ICoMST
49th International Congress of Meat Science and Technology
2nd Brazilian Congress of Meat Science and Technology

Metabolic Modifiers and Genetics: Effects on Carcass Traits and Meat Quality

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SUMMARY

Metabolic modifiers are compounds that are either fed to animals, injected frequently, or implanted to improve rate of gain, improve feed efficiency, increase dressing percent, increase carcass meat yield percentage, improve visual meat quality, extend shelf-life, or improve meat palatability. Most metabolic modifiers have been developed and researched to improve growth performance and carcass composition, with fewer of them developed or researched specifically to improve meat quality. Research activity on metabolic modifiers that can be fed to livestock to improve or enhance meat quality has been extensive in the past few years, particularly in swine. Several in-depth review papers could be written on specific categories or types of metabolic modifiers. This paper will present a general review of the effects of metabolic modifiers and genetics on carcass composition and meat quality. Ellis and McKeith (1999) reviewed the effects of nutrition on the quality of meat from non-ruminants and Owens and Gardner (1999) reviewed the effects of ruminant nutrition on meat quality at the 1999 Reciprocal Meat Conference. Therefore, the effects of type of feed, energy source, dietary protein/energy ratio, feed withdrawal prior to slaughter, and related topics on beef and pork meat quality are not included here. Because there is considerably less research on the effects of metabolic modifiers in sheep and goat production or other minor meat species, the review will focus mainly on cattle and pigs, with some inclusion of poultry.

Emphasis will be on those metabolic modifiers that are or likely will be approved for use in cattle and pigs in the U.S. and other developed countries. Discussion of meat quality will include factors that affect visual quality, such as color, marbling, firmness, and maturity; factors that affect processing or packaged display quality, such as pH, color, water holding capacity, and antioxidant potential; sensory traits of tenderness, juiciness and flavor; safety; or human nutritional characteristics. Meat quality will be emphasized more than carcass composition or meat yield percentage.

Metabolic modifiers will be categorized as: 1) antibiotics, 2) ionophores, 3) anabolic steroids, 4) somatotropin, 5) phenethanolamines or beta agonists, 6) vitamins or vitamin-like compounds fed in supra-nutritional levels, 7) conjugated linoleic acid, and 8) other modifiers.

Keywords

Metabolic modifiers, carcass traits, meat quality, anabolic steroids, genetics.

A. METABOLIC MODIFIERS

Antibiotics

Beerman (1995) stated that the primary benefit of sub-therapeutic doses of antibiotics in diets for livestock is the control of harmful bacteria. Research has shown reductions in death losses and improvements of 5 to 10% in growth rate and(or) feed efficiency when bacterial contamination was a problem. This benefit is particularly true for poultry. Other than this benefit, sub-therapeutic levels of antibiotics in diets for livestock virtually have no affect on carcass composition or meat quality and, therefore, their use in the U.S. is being discouraged.

Ionophores

Ionophores are defined as organic substances that bind polar compounds and act as ion transfer agents to facilitate movement of monovalent (sodium and potassium) and divalent calcium ions through cell membranes (Beerman, 1995). These changes affect the transport of nutrients and metabolites across cell membranes. Ionophores are fed to over 90% of all feedlot cattle in the U.S., with doses ranging from 6 to 33 ppm of the diet. Monensin® is the most common ionophore for cattle. With the changes in transport of nutrients and metabolites across cell membranes, feed efficiency is improved consistently in cattle. Generally, this is accomplished by reduced feed intake without compromising rate of gain, or increased gain without any change in feed intake. Most studies show an improvement of 4 to 12% in feed efficiency, primarily through reduced feed intake. Beerman (1995) concluded that the effects of ionophores on dressing percentage and carcass composition are too small to be of economic importance. Research was lacking on effects of ionophores on meat quality.

Anabolic Steroids

Implants containing various anabolic steroids are used widely by the beef cattle industry in the U.S. in growing and finishing cattle because of economic incentives to increase growth rates and improve efficiency of feed utilization (Dikeman, 1997). Heifers and steers show the greatest response to steroid implants, whereas bulls do not show much response. In fact, bulls may deposit more, rather than less, fat when implanted. Implanted steers often achieve growth rate and feed efficiency similar to bulls (Fisher et al., 1986). In general, estrogenic implants are more effective in steers and androgenic implants more effective in heifers. Combination implants generally produce an additive effect compared to implants containing only an estrogenic or androgenic compound in both steers and heifers.

A review of the literature shows that anabolic steroid implants increase growth rate 10 to 20%. In general, breeds or types of cattle that have the greatest potential for muscle growth show the greatest response to implants. Greater responses often are observed during the first few weeks after implantation, suggesting a peak and then a decline in circulating concentrations of the hormones (Hayden et al., 1992).

The improvement in feed efficiency in response to implanting cattle with anabolic implants ranges from 5 to 14%. The improvement results from proportional increases in muscle growth relative to fat deposition (Keane and Drennan, 1987) and increases in feed intake (Beermann, 1994), which reduces the proportion of feed utilized for maintenance. Beermann (1994) stated that implanting cattle increases their potential mature size. Consequently, implanting increases the quantity of muscle growth and tends to delay fat deposition. At the same live weight, implanted cattle will have a higher percentage of muscle and a lower percentage of fat than non-implanted cattle. At the same age or time-on-feed, implanted cattle will have a greater weight of muscle and an equal or lower weight of fat. Dressing percentage will be increased slightly at a constant time endpoint. In addition, most anabolic steroid implants increase live and carcass weights significantly. Although anabolic steroids cause an increase in muscle growth and a decrease in fat deposition, meat yield percentage generally is not significantly altered because cattle are harvested at heavier weights. The cost effectiveness of anabolic steroid implants has been demonstrated repeatedly. In addition, implanting is a practical technology, there is no withdrawal time, and they are perfectly safe to use. No human health problems have been traced to approved anabolic steroid implants.

Approved anabolic steroid implants are characterized as being either estrogenic, androgenic, or a combination of both estrogenic and androgenic compounds. Another way to categorize anabolic agents is into natural hormones and xenobiotics, or combinations of these. Trenbolone acetate was approved in the late 1980's as a synthetic testosterone and is used in several combination implants. It is several times more potent anabolically than testosterone. The choice of implants and re-implant strategies by producers are dependent on the gender of cattle, stage of growth, and the potential impact on intramuscular fat (marbling) deposition and subsequent United States Department of Agriculture (USDA) quality grades. Unfortunately, the effects of implants on meat palatability have received little attention until recently. Beermann (1995) reported that the live weight required to attain "small" marbling necessary to grade USDA low Choice is increased 25 to 45 kg in steers administered trenbolone acetate x estradiol combination implants. This is because of the delayed fattening pattern of cattle receiving the implants. Combination implants containing trenbolone acetate are referred to in the beef cattle industry as "aggressive" implants because they generally increase growth rate, improve feed efficiency, delay fattening, and potentially decrease marbling to the greatest extent.

