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The Impact of Genetics on Pork Quality (Revised)

The starting point for this topic is that pork production is a business enterprise. Although most pork producers have personal enjoyment as one of their goals, the business must be profitable over the long run for the producer to realize the satisfaction that comes from a successful operation. We must also keep in mind that the quality of our product will have a major effect on our business and our future. This impact of meat quality will be seen on consumer acceptance of our product and the repeat business that is realized. The quality of our product will also have an influence on the price the producer receives for their product.

The retail market for pork is rapidly diverging into two different segments: commodity pork for our traditional grocery store sales of pork and value-added markets for pork that is consumed out of the home. These two market segments have different requirements for pork quality. The consumer at the grocery store prefers meat that is very lean with a consistent color and little purge.

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- **Color** - Loin color is often evaluated visually using a five-point scale with a score of one (1) meaning the pork is very light and pale and a score of five (5) designating dark red muscle color. An objective measurement of color is taken using a Minolta Chromameter after the fresh loin surface is allowed to bloom. The Minolta value measures light reflectance of the loin muscle. Lower values indicate darker loin color and higher values indicate a paler, lighter colored meat. Consumers generally prefer medium to darker colored meat

- **Ultimate pH** - This measures the acidity of the loin muscle and is taken 24 hours after slaughter using a pH meter. Higher pH is associated with lower drip loss, darker color, more firmness, and increased tenderness of the loin chop -- all positive attributes

- **Water Holding Capacity (WHC)** - – Water holding capacity is the ability of meat to retain its water during cutting, heating, grinding, and pressing. It's reciprocol, driploss, is the amount of exudate or moisture on the cut loin surface and can be estimated using the Kaufmann filter paper method. A pre-weighed piece of filter paper is placed on the loin muscle for a standard length of time and allowed to absorb moisture on the surface. It is then reweighed and the difference in weight is the WHC estimate. Lower numbers are more desirable due to their association with higher value for all segments of the industry.

- **Intramuscular Fat (IMF)** - - Intramuscular fat or lipid content is measured in the laboratory using a loin muscle sample. This trait is very important for consumer satisfaction with pork. Sensory panel scores for juiciness are improved with higher levels of IMF and extremely low values usually indicate poorer eating quality characteristics. Some people think that a minimum of 2% intramuscular fat is needed to produce consumer acceptable pork loins, although enhancement technology certainly replaces some of this need.

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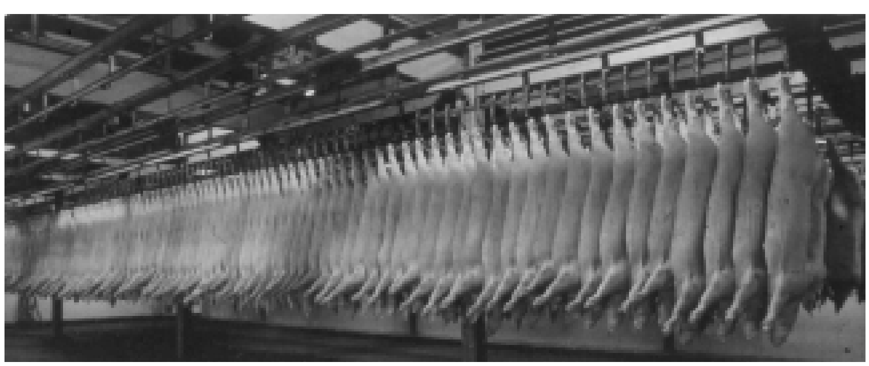
Unfortunately, if this very lean pork is overcooked at home, the resulting product does not lend itself towards repeat purchases. The consumer that is eating pork out of the home judges their satisfaction by the eating qualities of the product. The traits that maximize the satisfaction in this market (marbling, juiciness and tenderness) are different than traits that maximize grocery store sales. The different markets have different needs for pork quality and both must be satisfied.

