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Genetic Principles and Their Applications

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Introduction

Genetics influence economically important traits such as litter size, litter weights, growth rate, feed efficiency, backfat thickness, pork quality, and feet and leg soundness. Producers need to know how to apply genetic principles in selection and mating of animals to improve their herds.

Inheritance

Body cells in domestic pigs contain 38 chromosomes. Chromosomes are thread-like structures that contain genes, the basic unit of inheritance. During the process of reproductive cell division (meiosis), chromosomes occur in pairs (called homologous chromosomes), and only one member of each chromosome pair is passed on to sperm and egg cells. During fertilization, a sperm cell unites with the egg cell to form a zygote which will develop into the pig fetus.

Because chromosomes contain genes, the offspring will receive half of its genes from each parent. However, each individual in the litter will receive a different sample of its parents' genes due to the nature of the meiotic process. Litter mates are expected to have about 50% of the same genes while half-sibs will have approximately 25% of their genes in common.

The location of a gene on a chromosome is called the locus. At the same locus on homologous chromosomes are genes that affect the same trait. These corresponding genes are referred to as a gene pair. For a given pair, the genes can be identical (homozygous) or different (heterozygous) as shown by the following example:

B = symbol for the gene causing black hair
b = symbol for the gene causing red hair

Animal	Genotype	Phenotype
1	BB	black
2	Bb	black
3	bb	red

Animal #1 is homozygous at this locus because it has the same genes whereas individual #2 is heterozygous. A particular gene combination is referred to as the genotype while the physical appearance (what is seen or measured) is called the phenotype. Based on these phenotypes, B is referred to as the dominant gene, and b is the recessive. For these two genes, complete dominance exists since B covers the effect of b. However, different degrees of dominance, or a lack of dominance, can occur for other genes.

Hair color is an example of a qualitative trait because the phenotypes fit into distinct categories or classes. Qualitative traits are controlled by one or a few pairs of genes. Genotypes for qualitative traits are often predicted based on mating tests. Laboratory analyses of blood samples have been used to predict genotypes of qualitative traits such as porcine stress syndrome (PSS).

Quantitative traits generally do not fit into distinct classes for phenotypes. Examples of quantitative traits are backfat thickness, feed efficiency, days to market, 21-day litter weight, and number of pigs born alive. These traits are controlled by many pairs of genes. The expression of these traits (phenotype) is influenced by the animal's genes (genotype) and the environment. With uniform care, feeding, and housing, pigs within a group will express less variation in performance from environmental effects, which results in more accurate genetic evaluations.

An individual's genetic value for a trait is affected by an additive component and a non-additive component. The additive genetic component is due to the effects of the genes, independent of their interaction with other genes. Since individual genes are passed from parent to offspring, this component is inherited and can be improved through proper selection.

The trait's non-additive genetic value is due to the interaction of genes. Since gene combinations are not passed from parent to offspring, a trait's non-additive value is not inherited, but can be improved through crossbreeding or outcrossing. This improvement in non-additive value is referred to as heterosis or hybrid vigor. The opposite of heterosis is inbreeding depression. Inbreeding depression is the drop in performance due to a decrease in non-additive value resulting from mating related animals.

The additive genetic component is commonly referred to as the breeding value. Animals that excel in this component produce offspring with high breeding values. This would be expected since an animal passes one-half of its breeding value on to the progeny. Because of this, one-half of the individual's breeding value is the progeny difference (PD). The PD is the difference between the average performance of the individual's offspring and the average performance of all progeny in the population.

Factors Affecting the Rate of Genetic Improvement

Selection is the process of evaluating and choosing certain individuals for breeding purposes. The selection goal is to choose animals with the best predicted breeding values so that genetic improvement can occur within the herd. The rate of improvement from selection is affected by five factors: selection accuracy, intensity of selection, variation in breeding values, generation interval, and genetic correlation.

1) Selection accuracy. A pig's actual breeding value for a quantitative trait is never known; however, it is possible to estimate its breeding value. The strength of the relationship between actual and estimated breeding values is the selection accuracy. Accuracies vary from 0.01 to 0.99. With higher accuracy, there is a stronger correlation between the actual and estimated breeding value. Genetic progress is greater when selection is based on records with high accuracies. The selection accuracy is affected by several factors including the heritability of the trait, how animals are treated within a group, method of data collection, and the performance information used in evaluating animals.