There are no major research reports demonstrating that anabolic steroid implants improve visual meat quality or meat palatability. The majority of research shows some reduction in marbling and tenderness when compared to non-implanted controls, although not all reductions are statistically significant. Obviously, the type of implant or re-implant strategy, type of cattle, and length of time on feed can have significant effects on the results. Belk and Cross (1988) and Morgan (1997) reported that the 'aggressive' use of anabolic implants commonly compromises beef carcass quality grades and increases the incidence of dark cutting carcasses. Furthermore, Foutz et al. (1990), Samber et al. (1996), Morgan (1997), and Roeber et al. (1999) indicated that some aggressive implanting strategies have been implicated as a possible cause of reduced meat palatability, specifically tenderness. In general, both trained and consumer sensory panels rate steaks from non-implanted controls as being more tender than those from implanted steers and heifers. In addition, Warner-Bratzler shear force (WBSF) values generally are lower (more tender) for steaks from non-implanted controls than for those from implanted cattle (Table 1). However, because at least 90% of all fed cattle in the U.S. are implanted, it is not very meaningful to evaluate the effects of various implants and implant strategies on marbling and palatability in comparison to non-implanted controls. It would be more meaningful to evaluate whether or not there are differences among implants or implant strategies in their effects on the incidence of dark cutters, reduced marbling, or decreased meat palatability.

Roeber et al. (1999) utilized 448 small- to medium-framed British crossbred steers to study the effects of different implants and implant strategies on performance, carcass and meat traits, and cooked meat palatability (Tables 2 and 3). Cattle were implanted at the beginning of the feedlot phase with one of five implant types, or not implanted. Cattle were then re-implanted after 59 d with the same or different implants, or not implanted to result in seven implant strategies and a non-implanted control group. The cattle were fed to a high degree of finish. Mean fat thicknesses and USDA yield grades did not differ among the various implant strategies (Table 2), although there were some differences in the percentage of yield grade 4 and 5 carcasses as well as in the percentage of Prime and Choice carcasses. The cattle implanted with Encore and Component T-S® had higher marbling scores than those implanted with Revalor-S®/Revalor-S® and No implant/Synovex Plus®. This group also had a higher percentage of carcasses grading USDA Choice and Prime than those implanted with Ralgro®/Synovex Plus®, Revalor-S®/Revalor-S®, Revalor-S®/No Implant, or Synovex Plus®/No Implant. The Revalor-S®/No Implant treatment group resulted in steaks with higher WBSF values than those from non-implanted controls (Table 3). In addition, the percentage of steaks with shear values >3.86 kg was less (P<0.05) for cattle implanted with Encore and Component T-S® than for those implanted with Revalor-S®/No implant and No Implant/Synovex Plus®. The Encore and Component T-S® implant resulted in the least increases in live and carcass weights. A consumer panel found that steaks from non-implanted controls were more tender than nearly all implant treatment groups; however, there were no differences among implant groups except that steaks from the Encore and Component T-S® treatment group were more tender than steaks from all other implant treatment groups, likely because this is a 'less aggressive' implant regimen. The various implant strategies involving either Revalor-S® or Synovex Plus® reduced marbling and tenderness compared with non-implanted controls, but the differences among implant strategies involving these two implants were minimal.

Implant Composition/Release Time

Implant	Estrogenic effect	Androgenic effect	Release time
Synovex-C	7.2 mg	0 mg	120 d
Calf-oid	7.2 mg	0 mg	120 d
Ralgro	11-13 mg	0 mg	70 d
Compudose	24 mg	0 mg	160 d
Endore	43.9 mg	0 mg	160 d
Synovex-S	14.4 mg	0 mg	120 d
Synovex-H	14.4 mg	200 mg	120 d
Synovex Plus	28 mg	200 mg Trenbolone acetate	120 d
Finaplix-S	0 mg	140 mg Trenbolone acetate	105 d
Finaplix-H	0 mg	200 mg Trenbolone acetate	105 d
Revalor-S	16 mg	80 mg Trenbolone acetate	120 d

1 mg Trenbolone acetate = 8-10 times effect as 1 mg testosterone.

Nichols et al. (1996) summarized numerous experiments involving a total of 600 English x Continental crossbred heifers that were implanted with Revalor-H® with or without feeding of melengestrol acetate (MGA), or implanted with Finaplix® plus MGA. Pooled data showed no differences among treatments in marbling, percentage of Choice carcasses, muscle color score, or incidence of dark cutters. However, the incidence of dark cutters in one study was 5.1% for the Finaplix® plus MGA treatment compared to 0.0% for the non-implanted controls. Regardless of time on feed or postmortem aging time, steaks from heifers implanted with Revalor-H®, or Revalor-H® and fed MGA had higher (P< .05) WBSF values when compared to steaks from non-implanted controls (Table 4). Additionally, sensory panel ratings indicated that steaks from Revalor-H® and Revalor-H® plus MGA treatments were less tender compared to steaks from non-implanted controls (Table 4). However, there were no differences in sensory panel ratings for tenderness among steaks from heifers in the Revalor-H®, Revalor-H® plus MGA, and Finaplix® plus MGA treatments. The authors concluded that the magnitude of the WBSF differences were of questionable practical magnitude. My interpretation of these data is that Revalor-H® and Finaplix® plus MGA certainly do not improve tenderness and have the potential to reduce tenderness.

In a Technical Bulletin published by Hoechst-Roussel Agri-Vet Company (1991), data from 1,950 steers in five trials were analyzed in which steers were implanted with different strategies using Revalor-S®, Synovex-S®, and Finaplix®. Implanting twice with Revalor-S® and twice with Synovex-S® + Finaplix® resulted in a lower percentage of Choice carcasses (60% vs. 69%) than for the other implant strategies (Table 5). Neither Warner-Bratzler shear force values nor sensory panel evaluations were conducted in these experiments. Nichols et al. (1993) stated in a Technical Bulletin, "If high quality grade (high marbling) is of concern, DO NOT use Revalor-S® within 70 days of slaughter." Implanting with Revalor-S® at the beginning of the feeding period and again after 70-120 days was described as an 'aggressive implant program' by these authors.