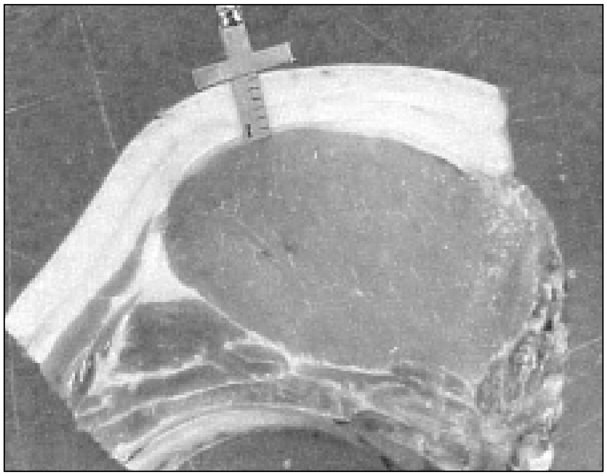
So then just what is product quality? In the past quality was simply "lean", but today it's a totally different story. The word quality can mean many things, but most importantly, it means customer satisfaction with the product. Ideal quality in fresh pork can be defined as a combination of traits that results in a wholesome product that tastes good, has good value and generates repeat sales.

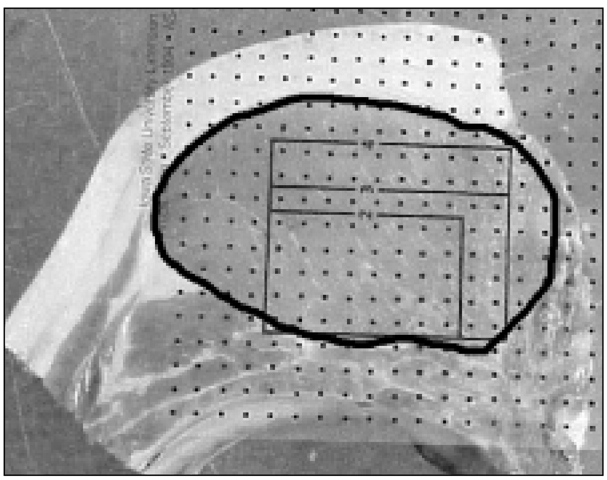
The four primary measurements of meat quality that have been identified as key traits to consider in evaluation of muscle quality are color, ultimate pH, water holding capacity, and intramuscular fat. These traits are important because they are related to attractiveness, palatability, and product loss during processing, storage and cooking, and therefore, account for a large portion of the economic loss associated with poor quality pork. A description of each trait follows.

Inferior muscle quality continues to be a serious pork industry problem (Kauffman et al., 1992). The increased participation in merit buying programs by producers (Kauffman and Russell, 1993) has increased the emphasis given to leanness and muscling in selection programs of the seedstock industry. Unfortunately, this emphasis on leanness has resulted in a reduction in meat quality and eating quality traits of pork. Breeders in Denmark have been very successful in increasing carcass lean but now face the problem of reduced eating quality. British breeders have increased carcass lean percent for over fifteen years but have also reduced intramuscular fat, a measure of meat quality, below acceptable levels (Warkup, 1993; Barton-Gade, 1990).

The trends we have seen in swine marketing over the past few years have changed dramatically. In the early 1990's we saw the pricing system change from one based solely on weight of truckloads to one based on the lean value of each individual carcass, with an optimum weight range for each carcass which must be met to avoid discounts. Premiums are given to selected producers who can deliver large quantities of hogs in







regularly scheduled shipments directly to the packer. There is now an assumption of freedom from residues where the producer pays for any violation of that assumption. The reasons for the current pricing structure start with the point that most of the above mentioned criteria directly influence the profitability of the packer. Much of this is derived when the consumer puts pressure on the retailer for a lean, high quality product. The retailer then transfers this pressure economically to the packer, who transfers this pressure economically to the commercial producer, who transfers this pressure economically to their seedstock supplier. However, the system is certainly not constant. The industry is now seeing adjustments to the price of the carcass based on the estimated meat eating quality of its components. If a carcass is exceptionally lean, the base carcass price is discounted at many packing plants due to the loss of value in the belly (for bacon) that is associated with these ultralean animals. Some packing plants are also adjusting their base prices according to the historical pH of the carcasses from specific pork producers.