Selection accuracies are higher as the heritabilities increase, as shown by Table 1. Heritability is a statistical term which estimates the fraction of the total variation in a trait among animals due to additive genetic variation. If a trait has a high heritability, the animal's phenotype is a good indicator of its breeding value. Traits with high heritabilities respond faster to selection than low heritability traits.

When selecting replacements pork producers should not ignore lowly heritable traits such as number born alive and 21-day litter weight. For these traits, the selection accuracy can be improved by using individual and relative records when making selection and culling decisions.

A contemporary group is a set of animals that have been fed, managed, and raised in the same building or area. A contemporary group could include a set of growing-finishing pigs housed in the same facility or a group of sows farrowing litters in a building during the same time period. There are many small environmental differences among animals within a contemporary group. Thus, it is important to treat all animals the same and provide adequate feeder and waterer space to reduce environmental differences and improve the selection accuracy.

Producers need to use a consistent and accurate method of collecting records on animals within the contemporary group to help improve the selection accuracy. Training in the collection of records is helpful. The National Swine Improvement Federation has an ultrasonic certification program for individuals wanting to measure carcass traits. Individuals collecting data should use the same measurement techniques on all animals and use equipment that provides accurate data. Finally, the producer must accurately record collected data.

Collected records should be adjusted for known environmental differences between pigs to improve the accuracy. These adjustments are necessary to place all animals on a more comparable basis.

Another factor affecting accuracy is the number and type of records used in evaluating animals. Performance records on individuals, parents, progeny, siblings, and other relatives can be used by genetic evaluation programs in predicting breeding values. Producers using whole-herd testing for a few years will have performance records from these various sources. The use of progeny records is especially beneficial in increasing the accuracy, as shown by Table 2. This table demonstrates that each additional source of information (both number and type of records) can improve the accuracy when compared to using only individual records.

2) Intensity of selection. In a population of pigs, the average performance for a trait is called the mean. Variation about the mean is measured by the standard deviation. About 68% of the pigs will lie within one standard deviation (plus and minus) of the mean and about 95% will lie within two standard deviations. The

Table 1. Heritabilities* and accuracy values (based on individual records) for some economically important traits.

Trait	Heritability	Accuracy
Number born alive	.10	.32
Number weaned	.05	.22
21-day litter weight	.15	.39
Days to 230 lb	.35	.59
Feed efficiency	.30	.55
Backfat thickness	.40	.63

* Lamberson, W.R. and E. R. Cleveland. 1987. Genetic parameters and their uses in swine breeding. NSIF-FS3. National Swine Improvement Federation.

Table 2. Accuracy values based on different types of records and heritabilities.*

Records	Heritability .1	Heritability .3
Individual	.32	.55
Individual + 2 parents	.38	.67
Individual + 5 full-sibs	.41	.64
Individual + 10 full-sibs	.48	.68
Individual + 10 half-sibs	.34	.57
Individual + 50 half-sibs	.46	.64
Individual + 10 half-sib progeny	.52	.71
Individual + 40 half-sib progeny	.73	.82

*Kemp, R. and T. Stewart. 1988. Performance records on relatives. NSIF-FS7. National Swine Improvement Federation.

selection intensity is a measure of the superiority of the selected animals in standard deviation units. Table 3 indicates the intensity values when selecting different percentages of animals within a group or herd. For example, the selection intensity would be 2.66 if a producer selects among the top 1% of the tested boars within a group. Selecting among the top 10% of the boars will result in a selection intensity of 1.76. If the generation interval is the same for both examples, a producer could expect 50% more progress when selecting among the top 1% of the boars compared to among the top 10%.

Table 3. Selection intensities for different percentages of animals saved.*

Percentage saved	Selection intensity
1	2.66
5	2.06
10	1.76
15	1.55
20	1.40
25	1.27
30	1.16
35	1.06
40	.97

* Van Vleck, L.D. et al. 1987. Genetics for the Animal Sciences. W.H. Freeman and Company.