Table 1. Warner-Bratzler Shear Force Value Change Stratified by Implant Strength and Type[a]

First Implant	Second Implant	Third Implant	WBSFb lb.
	Non-implanted		
ME[c]	–	–	+.10
ME	ME	ME	+.93
A	–	–	+1.30
ME/A	ME/A	–	+1.57
SE	–	–	+.94
SE	SE	–	+.97
SE/A	–	–	+1.08
SE/A	SE/A	–	+1.40
MC	–	–	+.25
MC	MC	–	+1.70
SC	–	–	+1.70
SC	SC	–	+1.30

[a] Source: OSU Implant Data Base.
[b] WBSF: Warner-Bratzler shear force value, lb. change in WBS compared to nonimplanted controls.
[c] Implant classification: ME, SE, A, MC and SC are mild estrogen, strong estrogen, androgen, mild combination and strong combination, respectively.
From Morgan (1997).

Table 2. Least Squares Means for Carcass Traits Stratified by Implant Strategy Groups (n = 403)

Implant Strategy	Hot Car. Wt. (lb.)	Adj. Fat (in.)	YG	Marbling*	QG**	% Prime/ Choice	% Y4/Y5
No Implant/No Implant	737.4^{b}	.66	3.51^{ab}	524.3^{a}	523.8^{a}	94.4^{a}	24.1
Encore & Component T-S/No Implant	777.2^{ab}	.65	3.47^{ab}	511.6^{ab}	515.1^{ab}	93.2^{ab}	18.2
Ralgro/Synovex Plus	798.8^{a}	.69	3.59^{ab}	459.2^{bc}	460.7^{c}	77.4^{c}	28.3
Ralgro/Synovex-S	796.8^{a}	.64	3.40^{ab}	482.7^{abc}	487.5^{abc}	81.3^{abc}	6.3
Revalor-S/Revalor-S	809.5^{a}	.67	3.45^{ab}	449.6^{c}	454.1^{c}	66.7^{c}	18.8
Revalor-S/No Implant	795.9^{a}	.71	3.70^{a}	467.0^{bc}	474.0^{abc}	76.9^{c}	34.6
No Implant/Synovex Plus	791.0^{a}	.64	3.35^{b}	458.3^{c}	463.4^{bc}	78.9^{bc}	7.8
Synovex Plus/No Implant	794.1^{a}	.71	3.61^{ab}	470.4^{bc}	471.4^{bc}	75.0^{c}	25.5

[a,b,c] Means in the same column with different superscript letters differ ($P<0.05$).
* Marbling scores are coded as: 300 = slight, 400 = small, 500 = modest, and 600 = moderate.
** USDA quality grades are coded as: 100 to 299 = Standard, 300 to 349 = Low Select, 350 to 399 = High Select, 400 to 499 = Low Choice, 500 to 599 = Average Choice, and 600 to 699 = High Choice.
From Roeber et al. (1999).

Table 3. Least Squares Means and Frequency Distribution of Warner-Bratzler Shear Force Values Stratified by Implant Strategy (n = 298)

Implant Strategy	WBSF Value (kg)	St. Dev.	No. Head <3.86 kg	No. Head >3.86 kg	Percent >3.86 kg
No Implant/No Implant	2.97^{b}	.66	33	3	8.3
Encore & Component T-S/No Implant	3.19^{ab}	.48	36	3	7.7
Ralgro/Synovex Plus	3.42^{ab}	.58	30	8	21.1
Ralgro/Revalor-S	3.31^{ab}	.62	28	10	26.3
Revalor-S/Revalor-S	3.29^{ab}	.54	31	5	13.9
Revalor-S/No Implant	3.52^{a}	.61	25	11	30.6
No Implant/Synovex Plus	3.42^{ab}	.67	26	11	29.7
Synovex Plus/No Implant	3.30^{ab}	.51	31	6	16.2

^{a,b} Means in the same column with different superscript letters differ ($P<0.05$).
From Roeber et al. (1999).

Table 4. Effect of Implant Treatment on Ribeye Steak Peak Shear Force Values and Sensory Panel Tenderness Scores at 14 Days of Aging (Least Squares Means).

	Implant Treatment[a]					
Trait	CONT	MGA	FINMGA	REV	REVMGA	Effect[b]
Shear force, lbs.	7.76^{c}	7.95^{cd}	7.93^{cd}	8.27^{de}	8.34^{e}	CI RF
Very tender steaks[f], %	70.70	66.70	72.60	61.20	59.10	
Tender steaks[f], %	18.10	20.00	12.80	23.30	26.10	
Tough steaks[f], %	11.20	13.30	14.60	15.50	14.80	
Sensory panel[g]	5.96^{c}	5.88^{cd}	5.87^{cde}	5.72^{e}	5.76de	CI

[a] Implant treatments: CONT = nonimplanted, MGA = melangestrol acetate, FINMGA = Finaplix-H® plus MGA, REV = Revalor-H®, REVMGA = Revalor-H® plus MGA.
[b] Contrast effects: CI ($P<0.05$) = control vs all implants; RF ($P<.05$) = REVMGA vs FINMGA.
[c,d,e] Means in the same row with different superscripts differ ($P<.05$).
[f] Based on shear force: very tender = <8.5 lbs., tender = 8.6 to 10 lbs., tough = >10 lbs.
[g] 8 = extremely tender; 6 = moderately tender; 4 = slightly tough.
From Nichols et al. (1996).

Table 5. Effect of Implant Treatment on Carcass Traits (Least Squares Means)

Carcass Data	Day 1: Day 67-70:	Revalor-S —	Synovex-S Revalor-S	Revalor-S Revalor-S	Synovex-S Synovex -S	Synovex-S Finaplix-S
Hot carcass wt.		777^{c}	783^{b}	792^{a}	770^{d}	787^{ab}
Marbling[d]		4.29^{a}	4.22^{a}	4.10^{b}	4.33^{a}	4.10^{b}
% Choice		68^{a}	70^{a}	61^{b}	69^{a}	59^{b}
KPH fat, %[e]		2.39	2.45	2.39	2.40	2.41
Backfat thickness, in.		$.51^{b}$	$.54^{a}$	$.51^{b}$	$.52^{b}$	$.50^{b}$
Ribeye area, in^2 [f]		12.49^{b}	12.66^{b}	13.04^{b}	12.65^{b}	13.53^{a}
Yield grade		3.09^{a}	3.13^{a}	2.99^{a}	3.00^{a}	2.75^{b}

[a,b,c] Means in same row with different superscripts differ ($P<0.05$).
[d] 3 = slight, 4 = small, 5 = modest, 6 = moderate.
[e] Kidney, pelvic and heart fat as a % of hot carcass weight – estimated visually.
[f] Ribeye muscle area between the 12th and 13th ribs.
From Hoechst-Roussel Agri-Vet Company (1991).