This pricing structure from the packer creates a dilemma for the commercial swine producer. The packers' perspective is to first keep their customers happy, keep their kill line full (to minimize fixed costs), maximize the percent lean in the carcasses while minimizing meat quality problems, and enhance uniformity while paying as little as possible for the pigs. The producers' perspective is to first have someone to buy the pigs, then they must decrease the cost of production relative to market price so as to maximize profit. The bottom line is that they must balance the demands of the packer against the totality of factors that really influence profit in their operation. But it is essential that both parties keep in mind that they must have each other making a profit for either to make a profit over the long run.

The commercial pork producer has the option of focusing on several different types of traits. Carcass traits (such as percent lean, meat quality) have a strong genetic influence and therefore are easy to change through selection.

However, selection for extreme leanness will reduce growth, reproduction, and meat quality. An improvement in Fat Free Lean Index (FFLI) of 1% will result in an increase in profit of approximately $0.33/cwt. The effect of meat quality on price is not yet known. Growth traits (such as days to market and feed conversion) are moderate in genetic influence and can also be changed through selection. However, selection for fast growth rate will usually increase backfat thickness. If the producer can reduce days to market by one day it will enhance profit by about $0.07/cwt. Reproductive traits (such as litter size, farrowing rate) are low in genetic influence and are harder to change with selection. The best reproduction will usually increase growth rate but add fat to the animal. Economically, it is very important as an additional pig born alive will add approximately $13/sow to profit. It is probably best then for the commercial producer to first make sure carcass merit is adequate to ensure purchase of their hogs. Then, they should balance reproduction, growth, and carcass merit so as to maximize overall profitability for their specific farm.

Genetic Improvement

The genetic improvement program for any pork operation involves two primary components: the use of an accurate selection program and an optimal mating system to ensure long-term genetic improvement. The most efficient mating system for most swine producers is some form of a terminal cross. A proper terminal cross will ensure maximum heterosis for reproductive and growth traits and it requires less labor overall as there is more consistency in the job expected of all employees. It also allows for more consistency of product in terms of hair color and performance. The best use of specialized sire and dam lines is another advantage of the terminal cross.

For the commercial producer to make genetic improvement in meat quality traits, they must first realize that both the sire and the dam contribute equally to the genetic merit for meat quality. Next, they must purchase from a seedstock source that measures meat quality and has lines that are objectively proven to be superior for meat quality. The first selection decision is which population to purchase from. For example, different populations would include DeKalb, Duroc, PIC or Hampshire. The second selection decision is which line within the chosen population to use. For example, the EB line of terminal sire from DeKalb, or the Great Dane line of purebred Durocs, or the L280 line boar from PIC, or the Osborne line of purebred Hampshires. The third selection decision is which boar from the chosen line to use. This decision must be guided by the individual performance testing programs offered by each seedstock source.

The decision as to which population has the best genetic merit for any specific trait is a difficult one. The producer must consider diverse traits such as reproduction, feed conversion, lean gain, and meat quality. To answer which population is best, you must have the different populations tested at the same time, in a representative facility, by unbiased personnel using the most accurate BLUP genetic evaluation procedures. Both seedstock breeding companies and independent purebred based suppliers are viable populations.
Commercial companies have an

Table 1. Sire line means for growth and carcass traits in the National Genetic Evaluation Program.

Sire Line	Average Daily Gain (lb/d)	Lean Gain on Test (lb/d)	Tenth Rib Backfat (in.)	Loin Muscle Area (sq. in.)
Berkshire	1.85^{c}	$.63^{c}$	1.25^{d}	5.74^{c}
Danbred HD	1.83^{c}	$.72^{a}$	$.98^{a}$	6.75^{a}
Duroc	1.95a	$.70^{ab}$	1.13^{c}	6.14^{b}
Hampshire	1.87^{bc}	$.71^{a}$	1.01^{a}	6.58^{a}
NGT Large White	1.87^{bc}	$.65^{c}$	1.17^{cd}	5.62^{c}
NE SPF Duroc	1.97^{a}	$.73^{a}$	1.11^{bc}	6.35^{ab}
Newsham	1.90^{ab}	$.73^{a}$	$.98^{a}$	6.45^{a}
Spotted	1.84^{c}	$.63^{c}$	1.24^{d}	5.83^{c}
Yorkshire	1.84^{c}	$.68^{b}$	1.05^{ab}	6.17^{b}

Crossbred pigs of HAL Normal Genotype.
Least squares means with same superscript are not different (P<.05).