Selection intensities will be lower for females than males since relatively large numbers of gilts must be saved compared to the number of boars needed. Seedstock and commercial producers should strive to select among the top 25% of the gilts from each contemporary group. Ideally, seedstock producers should select among the top 1% to 3% of the boars within a group for replacements. Commercial producers should strive to select among the top 50% of the boars.

3) Variation in breeding values. The rate of genetic change is more rapid when selection is made within a group with more variation in breeding values. If the environment is similar and large differences exist between the poorest and best animals, one would expect the group to have considerable variation in breeding values. Greater variation in breeding values should exist as the size of the group being evaluated increases. Seedstock producers may not be able to increase the number of sows in their operations, but hopefully they can increase contemporary group size to a certain extent. Utilizing management practices that improve the number of pigs weaned per litter will increase group size. Producers should measure performance on more animals in each group. Performance testing only a small part of the herd can prevent the evaluation of some superior animals, decrease the variation in breeding values, and bias the evaluations.

4) Generation interval. The generation interval within a herd is the average age of the parents when their offspring are born. Herds that have mostly older breeding animals have longer generation intervals which reduces the rate of improvement per year. The generation interval can be decreased by using rapid culling of boars and sows. If possible, avoid keeping purebred sows beyond the fourth litter and crossbred sows beyond the sixth parity. Low indexing purebred sows can be culled when higher indexing gilts are available. Seedstock producers should replace boars after a set number of matings or when higher indexing boars are available.

5) Genetic correlation. Selection for one trait can lead to changes in other traits. For example, selection for less backfat can lead to an increase in the number of days needed to reach market weight. Why does days to market tend to increase when selection is based solely on less backfat? Remember that a large number of genes affect a quantitative trait such as backfat thickness. Some of these genes may also influence days to market. Selection for less backfat will result in changes in the frequency of genes affecting that trait as well as for days to market. Correlated changes in days to market might be expected due to the shift in gene frequency.

The association between two traits can be statistically measured in terms of the genetic correlation. The size of the genetic correlation estimates the strength of the relationship between breeding values for two traits. A genetic correlation close to -1 or +1 indicates that a strong relationship exists between traits while values close to zero (0) represent a weak association.

Genetic correlations can be negative or positive depending upon which traits are involved. If a negative correlation exists, animals with positive breeding values for one trait will tend to have negative breeding values for the second characteristic. For example, a -.60 genetic correlation exists between average daily gain and feed/gain ratio. Based on this correlation, one can expect pigs with high breeding values for average daily gain would tend to have desirable, low breeding values for feed/gain ratio. In that situation, a favorable genetic correlation exists among traits. If a positive genetic correlation exists, animals with high breeding values for one trait will tend to have high breeding values for the second characteristic. For example, a .25 genetic correlation exists for average daily gain and backfat thickness. Pigs with high breeding values for average daily gain will tend to have high, undesirable breeding values for backfat thickness. In that situation, an unfavorable genetic correlation exists among traits.

Genetic correlations affect the rate of response from selection. Fortunately, genetic correlations are one of several factors taken into consideration when deriving selection indexes.

Selection of Individual Animals

On-farm testing programs should involve the collection of records on boars, gilts, and sows. The National Swine Improvement Federation has recommendations on methods of collecting on-farm data outlined in its publication, "Guidelines for Uniform Swine Improvement Programs".

Collected data should be processed through computerized genetic evaluation programs. Advanced genetic evaluation programs use Best Linear Unbiased Prediction (BLUP) procedures. BLUP procedures use individual, relative, and progeny records as well as genetic ties among herds in calculating expected progeny differences (EPDs). The EPD is equal to one-half of the estimated breeding value (EBV). For example, a boar with an EBV of -.20 in. for backfat thickness would have an EPD for backfat of -.10 inches. The EPD predicts how well an individual's offspring are expected to perform compared to progeny from average parents. For example, a boar with an EPD of -.10 in. for backfat thickness would be expected to sire pigs with .10 in. less backfat than offspring from an average parent in that breed. Thus, the EPD is an estimate of an animal's genetic worth as a parent. EPDs are computed for the measured traits.

