or time, may make it impractical to include them in the selection criterion. Therefore, the selection criterion may include traits which themselves are of little or no value but are correlated with traits of high value. A 21-day litter weight is an example of such a trait. Because few pigs are sold at 21-days of age, there is little direct value assigned to the litter's weight. However, 21-day litter weight is correlated with several traits which are of high economic value and is therefore useful as part of the selection criterion. Heavy litters at 21-days are produced by sows with good maternal ability. Sows with good maternal ability have higher pig survival rates and produce adequate milk to support growth. Pigs from heavy litters tend to be heavy themselves, are more vigorous, adjust to the postweaning facilities more readily, and reach market weight faster. Therefore, litter 21-day weight is an excellent selection criterion that is easily and inexpensively measured and an indicator of several traits of high economic value, specifically pig numbers, survival, and growth rate. Other instances of traits that may be in the selection objective but not in the selection criterion are those that cannot be measured directly on the individual.

Some traits are sex limited. Boars don't bear litters, but their genetic potential for litter size is still important. Longevity in the breeding herd is valuable, but can only be recorded when the animal is culled or dies. Many carcass quality traits are not yet directly observable on the breeding candidates since they require slaughter. When these traits are included in the selection objective, the selection criterion should include correlated sources of information such as other traits and information on relatives.

After the list of traits to be used as the components of the selection criterion is developed, using the traits to identify animals for selection depends on the method of selection used. With tandem selection, the order in which the traits are to be used is decided; then animals are selected on one trait in turn by generation. If independent culling levels are used, the minimum level of performance for each trait is determined, and all animals not satisfying all standards are culled. With index selection, the heritabilities and genetic correlations are combined with the economic value to determine a numeric weighting for each trait. For each animal, the performance of each trait is multiplied by the weighting factor and summed to determine the index value. The animals are ranked on the index value and those with the greatest values are selected. The task of developing selection indexes is greatly simplified when combined with a genetic evaluation system. The Expected Progeny Deviations (EPD) are calculated considering the genetic variances and correlations among traits and utilize all available performance information from relatives to increase the accuracy of the evaluation. A breeder can simply multiply the EPD of each trait by its economic value and sum the results. Those animals with highest index values are the ones expected to have the highest value as parents. With personal computers and software available today, this computational task is not as cumbersome as it once was.

Summary

Improving the performance in multiple traits simultaneously is usually desired in genetic improvement programs. It is important that only traits of economic importance to the breeder and customers are included in selection objectives. Expanding the number of traits in the objective reduces the rate of improvement in individual traits but may increase overall productivity. Multi-trait improvement programs account for differences in economic value among traits, differences in heritability, variation and correlations among traits. All available information describing the performance of individuals and their relatives should be utilized. Selection indexes utilizing expected progeny deviations estimated from performance data of individuals and their relatives best satisfy these requirements.

Recommended economic values of traits and selection indexes for paternal, maternal, and general genetic lines are available in the National Swine Improvement Federation (NSIF) guidelines for uniform swine improvement programs.

Information developed for the Pork Information Gateway, a project of the U.S. Pork Center of Excellence supported fully by USDA/Agricultural Research Service, USDA/Cooperative State Research, Education, and Extension Service, Pork Checkoff, NPPC, state pork associations from Iowa, Kentucky, Missouri, Mississippi, Tennessee, Pennsylvania, and Utah, and the Extension Services from several cooperating Land-Grant Institutions including Iowa State University, North Carolina State University, University of Minnesota, University of Illinois, University of Missouri, University of Nebraska, Purdue University, The Ohio State University, South Dakota State University, Kansas State University, Michigan State University, University of Wisconsin, Texas A & M University, Virginia Tech University, University of Tennessee, North Dakota State University, University of Georgia, University of Arkansas, and Colorado State University.