Table 2. Sire line means for meat quality traits in the National Genetic Evaluation Program.

Sire Line	Minolta	Ultimate pH	Drip Loss (%)	Intramuscular Fat (%)
Berkshire	21.8^{a}	5.91^{a}	2.43^{a}	2.43^{bc}
Danbred HD	22.6^{b}	5.75^{cd}	$3.34c^{d}$	2.61^{b}
Duroc	22.3^{ab}	5.85^{ab}	2.75^{ab}	3.19^{a}
Hampshire	23.3^{c}	5.70^{d}	3.56^{d}	2.61^{b}
NGT Large White	21.4^{a}	5.84^{ab}	$2.92b^{c}$	2.25^{c}
NE SPF Duroc	22.6^{b}	5.88^{ab}	2.81^{ab}	3.30^{a}
Newsham	22.2^{ab}	5.82^{bc}	2.99^{bc}	2.27^{c}
Spotted	22.9^{bc}	5.83^{bc}	2.88^{b}	2.65^{b}
Yorkshire	22.1^{a}	5.84^{ab}	2.85^{b}	2.42^{c}

Crossbred pigs of HAL Normal Genotype.
Least squares means with same superscript are not different (P<.05).

advantage in mandatory testing programs, while the pure breeds have an advantage in more genetic diversity in their nucleus lines. Both seedstock sources utilize accurate breeding value estimation programs.

National Genetic Evaluation Programs

The Terminal Sire Line National Genetic Evaluation Program (NGEP) and the Maternal Line Evaluation Program (MLEP) conducted by National Pork Producers Council (NPPC) were programs designed to estimate sire line differences and dam line differences for growth, carcass, reproduction, meat quality, and eating quality traits. Results of these programs were released in 1995 and 1999, respectively. Base values or means for the numerous traits evaluated assisted producers and their seedstock suppliers in identifying lines that excelled in the economically important traits. Heritabilities and genetic correlations, concepts that are important in selection programs and in setting breeding objectives, were also estimated in the NGEP.

Tables 1-3 list sire line means estimated from the NGEP and indicate that significant differences between sire lines exist in growth, carcass, meat quality, and eating quality traits. In general, the sire lines that excelled in the familiar carcass traits of tenth rib backfat and loin muscle area (Danbred, Hampshire, Newsham) were not the most desirable for the meat and eating quality traits. Conversely, the sire line that was superior for most quality traits (Berkshire) also sired the fattest pigs with the smallest loin muscle areas. Duroc-sired pigs were intermediate for backfat and loin muscle area and slightly below the Berkshire-sired pigs for most quality traits.

Maternal lines also play an important genetic role in determining the meat quality of pork. The NPPC Maternal Line Evaluation Program compared six different maternal populations as to their relative genetic merit for reproduction, growth, carcass and meat quality traits. Table 4 shows the relative differences between these six populations for the meat quality traits of 24-hour pH, color score and intramuscular fat percentage. There were no significant differences between the different maternal populations in these meat eating quality traits. All genetic populations were quite acceptable in their pH levels and color scores and all were somewhat low in IMF%. These results suggest that none of the tested maternal lines have an advantage in meat quality.

Heritabilities and genetic correlations for selected carcass and quality traits are listed in Table 5. Note that heritabilities for meat and eating quality traits are mostly low to moderate in magnitude, indicating that selection within sire line will be difficult. Genetic correlations also have the potential to limit selection progress due to a correlated response in one trait when selection for another trait is practiced. A favorable correlation means that selection for one trait improves another correlated trait, while a large, unfavorable correlation makes simultaneous improvement in both traits more difficult. The genetic correlation between tenth rib backfat and intramuscular fat is strong (.30) and demonstrates the need for

Table 3. Sire line means for eating quality traits in the National Genetic Evaluation Program.