Samber et al. (1996) conducted an excellent research study on the effects of implant strategies on performance and carcass quality of steer calves finished for 212 d on feed. Most previous studies utilized yearling cattle. They evaluated six implant strategies involving combinations of Ralgro®, Revalor-S®, and Synovex-S®; initial implantation at 0 d or 30 d after the start of the feeding period followed by re-implantation at 60, 75 and(or) 130 days; and two protein levels for the treatment involving three Revalor-S® implants. There was no reduction in the percentage of Choice and Prime carcasses with the use of Synovex-S®/Revalor-S® or Revalor-S®/Revalor-S® (Table 6). However, all treatments receiving three successive implants had lower percentages of Choice and Prime carcasses than the non-implanted control group. Increasing the percentage of protein in the diet seemed to lessen the detrimental effect of three consecutive Revalor-S® implants on quality grades. Loin steaks from calves implanted with Revalor-S® two or three times had higher shear force values than steaks from non-implanted control calves (Table 6). Steaks from calves implanted twice (30 and 130 d) with Revalor-S® had higher shear force values than those implanted (0, 60 and 130 d) with Ralgro®/Synovex-S®/Revalor-S®. These results suggest that delaying the initial implanting until after the cattle are on full feed may have more effect in repartitioning nutrients from fat deposition to muscle deposition than when implanting at the beginning of the finishing period.

Research has shown that Revalor-S® or Finaplix-S® administered late in the finishing period (Foutz et al., 1990), or that Synovex-S® or trenbolone acetate administered twice (Foutz et al., 1989) adversely affected shear force values. Apple et al. (1991) implanted Holstein calves from about 4 months of age to harvest with Ralgro®, Synovex-S®, Finnaplix-S®, or a combination of Finnaplix-S® followed by Synovex-S®. Only 50% of the steers implanted with Finnaplix-S® followed by Synovex-S® graded USDA Choice compared with 75 to 90% for the other implant treatments. **Longissimus** steaks from cattle implanted with Synovex-S®, and Finnaplix-S® plus Ralgro® tended to have decreased tenderness when compared to steaks from non-implanted cattle. Belk and Savell (1992), Gerken et al. (1995), Huck et al. (1991), and Kuhl et al. (1993) found no detrimental effects of implants on tenderness when cattle were implanted only one time. These results show that implants containing trenbolone acetate administered more than once and(or) late in the finishing period can have a detrimental effect on meat tenderness.

In an implant study by Gerken et al. (1995), 24 cloned Brangus calves were implanted with an estrogen (Synovex-S®) implant, resulting in lower ($P<0.05$) marbling than implanting with androgen (Finaplix-S®) or a combination (Revalor-S®) implant. In addition, implanting with estrogen resulted in lower tenderness and flavor scores and higher WBSF values for top sirloin (**gluteus medius**) steaks than when implanting with androgen. However, implant type did not affect palatability of the top round (**semimembranosus**) or top loin (**longissimus**) steaks. These results demonstrate a disadvantage in implanting steers with an estrogen implant compared to implanting with an androgen or combination implant.

Platter et al. (2003) conducted an extensive study on the effects of repetitive use of anabolic implants on beef carcass quality, tenderness and consumer ratings for palatability. This study involved 550 steers allocated to 10 different lifetime implant strategies and a non-implanted control. The time of implanting and re-implanting and the type of implants used are shown in Table 7. Some of the implant strategies involved five implant times. The use of implants increased average daily gain by 11.8 to 20.5% from weaning to harvest, increased carcass weights by 8.9 to 13.8%, and increased **longissimus** muscle area. Carcasses from the control group had higher marbling scores than carcasses from all implant treatments, and carcasses from steers implanted twice during the feedlot phase only had higher marbling than two of the treatments receiving four or five implants. Implanting at branding time or weaning did not affect meat quality or palatability, whereas implanting at

Table 6. Least Squares Means for Beef Carcass Traits and Shear Force Values as Affected by Implant Treatment

Trait[a]	Experimental Treatment Group						
	CON	RAL/ SYN/REV	RAL/ REV/REV	SYN/ REV	REV/ REV	REV/ 3X-12.5%	REV/ 3X-14.5%
Carcass weight, kg	381^{c}	391^{c}	397^{c}	396^{c}	394^{c}	400^{c}	396^{c}
FT, cm	1.36^{cd}	1.26^{d}	1.43^{c}	1.44^{c}	1.49^{c}	1.26^{d}	1.36^{cd}
YG	3.35^{de}	3.23^{ef}	3.40^{cde}	3.47^{cd}	3.62^{c}	3.12^{f}	3.23^{ef}
Marbling[b]	457^{c}	421^{de}	420^{de}	458^{c}	443^{cd}	400^{e}	435^{cd}
% Choice and Prime	85.9^{c}	62.2^{fg}	65.3^{efg}	80.2^{cd}	79.5^{cde}	54.9^{g}	73.1^{def}
Shear force, kg	2.58^{f}	2.74^{def}	2.75^{def}	2.64^{ef}	3.01^{c}	2.92^{cd}	2.86^{cde}

[a] Abreviations used: FT, fat thickness; YG, calculated USDA yield grade.
[b] 300 = slight, 400 = small, 500 = modest.
[c,d,e,f,g] Means in the same row lacking a common superscript letter differ ($P<0.05$).
From Samber et al. (1996).

backgrounding before the feedlot phase negatively affected shear force values. Steaks obtained from steers in the control group had lower shear force values (Table 7) and were rated by consumers as more desirable for tenderness like/dislike than steaks obtained from steers in all implant treatment groups (Table 8).

Table 7. Experimental Design Outlining Implant Strategy, Marbling Scores, USDA Quality Grade Distribution, Warner-Bratzler Shear Force Values (WBS) for Striploin Steaks, and Consumer Sensory Panel Scores[a]