Producers can make meaningful comparisons among animals based on EPDs because these values are expressed in actual units for each trait deviated from the population average. For example, EPDs for backfat are expressed in inches while those for 21-day litter weight are listed in pounds. Negative EPDs are desirable for backfat, days to market, and feed/gain ratio while positive values are desired for number born alive, 21-day litter weight, and average daily gain.

Depending upon how the records are processed in calculating EPDs, the population base for the analyses may be the herd or the whole breed. If the population base for the analyses is the herd, EPDs can be used to compare pigs within that herd but not with animals in other herds. In this situation, one would consider high EPD animals to be superior individuals within that herd but not necessarily for the whole breed.

Within-herd EPDs can be used to compare animals of different ages throughout the herd. Because of this, EPDs can be used for both selection and culling purposes. Producers can select young boars and gilts with the best EPDs to serve as replacements. After animals produce offspring, their EPDs are recalculated based on their progeny records. Sires and dams with low EPD's can be culled.

With across-herd analyses, the population base is the whole breed. Breed associations publish EPDs from across-herd sire summaries which producers use to compare boars. Each year the across-herd sire summary presents updated EPDs. EPDs change as more records are included in the analyses. Also the population being evaluated will change with years. If genetic progress is occurring, the population base will be improving. In this situation, an above-average boar (based on EPDs) in one year, may be evaluated as an average animal several years later. When buying semen, strive to select high EPD boars based on recent across-herd evaluations. Avoid trying to compare boars from sire summaries of different years.

Besides providing EPDs, genetic evaluation programs provide accuracy values that measure the reliability of the EPDs. High accuracy EPDs are more reliable and are less likely to change with further evaluations. Producers can put more confidence in EPDs with high accuracies.

When buying semen, consider both EPDs and accuracies in selecting boars. For producers wanting to reduce the risk in selection, choose semen from several boars with high-accuracy values and moderate to high EPDs. Use the high EPD boars for most of the matings. For producers willing to take more risk in selection, choose high EPD boars that differ in accuracy values. With these high EPD boars, use the individuals with the highest accuracies for a greater number of matings.

Producers need to decide how to use EPDs on several traits when selecting animals. One method is to set minimum standards for the EPDs for the various traits. Animals that perform above the standards would be selected.

Another method of selecting animals is by using one of the selection indexes provided by the genetic evaluation program. Indexes give each animal an overall score based on its EPDs for the various traits. Animals can be ranked based on index scores and the top individuals can be selected.

Economic and genetic factors are used in deriving index equations so that each trait is emphasized according to its contribution to overall merit. Indexes allow superior performance in one trait to compensate for average performance in another trait. Selection indexes take into consideration the genetic correlations among traits so that simultaneous improvement of multiple traits will occur.

Several indexes are being used by producers. A sow productivity index (SPI) includes number born alive and 21-day litter weight. Number born alive, 21-day litter weight, adjusted backfat, and days to market are included in the maternal line index (MLI). The terminal sire index (TSI) includes adjusted backfat and days to market. Seedstock producers can use the MLI to select animals in maternal and dual purpose breeds. The TSI can be used in terminal sire breeds. Either the MLI or TSI can be used in culling sows in terminal sire breeds.

Commercial producers are encouraged to use the MLI when selecting boars or gilts to use in the maternal line of a terminal cross or rotaterminal crossbreeding program. The TSI is recommended when selecting terminal sires. Either the MLI or TSI can be used when selecting boars for rotational crossbreeding programs.

Consider the data in Table 4 to illustrate the use of indexes. When selecting a boar to sire replacement gilts for a rotaterminal crossbreeding system, boar 30-11 would be the best choice because it has the highest score for the MLI. In selecting a terminal sire, boar 27-5 would be the proper choice because it has the highest score for the TSI.

Across-herd sire summaries can be used as a tool in selecting boars. Ideally, producers should buy high indexing sons of higher ranking boars in the sire summary.

Table 4. Index scores for a group of boars.