Sire Line	Cooking Loss (%)	Instron Tenderness (kg	Tenderness Score (1-5)	Moisture Content (%)
Berkshire	22.5[a]	5.33[a]	3.50[a]	66.0[a]
Danbred HD	24.3[b]	5.85[c]	3.45[ab]	65.3[ab]
Duroc	23.1[ab]	5.64[b]	3.38[ab]	65.0[b]
Hampshire	26.0[d]	5.82[c]	3.36[ab]	65.0[b]
NGT Large White	22.9[ab]	5.75[bc]	3.16[c]	65.5[ab]
NE SPF Duroc	22.5[a]	5.52[ab]	3.36[ab]	65.3[ab]
Newsham	24.2[bc]	5.87[c]	3.25[bc]	65.1[b]
Spotted	23.4[ab]	5.68[b]	3.16[c]	65.5[ab]
Yorkshire	23.5[bc]	5.87[c]	3.26b[c]	65.3[ab]

Crossbred pigs of HAL Normal Genotype.
Least squares means with same superscript are not different (P<.05).

Table 4. Dam line means for eating quality traits in the NPPC Maternal Line Evaluation Program.

Dam Line	pH	Color	IMF%
American Diamond	5.63	3.15	2.00
Danbred	5.63	3.17	1.93
DeKalb DK44	5.63	3.05	2.09
DeKalb MXP	5.66	3.12	1.94
NSR	5.63	3.14	2.08
Newsham	5.62	3.21	1.90

Least squares means.

Table 5. Heritabilities and genetic correlations for selected traits in the National Genetic Evaluation Program.

	BF10	LMA	MIN	PH	IMF	C.L.	INST
Tenth Rib BF	.46						
Loin Muscle Area	-.61	.48					
Minolta	.08	.02	.25				
Ultimate pH	.03	-.11	-.49	.38			
Intramuscular Fat	.30	-.25	.11	0	.47		
Cooking Loss	.01	.01	.26	-.45	-.02	.08	
Instron	-.17	.15	.18	-.42	-.17	.58	.20

Heritabilities on diagonal and genetic correlations below diagonal.

monitoring both traits.

Major Genes
Napole Gene

Two major genes with effects on carcass, meat, and eating quality traits in swine have been identified, the Napole (RN) gene and the halothane (HAL) gene which is associated with the Porcine Stress Syndrome (PSS). The RN gene was reported by LeRoy et al. (1990) and was described as a dominant allele (RN-) and recessive allele (rn+) that is simply inherited (one locus). The effect of the RN- gene had previously been identified by Monin and Sellier (1985). The effect of the dominant RN- allele is to reduce the ultimate pH of all muscle, but especially the longissimus dorsi and ham muscles. Meat with extremely low ultimate pH has poor curing and processing characteristics.

Results of the National Pork Producers Council (NPPC) Pork Challenge Test (Goodwin, 1994) and the National Genetic Evaluation Program (NPPC, 1995) support this previous work. Data presented in Table 6 is from research done at the University of Illinois. This work shows that the presence of the dominant RN gene results in carcasses with a reduced yield and meat with a reduced water holding capacity increased drip and cooking loss and more purge in the ham and loin muscles.

Halothane Gene

The halothane (HAL) gene or stress gene is a mutation on chromosome 6 of the pig at nucleotide 1843. The HAL gene increases lean meat content but is also associated with pale, soft, and exudative (PSE) pork and PSS. The Porcine Stress Syndrome (PSS) is a genetic abnormality whereby the animal lacks the ability to adapt to stressors encountered during its lifetime. It was first characterized by Topel et al. (1968) as a condition in which stresses such as physical exer-

Table 6. Least squares means for Napole gene effects on yield, water holding capacity, drip loss, cooking loss and purge from University of Illinois research.