Item	Experimental treatment group[b]										
	1	2	3	4	5	6	7	8	9	10	11
Implant at branding	NO	NO	NO	NO	C	NO	C	C	C	C	C
Implant at weaning	NO	NO	NO	NO	NO	RA	NO	NO	RA	RA	RA
Implant at backgrounding	NO	NO	RA	S	S	S	RA	S	RA	S	S
Implant at feedlot entry	NO	S	S	S	NO	S	S	S	S	S	REV
Re-implant in feedlot	NO	REV	REV	REV	REV	REV	REV	REV	REV	REV	REV
Marbling score[cd]	538^{w}	485^{x}	465^{xy}	454^{xyz}	464^{xyz}	439^{yz}	442^{yz}	457^{xyz}	460^{xyz}	453^{xyz}	430^{z}
Choice and Prime, %	82	70	74	64	68	56	60	62	72	64	60
Overall mean WBS, kg	3.54^{z}	3.95^{y}	4.46^{w}	41.9^{wxy}	4.19^{wxy}	4.15^{wxy}	4.12^{wxy}	4.05^{xy}	4.05^{xy}	4.14^{wxy}	4.38^{wx}
Steaks #4.5 kg (14-d), %	82^{w}	66^{wx}	44^{wx}	56^{wx}	54^{wx}	58^{wx}	50^{wx}	70^{wx}	62^{wx}	58^{wx}	38^{x}
Steaks $4.5 kg (21-d), %	94	88	76	74	76	80	78	84	82	80	64
Tenderness[e]	31.5^{z}	3.79^{y}	4.05^{xy}	4.00^{xy}	3.87^{xy}	3.91^{xy}	3.78^{y}	3.96^{xy}	3.71^{y}	3.80^{xy}	4.25^{x}
Flavor[e]	3.34^{z}	3.62^{yz}	3.81^{xy}	3.76^{xy}	3.71^{xy}	3.73^{xy}	3.74^{xy}	3.83^{xy}	3.70^{xy}	3.82^{xy}	3.92^{x}
Juiciness[e]	3.54^{z}	3.91^{y}	4.17^{xy}	4.11^{xy}	4.00^{xy}	4.12^{xy}	4.02^{xy}	4.17^{xy}	4.06^{xy}	4.02^{xy}	4.30^{x}

[a] Adapted from Platter et al. (2003).
[b] Abbreviations used: NO = no implant; C = Synovex-C (10 mg of estradiol benzoate, 100 mg of progesterone); RA = Ralgro (36 mg of zeranol); S = Synovex-S (20 mg of estradiol benzoate, 200 mg of progesterone); REV = Revalor-S (24 mg of 17-$ estradiol, 120 mg of trenbolone acetate).
[c] Adjusted to a common fat thickness.
[d] 300 = slight, 400 = small, 500 = modest.
[e] Tenderness, flavor, and juiciness like to dislike ratings by consumers where: 1 = like extremely and 9 = disliked extremely.
[w,x,y] Means in the same row lacking a common superscript letter differ (P<0.05).

Table 8. Least Squares Means for Consumer Sensory Ratings of Steaks from Implant Strategies Differing by Number of Implants Administered[a]

	Means by number of implants administered					
Consumer sensory response	0	2	3	4	5	SEM
Tenderness[b]	3.15^{z}	3.79^{y}	3.97^{y}	3.88^{y}	3.93^{y}	0.16
Flavor[b]	3.34^{z}	3.62^{y}	3.76^{y}	3.77^{y}	3.82^{y}	0.09
Juiciness[b]	3.54^{z}	3.91^{y}	4.10^{y}	4.10^{y}	4.13^{y}	0.12
Satisfaction with overall eating quality, %	73.6^{y}	65.0^{z}	63.2^{z}	63.5^{z}	63.5^{z}	3.08

[a] Adapted from Platter et al. (2003).
[b] Tenderness, flavor, and juiciness like to dislike ratings by consumers where: 1 = liked extremely and 9 = disliked extremely.
[y,z] Means in the same row that do not have a common superscript differ (P<0.05).

In a survey on the factors contributing to the incidence of dark cutting beef involving over 2.6 million cattle over 3 yr, Scanga et al. (1998) classified implants as androgenic (Synovex-H®, Finaplix-H/S®); estrogenic (Synovex-S®, Ralgro®,); combination (Revalor-H/S®); double androgens (Finaplix® and Synovex-H®); and estrogen x combinations (Synovex-S®/RevalorH/S®). All heifers were fed MGA. Implanting steers with combination x combination implants resulted in more dark cutters than implanting with estrogen x estrogen or estrogen x combination (Table 9). In addition, implanting less than 100 d before slaughter increased the incidence of dark cutters (Table 10). Temperatures exceeding 35°C were very critical for the combination x combination strategy. In heifers, estrogen x estrogen caused more dark cutters than combination implants. Again, implanting less than 100 days before slaughter increased the incidence of dark cutters in heifers, and temperatures greater than 35°C were critical for most implants. These authors concluded that increased risk of incurring dark cutting beef resulted from the use of estrogenic re-implants before slaughter in heifers and combination implants used singly in steers (either as the initial implant or as re-implants before slaughter), or from use of combination implants while on-feed, and from combination re-implantation strategies. They concluded that using good handling facilities, good animal handling practices, and proper shipping practices with the use of 'moderate' growth-promoting implants can minimize the incidence of dark cutting beef.

Research results on the effects of implants on meat quality show that some implants and implant strategies have the potential to increase the proportion of dark cutters, decrease marbling and the percentage of Choice carcasses, and(or) decrease tenderness. The first two effects have direct and immediate negative economic consequences, whereas the latter effect likely results in decreased consumer confidence and demand for beef and has a significant long-term negative economic consequence. Cattle absolutely should not be re-implanted with aggressive or moderately aggressive implants within 70 days of slaughter and special care should be used when handling implanted cattle during hot weather. Manufacturer recommendations and warnings should be followed very closely to minimize the chances for negative effects of implants on meat quality. Implants are much too effective in improving efficiency of production to not use them, but their use needs to be managed extremely well.

Limited research was found on the effects of anabolic implants in poultry, sheep and pigs. Maurice et al. (1985) and Castaldo et al. (1990) demonstrated that growth rate and feed efficiency were improved significantly with trenbolone acetate or trenbolone acetate x zeranol implants in turkeys. This response was enhanced as dietary protein density increased. Carcass fat was not affected. Anabolic steroid implants have not, however, been approved for use in poultry in the U.S. Only one implant (zeranol) is approved for lambs and it is not used widely because it is not effective. Hancock et al. (1991) stated that, under the appropriate conditions, anabolic steriods can be very efficacious in swine. Historically, however, estrogens and androgens have not been considered to be particularly effective growth enhancers in pigs according to Roche and Quirk (1986). Anabolic steroids are not approved for growth regulation in pigs in the U.S. Even so, Lee et al. (2002) studied the effects of implanting castrate pigs weighing 59 kg with Revalor-H® (trenbolone acetate plus estradiol-17$) on performance, carcass composition and meat quality. Overall, pork quality was not affected by implantation or diet manipulation. However, backfat thickness was reduced with implantation.