Boar no.	Index	
	Terminal (TSI)	Maternal (MLI)
27-5	128	70
32-7	88	157
29-2	102	117
23-10	88	152
30-11	104	160
31-10	113	138
47-12	92	109
58-5	95	105
20-11	65	88
50-5	93	71

Crossbreeding

Crossbreeding is mating animals from different breeds or lines. Pork producers use crossbreeding to produce hybrid vigor (heterosis) and to combine the attributes of various breeds for commercial production of pigs.

A trait shows heterosis due to an increase in the non-additive genetic value resulting from mating animals of different breeds. The degree of relationship among breeds in the cross affects the non-additive value which in turn influences the level of heterosis. Crossing breeds or lines that are least related genetically results in a large increase in non-additive value and a high degree of heterosis.

Heterosis exists when crossbred offspring perform better than the average of the parental breeds or lines. The performance of a given cross may be more or less than the performance of the best parental breed; thus, selection of the right breeds is important.

Generally, heterosis is measured as the percent improvement in performance of crossbred animals over the average of their parental breeds. Heterosis percentages based on a number of crosses are presented in Table 5.

Heterosis percentages vary among performance traits (Table 5). Lowly heritable traits, such as 21-day litter weight, have a higher degree of heterosis than highly heritable traits such as backfat. Three forms of heterosis are: individual, maternal, and paternal. Crossbred pigs express individual heterosis that results in faster rates of gain and better survival compared to purebred hogs. Maternal heterosis causes crossbred sows to farrow more pigs and to wean larger, heavier litters than purebred sows. Paternal heterosis causes crossbred boars to reach puberty earlier and express more sexual aggressiveness than purebred sires.

Mate sows with boars of different genetic composition to maximize individual heterosis in the offspring. If the parents share any breed in common, some loss of heterosis will occur. For example, a backcross mating of a Duroc boar to Duroc-Landrace F1 gilts results in only 50% of the maximum individual heterosis being achieved (Table 6). To maximize maternal heterosis, use crossbred females produced from parents of different breeds.

Commercial producers are encouraged to use planned crossbreeding systems. The three types of crossbreeding systems commonly used by pork producers are the rotational, terminal, and rotaterminal. The expected heterosis levels for the three systems are shown in Table 6.

Table 5. Average percent heterosis advantage for various swine traits.*

Trait	First cross using purebred females as parents	Multiple cross using crossbred females as parents
	% Advantage of offspring over parents	
Number pigs born alive	0.5	8.0
Number pigs at 21 days	9.0	23.0
21-day litter weight	10.0	27.0
Days to 220 lb.	7.5	7.0
Feed per pound gain	2.0	1.0
Backfat	-2.0	-2.0
Loineye area	1.0	2.0

* Ahlschwede, W.T. et al. 1988. Crossbreeding systems for commercial pork production. PIH-39. Pork Industry Handbook.

Table 6. Percentage of the maximum heterosis obtained from various crossbreeding systems with breeds A, B, C, and D.

System	Percent Heterosis	
	Offspring	Maternal
Crosses for replacement gilts:		
A boar x B sows	100	50
C boar x .5A-.5B sows	100	100
A boar x .5A-.5B sows	50	100
Rotations of:		
2-breeds	67	67
3-breeds	86	86
4-breeds	93	93
Terminal crosses of:		
D boar x .5A-.5B sows	100	100
D boar x .75A-.25B sows	100	50
D boar x .5A-.25B-.25D sows	75	100
Rotaterminal with:		
2-breed sow rotation	100	67
3-breed sow rotation	100	86

With the rotational system, the producer alternates the use of two or more selected breeds of sires. Replacement gilts are produced from the rotation and mated to the least related breed of sire in the system. Dual purpose breeds should be used in this program.

For the terminal cross, prolific crossbred replacement gilts are purchased or raised by the producer. These females should be mated to unrelated terminal sires with all offspring being marketed.

The rotaterminal system is a combination of the rotation and terminal cross. A 2- or 3-breed rotation in about 15% to 20% of the herd is used to produce replacement females for the entire program. The remaining 80% to 85% of the sows are mated to terminal sires with all offspring being marketed. An example of a rotaterminal system is shown in Figure 1.