Traits	RN (n=44)	rn+ (n=62)	Avg SE	Sig
Napole yield	91.65	95.28	.31	**
WHC/protein	1.95	2.10	.05	*
48 hr drip	7.5	4.97	.43	***
Cooking loss (%)	24.09	20.56	.70	***
Loin-purge (%)	4.47	3.55	.30	*
Ham-purge (%)	6.29	4.99	.28	*

*, **, *** significance at .05, .01, and .001 level
Animals with a GP value > 150 mmoles/g classified as RN-

Table 7. Economic Value of Stress Gene

Trait	Normal	Carrier	Diff	$/pig
Days 250	172.8	172.7	0	
BF 10, in.	1.13	1.12	0	
LMA, in2	5.94	6.23	.29	$1.65
Drip, %	2.61	3.09	.48	-.31
pH	5.85	5.84	0	
IMF, %	2.60	2.28	-.32	-3.17
Instron, kg	5.66	6.16	.50	-2.08
Total				**$-3.91**

tion transport, fighting or mating resulted in sudden death. Christian (1972) suggested malignant hyperthermia syndrome (MHS) in humans and PSS in swine to be synonymous and provided evidence in support of a theory of autosomal recessive inheritance with variation in penetrance.

Inheritance of the HAL gene (Mabry et al, 1981) is from a single locus and there are two alleles: normal (N) and mutant (n). There are three possible genotypes: normal (NN), carrier (Nn) and mutant (nn). The halothane gas screening test developed by Christian (1974) and Eikelenboom and Minkema (1974) was used to detect mutant genotype pigs, but it was unable to distinguish between normal and carrier animals. Development of the DNA probe test (Fujii et al., 1991) made it possible to identify all three genotypes and to evaluate the effect of the HAL gene on performance and quality traits.

The use of carrier (Nn) and homozygous mutant (nn) sires to produce market hogs in the U.S. became popular in the 1990's due to the perception that they will sire pigs with more desirable lean composition. Mating Nn males and normal (NN) females will result in offspring that are 50% NN and 50% Nn. If stress positive (nn) boars are mated to NN females, 100% of the offspring will be carriers (Nn). Research reported by Goodwin (1994) suggests that 30% to 50% of the carrier

(Nn) market hogs will produce carcasses with inferior muscle quality.

Results from the National Genetic Evaluation Program offer an excellent comparison of performance and carcass quality traits of normal and stress carrier animals. All barrows and gilts in the study were classified by their stress genotype using the DNA probe test. Of the 3,261 pigs that finished the test, 7 were mutant pigs (nn), 391 were carriers (Nn), and 2,863 were normal (NN). Differences between carrier and normal animals for various traits evaluated in this study are listed in Table 7. Differences between the two genotypes were not significant for growth rate or backfat at the tenth rib. The stress carrier group had a .29 sq. in. advantage in loin muscle area, which contributed to a slight advantage in carcass value. On the other hand, carrier pigs produced carcasses that were much less valuable to the packer and processor. Their meat was paler and less tender, and had less intramuscular fat and greater drip loss. The net economic value of a carcass containing the stress gene was -$3.91.