Table 9. Least Squares Means ± SE[a] for the Percentage of Dark Cutters per Pen by Implantation Strategy for Steers and Heifers and the Proportion of Pens above a 6% Incidence Level[b]

Implantation Strategy	No. of Pens	LS Means ± SE of % DC[c]	Pens > 6% DC, %
Steers			
Combination[d]/Combination[e]	165	$.86^{y}$ ± .003	7.9
Estrogen/Estrogen	553	$.08^{z}$ ± .009	0
Estrogen/Combination	61	$.19^{z}$ ± .008	1.6
Heifers			
Double Androgen/Androgen	6	$.67^{yz}$ ± .096	0
Androgen/Double Androgen	11	$.26^{z}$ ± .052	0
Androgen/Androgen	129	$.54^{yz}$ ± .001	3.1
Androgen/Combination	10	$.54^{z}$ ± .084	—
Androgen/Estrogen	46	1.66^{y} ± .033	0
Estrogen/Estrogen	12	$.92^{yz}$ ± .134	8.3

[a] Standard error of the least squares means.
[b] Pens with a greater than 6% incidence of dark cutters were considered epidemics and termed "blow-out" pens.
[c] Dark cutters (DC).
[d] Implant given as the cattle came on-feed.
[e] Implant given as reimplants before harvest (final implant).
[y,z] Means within sex class lacking a common superscript letter differ (P<0.05).
From Scanga et al (1998).

Table 10. Least Squares Means ± SE[a] for the Percentage of Dark Cutters per Pen by the Reimplant Treatment before Harvest and the Time between the Reimplantation and Harvest for Steers and Heifers

Implant Treatment	Mean Percentage of Dark Cutters per Pen	
	<100 d[b]	>100 d
Steers		
Androgen[c]	.02[z] ± .021	.19[wx] ± .02
Combination[d]	.32[w] ± .001	.17[x] ± .001
Estrogen[e]	.09[y] ± .001	.07[z] ± .001
Heifers		
Androgen	.58[u] ± .001	.42 ± .001
Combination	1.74[s] ± .011	50[uv] ± .003
Estrogen	.92[t] ± .002	78[t] ± .002

[a] Standard error of the least squares means.
[b] Time (d) from receipt of final implant to harvest.
[c] Androgen implants administered when cattle were placed in the feedyard.
[d] Androgen and estrogen implants administered as cattle were placed in the feedyard.
[e] Estrogen implants administered when cattle were placed in the feedyard.
[s,t,u,v,w,x,y,z] Means within and across subclass lacking common superscript letters differ (P<0.05).
From Scanga et al. (1998).

Vitamin D_3

Feeding vitamin D_3 has received much attention recently for its potential to improve meat tenderness. Dietary vitamin D_3 has been shown to increase blood and muscle calcium levels. Wheeler et al. (1997) showed that elevated levels of calcium in muscle increases calpain enzyme activity, thus promoting proteolysis. Feeding high levels of vitamin D_3 (0.5 x 10^6 to 7.5 x 10^6 IU/hd/d) 4 to 10 d before slaughter improved tenderness of the **longissimus thoracis** at 7 d postmortem, but not at 14 or 21 d (Swanek et al., 1999). Montgomery et al. (1999) reported that control carcasses had temperatures 15.6°C higher at 24 hr postmortem than carcasses from cattle fed vitamin D_3, but did not state whether this had any effect on their results. They reported lower WBSF values for inside round steaks from Continental steers fed vitamin D_3 at 10 d postmortem than inside round steaks from cattle not fed vitamin D_3. However, vitamin D_3 only reduced the variation and not the mean shear force values in **longissimus** steaks. These authors concluded that feeding vitamin D_3 will effectively improve tenderness if cattle tend to be tough and would have no impact on cattle that produce tender beef. Karges et al. (1999) reported a decrease in WBSF of both **longissimus** and **gluteus medius** steaks at 14 and 21 d postmortem. However, they also reported a decrease in hot carcass weight from feeding 6 x 10^6 IU/hd/d for 4 or 6 d. Swanek et al. (1999) reported more calpain enzyme activity in muscle from cattle fed vitamin D_3. On the other hand, Karges et al. (1999) reported that calpastatin activity was not altered in cattle fed vitamin D_3 for 4 or 6 d.

Vargas et al. (1999) fed steers vitamin D_3 alone (6 x 10^6 IU/hd/d), a combination of vitamin D_3 and vitamin E (1000 IU/hd/d), or neither vitamin and found that steaks from both vitamin D_3 treatments required less aging time than steaks from control cattle to reach a WBSF value of < 3.86 kg, which they considered to be 'very tender.'

Karges et al. (1999) found that dry matter intake in cattle was reduced from feeding vitamin D_3 for 2 d at 7.5 x 10^6 IU/d; 4 d at 15 x 10^6 IU/d; 5 d at 7.5 x 10^6 IU/d; and 6 d at 5 x 10^6 IU/d. In the study by Montgomery et al. (2002), feeding vitamin D_3 at 2.5, 5.0, and 7.5 x 10^6 IU/d for 9 d before slaughter resulted in negative average daily gains during the last 21 d of feeding, but not for those fed 0.5 or 1.0 x 10^6 IU/d. This decreased gain was partially due to decreased feed intake on d 7 and 8 of feeding vitamin D_3 compared to control steers. Although not statistically significant, final weight was 5, 11, and 16 kg lighter for cattle fed the 2.5, 5.0, and 7.5 x 10^6 IU/d, respectively. These findings raise important questions about the practicality of feeding vitamin D_3 to improve tenderness because livestock producers are not likely to use this practice if it reduces performance and efficiency.

Enright et al. (1998) fed pigs high levels of vitamin D_3 (331; 55,031; and 176,000 IU/hd/d) and found that muscle firmness was increased and drip loss was decreased at all three levels (Table 11). Furthermore, visual color scores of the **longissimus** muscle increased as the amount of vitamin D_3 in the diet increased. However, there was no improvement in meat palatability traits. A negative aspect of their research was that feeding high levels of vitamin D_3 reduced feed intake in pigs from 3.82 down to 2.90 kg/d and, consequently, reduced average daily gain from 0.77 to 0.07 kg/d for low and high vitamin D_3 levels, respectively, in the diet. Wiegand et al. (2002) reported that feeding 5 x 10^6 IU/d to pigs resulted in lower L* and higher a* values of loin chops at 7 and 14 d of storage. However, tenderness was not improved. They also reported a significant reduction in chilled carcass weight of pigs fed vitamin D_3.

In a study of normal and callipyge lambs fed 2 x 10^6 IU/d vitamin D_3 by Wiegand et al. (2001), serum but not muscle calcium level was increased with vitamin D_3 feeding. Consequently, there were no observed differences in shear force values or troponin-T degradation.