For the terminal cross, most producers buy replacement gilts. When all replacement females are purchased, management of the terminal cross is simplified compared to the other crossbreeding systems. With the rotation and rotaterminal systems, all replacement females are home-raised.

The terminal and rotaterminal programs are referred to as specialized crossbreeding systems. Specialized systems tend to produce more uniform market pigs compared to the rotation. Furthermore, specialized systems make better use of breed strengths while minimizing some weaknesses if the proper breeds or lines are selected. Producers are encouraged to use specialized systems that produce a high level of heterosis and fit into their management schemes.

Inbreeding

Most seedstock producers mate unrelated animals because they purchase their replacement boars. Seedstock herds practicing only within-herd selection can end up practicing inbreeding. Inbreeding refers to mating animals more closely related than the average of the breed, such as a brother-sister mating. Mating related animals results in offspring with more homozygous pairs of genes since relatives share some of the same genes.

The inbreeding coefficient estimates the increased proportion of homozygous pairs of genes. A higher inbreeding coefficient represents a greater degree of inbreeding. Inbreeding coefficients range from 0 (for non-inbred animals) to 100% but values over 50% are uncommon in livestock. Table 7 shows inbreeding coefficients for offspring from different matings.

Table 7. Inbreeding coefficients for various matings.

Type of Mating	Inbreeding, %
Grandparent-grandoffspring	12.50
Half brother-sister	12.50
Parent-offspring	25.00
Full brother-sister	25.00

Mating animals that share at least one common ancestor in their pedigree results in inbred offspring. A recent ancestor appearing frequently in the pedigree results in a greater degree of inbreeding. Distant ancestors, even if they appear frequently in the pedigree, will cause a lower inbreeding coefficient.

Linebreeding is a milder form of inbreeding that attempts to keep the offspring closely related to some ancestor that is dead or not available for use. Linebreeding has the same effects as inbreeding.

A rapid rate of inbreeding often depresses performance in certain traits due to a decrease in the non-additive value in those characteristics. Survivability and growth rate are often lower for inbred pigs. Inbred boars tend to show less interest in breeding and reach puberty at later ages than non-inbred individuals. Inbred sows often produce smaller, lighter litters than non-inbred females.

If deleterious or lethal genes are present, inbreeding can cause more birth defects to appear because it tends to concentrate undesirable genes within the line. Thus, inbred matings (such as sire-daughter) can be used to test for undesirable genes.

Inbreeding can occur when within-herd selection is used. High rates of inbreeding can easily offset any progress possible from within-herd selection. Thus, seedstock operations need to have an understanding of what factors affect the rate of inbreeding so they can take appropriate action if they use home-raised sires.

For operations practicing mainly within-herd selection of replacement boars, the genetic relationship among sires is important. If all selected replacement boars are sired by one individual, the herd can expect a faster inbreeding buildup. Consequently, it is important to start a within-herd breeding program with as many unrelated sires as possible. After the program is started, the number of replacement boars selected each year will affect the rate of inbreeding. The greater the number of sires, the lower the rate of inbreeding.

Seedstock herds that buy replacement boars should not expect problems with inbreeding. However, the rate of genetic improvement can be reduced if inferior boars are used in these herds. Thus, it is important to carefully choose breeding stock suppliers and select top animals from within those herds.

Summary

Economically important traits can be improved when pork producers understand and apply principles of genetics. Producers apply genetic principles when selecting (1) a crossbreeding program, (2) breeds, (3) seedstock suppliers, and (4) individual animals. Commercial producers should select crossbreeding systems that fit into their management schemes and make good use of both heterosis and breed strengths.

Advanced genetic evaluation programs using BLUP procedures provide useful information such as expected progeny differences (EPDs), accuracies, selection indexes, and across-herd sire summaries. Selection indexes provide overall scores on animals based on their EPDs for several traits. The emphasis given to the traits differ between the terminal sire index and the maternal line index. Select the appropriate index according to the role of the animals in the breeding program. Seedstock producers can use selection indexes for selecting and culling animals.

Related Publications

The following Pork Industry Handbook fact sheets contain additional information on understanding and applying genetic principles.