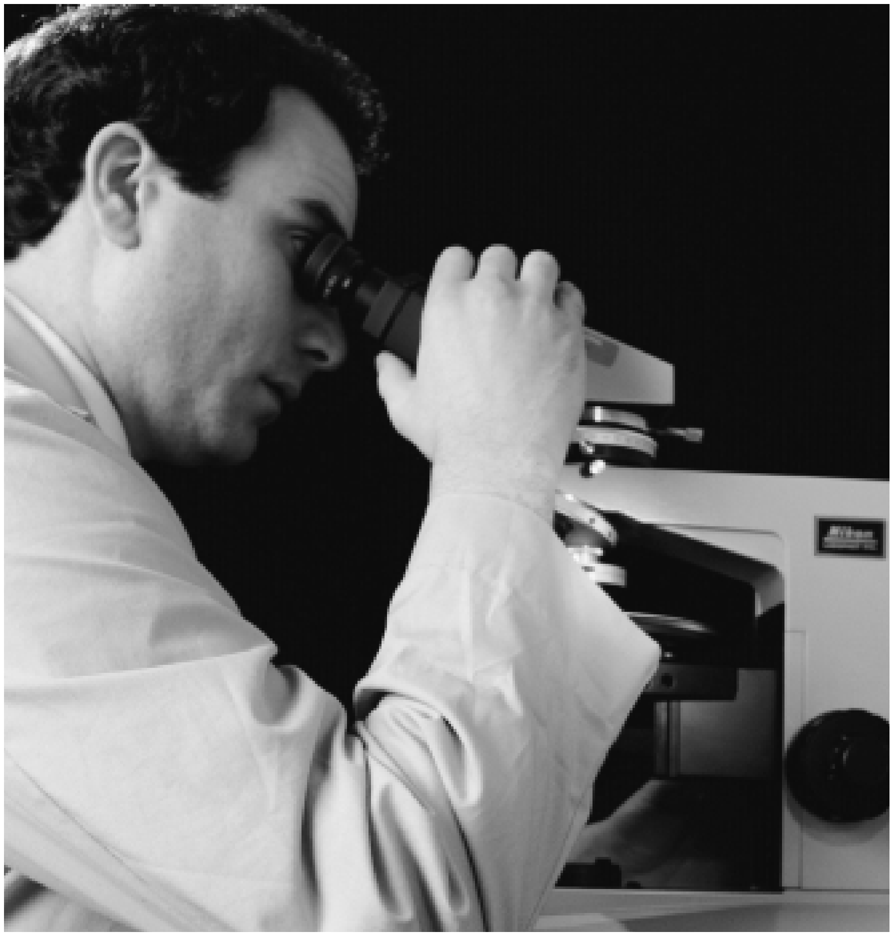
Table 8. Pork loins failing minimum muscle quality standards in the National Genetic Evaluation Program (NGEP).

	Stress Genotype	
Criteria	Normal (NN) 2,863 Pigs %	Carrier (Nn) 391 Pigs %
Very pale color	4.2	15.9
Very dark color	10.6	7.7
Devoid marbling	1.3	4.6
Firmness (soft)	10.4	27.9
Drip loss (exudative)	2.9	6.9
Overall rating*	22.5	36.8

*Some loins disqualified for several criteria. Overall rating includes each pig only once.

Table 8 lists the percentage of pork loins from each of the stress genotype groups that did not meet pork quality standards. Those standards were minimum or maximum levels of acceptability, depending on the trait. Carrier animals produced a higher percentage of loins that were extremely pale, devoid of marbling and excessively soft with excessive drip loss. The percentage of stress carrier genotype loins considered unacceptable (overall rating) was nearly twice that of the normal group.

The stress gene doesn't account for all of the industry's muscle quality problems since over 20% of the loins from pigs in this study without the gene were rated unacceptable. Elimination of stress carrier and stress positive animals from breeding programs will, however, significantly reduce PSE problems. In addition, proper handling procedures that reduce stress during transport and prior to slaughter also will affect pork quality. Consistent muscle quality should be the goal of all segments of the industry.



Summary

Results from the NPPC Genetic Evaluation Program projects show that large sire line differences exist in the industry for most of the meat and eating quality traits. Significant differences between maternal lines are not seen. Heritabilities and genetic correlations estimated from these studies demonstrate the need to monitor quality traits, as well as growth and carcass traits, in industry selection programs.

Producers will be affected as packer and processor payment programs for quality continue to evolve. Since investments in genetic programs are generally long term, producers should consider how their products might be marketed in the future when genetic decisions are made.

Commercial producers should follow several steps to implement the most profitable genetic system under today's marketing system. First, they should use a terminal crossbreeding program that is custom fit to their specific breeding and gestation facilities. They should balance the emphasis they place on each trait so as to first have a market, then maximize profit. They should use objective information to decide on a source of genetically superior breeding stock. Lastly, they should avoid advice from people with vested interests in which breeding stock is purchased.

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