Puls (1994) suggested that supplementing cattle with at least 2 x 10^6 IU/d vitamin D_3 could result in cattle toxicity. Furthermore, high levels of vitamin D_3 can be toxic to humans. The U.S. Recommended Dietary Allowance is 400 IU/d (10 µg) for infants, children, adults, and pregnant/lactating women. An intake of 10,000 IU/d for several months resulted in marked disturbances in calcium metabolism (Council on Scientific Affairs, 1987). Montgomery et al. (1999) reported a four to seven times higher concentration of vitamin D_3 in liver and muscle than normal when cattle were fed 5 x 10^6 IU/hd/d of vitamin D_3.

Table 11. Impact of Feeding High Levels of Vitamin D_3 to Pigs for 10 Days Prior to Slaughter on Meat Quality

Vitamin D_3 Level	Low	Moderate	High	SIG
Vitamin D_3 ('000 IU/kg)	.331	50.04	175	
Ultimate pH	5.50	5.53	5.47	NS
Subjective color	2.08^{a}	2.72^{ab}	3.08^{b}	(P<.01)
Hunter L*	54.58	52.49	51.20	NS (P<.07)
Hunter a*	6.33	6.43	6.54	NS
Hunter b*	16.69^{a}	15.99^{ab}	15.64^{b}	(P<.01)
Drip loss, %	4.39^{a}	3.21^{ab}	2.04^{b}	(P<.01)

[ab] Means in some row with different superscripts differ (P<0.05).
From Enright et al., 1998.

However, Montgomery et al. (2000) reported that concentrations of vitamin D_3 in liver were increased 71- and 114-fold by doses of 5 and 7.5 x 10^6 IU/d. Montgomery et al. (2000) stated that these levels raise a caveat with regard to the commercial adoption of feeding vitamin D_3 to improve beef tenderness because consumption of as little as 45 µg vitamin D_3 per day has been associated with signs of hypervitaminosis D in young children (citing American Academy of Pediatrics, 1963). Montgomery et al. (2002) stated that the increase in residues in liver samples poses a serious toxicological hazard, requiring livers to be removed from the food chain. These authors further stated that the increase in beef muscle concentrations does not seem to pose a toxicological hazard. Because Montgomery et al. (2002) found that feeding as little as 0.5 x 10^6 IU/d resulted in a significant improvement in tenderness of top round steaks at all times postmortem, an improvement in top loin steaks at 7 d postmortem, and no negative affect on feedlot performance or tissue residues, they concluded that cattle should be supplemented with no more than 0.5 x 10^6 IU/d vitamin D_3. To consider feeding levels higher than this requires more research be conducted on the safety of feeding vitamin D_3.

In summary, Vitamin D_3 may increase tenderness in beef early postmortem, improve firmness and color, and decrease drip loss in pork. However, feeding vitamin D_3 may not be adapted by the industry if it reduces feed intake and performance. In addition, there are important questions that need to be addressed about its potential toxicity in humans. Consequently, feeding vitamin D_3 as a metabolic modifier to improve meat quality may not be adapted by the industry until more research is conducted.

Vitamin E

Numerous studies have shown that feeding supra-nutritional levels of vitamin E improves meat color and can extend shelf-life of both beef and pork. There have been no reports of negative effects on feed intake or performance of cattle or pigs fed vitamin E as is reported for feeding vitamin D_3. Therefore, this metabolic modifier is practical and effective.

Several studies indicate that dietary vitamin E supplementation to steers results in accumulation of α-tocopherol in muscle tissue and that this antioxidant delays lipid and myoglobin oxidation. Consequently, color stability and retail shelf life of beef are prolonged (Faustman et al., 1989b; Figures 1 and 2). Ashgar et al. (1991) and Monahan et al.(1992, 1994) stated that vitamin E decreases lipid oxidation and drip loss, and improves the color of pork cuts. Inadequate color and water holding capacity are two major quality concerns in pork (Cannon et al., 1995).

Arnold et al. (1992) fed Holstein calves diets containing vitamin E at 300 IU/d for 266 d; 1,140 IU/d for 67 d; or 1,200 IU/d for 38 d and a control diet in which no vitamin E was fed. They found that color stability during retail display of **longissimus lumborum** steaks was extended by 2.5 to 4.8 d (Figure 3). **Gluteus medius** steaks had an extended color display life of 1.6 to 3.8 d. In addition, the accumulation of lipid oxidation products was suppressed for muscles from vitamin-E supplemented steers.

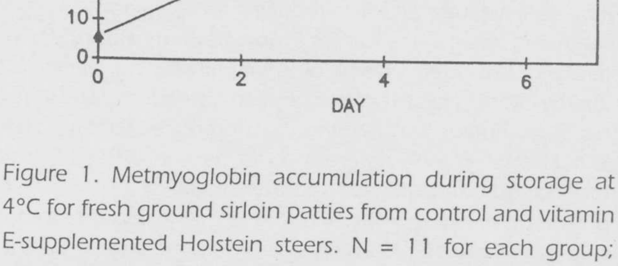

Figure 1. Metmyoglobin accumulation during storage at 4°C for fresh ground sirloin patties from control and vitamin E-supplemented Holstein steers. N = 11 for each group; standard error bars are indicated. From Faustman et al. (1989b).

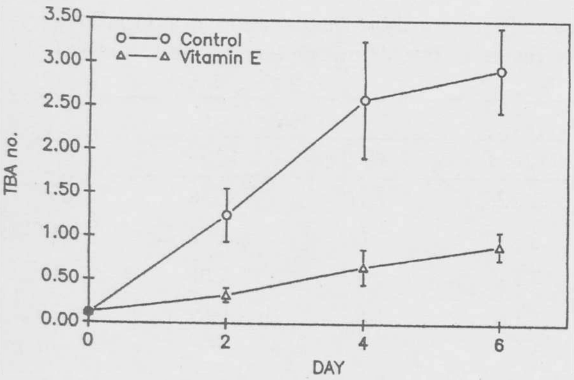

Figure 2. TBA numbers of fresh ground sirloin from control and vitamin E-supplemented Holstein steers during storage at 4°C. N = 11 for each group; standard error bars are indicated. From Faustman et al. (1989b).