PIH-9, Boar selection guidelines for commercial pork producers.

PIH-27, Guidelines for choosing replacement females.

PIH-39, Crossbreeding systems for commercial pork production.

PIH-58, Selection guidelines for the seedstock producer.

PIH-97, Swine genetic abnormalities.

PIH-101, Selection for feet and leg soundness.

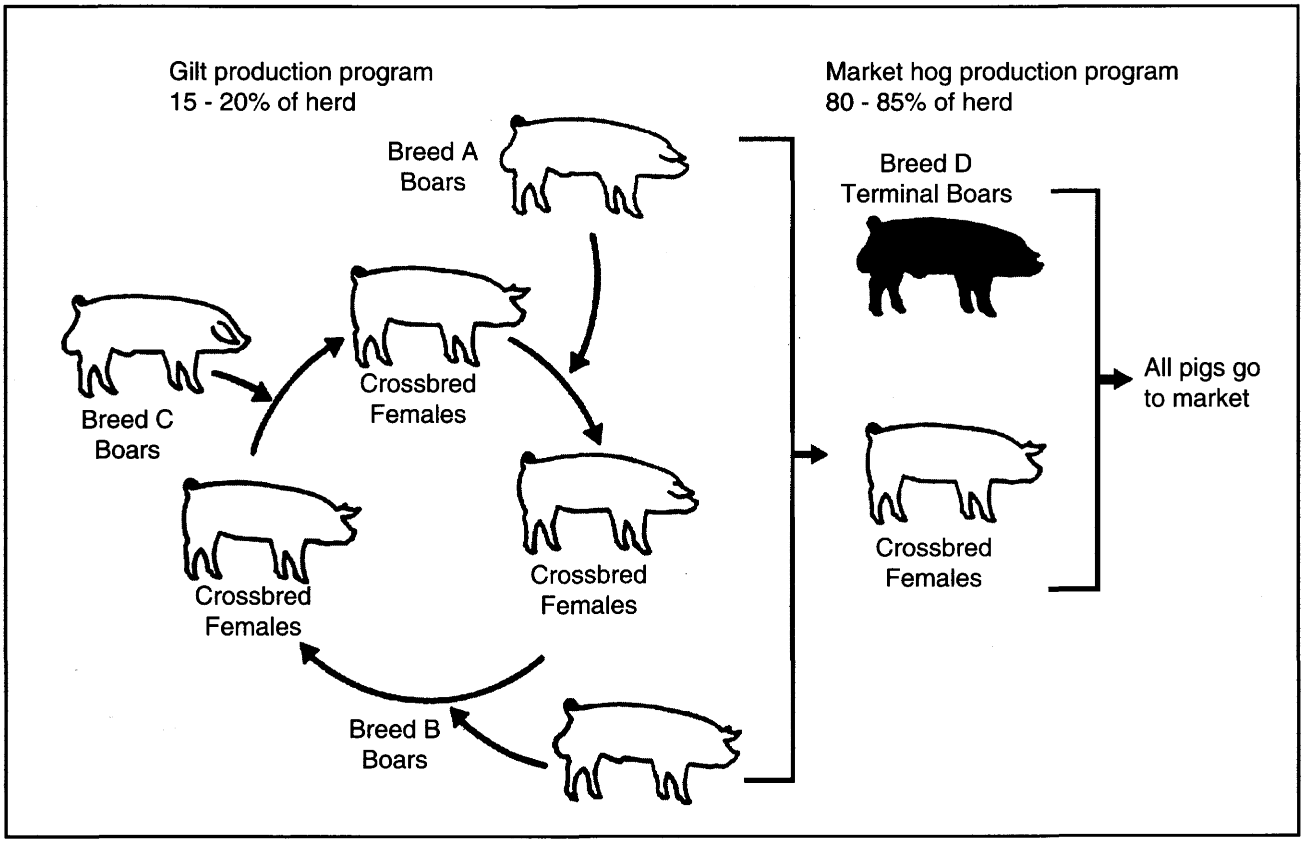

Figure 1. Rotaterminal crossbreeding system.

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