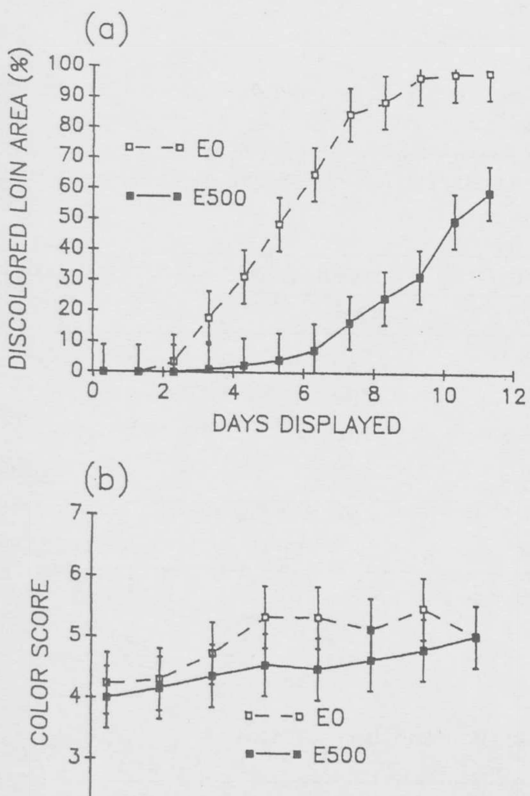

Figure 3. Effect of level of vitamin E supplementation on area of discoloration (a) and color score (b) of longissimum lumborum (loin) steaks (n = 34 steers). Color scores were associated with the following descriptive terms: 3 = moderately light cherry red, 4 = cherry red, 5 = slightly dark red, and 6 = moderately dark red. E0 = 0 IU/d of supplemental vitamin E; E500 = 300 IU/d of actual supplemental vitamin E. (From Arnold et al., 1992).

Liu et al. (1996b) fed Holstein steers 0, 250, 500 or 2,000 IU/d vitamin E for durations of 42 or 126 d and evaluated the effects on meat quality. Color display of fresh beef was extended 0.9 to 1.8 d from the lowest to highest feeding level when using the 'metmyoglobin threshold method' for determining when beef reached the end of its shelf life (Table 12). In addition, increases in TBARS were delayed in beef from cattle fed vitamin E. When estimation of display life was based on "hue angle measurements", Liu et al. (1996a) determined that color display life across the **longissimus lumborum**, **semimembranosus**, and **gluteus medius** stored under vacuum until 14 d and then displayed under simulated retail conditions was extended 2.0 (E250) to 5.0 (E2,000) d (Table 13). Collectively, supplementation of 500 mg of %α-tocopherol acetate per steer daily improved the mean color display life of the three muscles by 2.3 d, or essentially 100%. However, when muscles were vacuum aged for 56 d, color display life was decreased to 56% of that for meat aged 14 d, even though %α-tocopherol concentrations after 56 d were still 96% of 14-d values.

Lynch et al. (1998) compared diets containing 20 (basal diet) or 2,000 IU %α-tocopherol acetate/kg feed/d for 50 d in Friesian steers. Supplemented fresh, frozen, and vacuum packaged **longissimus longissimus, gluteus medius**, and **psoas major** muscles showed greater color and lipid oxidative stability than meat from the basal group after 7 d of retail display.

Vitamin E supplementation in pigs has also been studied extensively. Jensen et al. (1997) fed vitamin E at levels of 100, 200 and 700 mg/kg of %α-tocopherol acetate from weaning to slaughter at 90 kg. They found that %α-tocopherol levels in the **longissimus** and **psoas major** were linearly related to the logarithm of dietary %α-tocopherol supplementation. Dietary %α-tocopherol supplementation significantly reduced lipid oxidation as measured by TBARS in both raw and cooked meat during storage at 4°C for 6 d. Drip loss and color stability of raw muscle were not affected by dietary %α-tocopherol levels, but these authors concluded that the 100 mg %α-tocopherol acetate/kg feed resulted in sufficient %α-tocopherol levels in muscles to ensure minimum drip loss and optimum color stability. Cannon et al. (1995) also did not find an advantage in either color or drip loss when pigs were fed 100 mg/kg of vitamin E in the diet. Cheah et al. (1995) showed a significant reduction in drip loss from feeding 500 mg/kg of vitamin E for 46 d for both halothane negative and carrier animals (Table 14). Buckley et al. (1995) endorsed a possible mechanism for the effect of %α-tocopherol on drip loss proposed by Asghar et al. (1991) and Monahan et al. (1994) that %α-tocopherol could preserve the integrity of muscle cell phospholipids during storage, which could inhibit passage of sarcoplasmic fluid through muscle cell membranes. Lanari et al. (1995) found that feeding pigs 198 and 207 mg %α-tocopherol/kg feed enhanced color stability in the **longissimus** muscle during chilled storage compared to non-supplemented controls. However, Lanari et al. (1995) noted that the improvement in pork muscle color stability produced by dietary %α-tocopherol supplementation was not as profound as has been reported for beef muscle.

Table 12. Dose and Duration Effects of Supplemental Vitamin E on Time to First Detectable Discoloration for Longissimus Lumborum (LL), Semimembranosus (SM), and Gluteus Medius (GM)[a] calculated by the Metmyoglobin Threshold Method[b]

	LL		SM		GM		
Vitamin E, mg/d	42 d	126 d	42 d	126 d	42 d	126 d	Dose
0	3.67	4.22	1.56	2.22	1.78	1.78	2.54[c]
250	5.22	5.11	2.67	3.67	2.00	2.00	3.44[d]
500	4.67	5.55	3.11	2.89	1.77	1.88	3.31[cd]
2000	5.67	7.33	4.00	5.56	1.88	1.67	4.35[e]
SEM	.52		.57		.28		.28
Duration	4.81[c]	5.56[d]	2.83	3.58	1.86	1.83	
SEM	.26		.29		.14		
Muscle[f]	5.18[g]		3.21[h]		1.85[i]		

[a] All muscles were aged for 14 d.
[b] Thresholds were 14, 22, and 22% metmyoglobin for longissimus lumborum, gluteus medius, and semimembranosus, respectively.
[c,d,e] Means within a muscle or dose lacking a common superscript letter differ (P<.05).
[f] SEM = .13.
[g,h,i] Means within a row lacking a common superscript letter differ (P<.01).
From Liu et al. (1996b).

Table 13. Dose and Duration Effects of Supplemental Vitamin E on Color Display Life for Three Bovine Muscles Held in Vacuum Storage for 14 Days

	Longissimus lumborum		Semimembranosus		Gluteus medius		
Vitamin E, mg/d	42 d	126 d	42 d	126 d	42 d	126 d	Dose
0	3.3	4.7	1.0	2.3	1.0	1.7	2.3[a]
250	5.7	6.7	3.3	5.3	2.0	3.0	4.3[b]
500	6.0	7.7	3.3	5.3	1.0	4.3	4.6[b]
2,000	8.7	10.0	6.3	8.3	4.7	6.0	7.3[c]
Duration	5.9[a]	7.2[b]	3.5[a]	5.3[b]	2.2[a]	3.8[b]	
Muscle	6.6[d]		4.4[e]		2.9[f]		

[a,b,c] Means across durations within muscle or among doses lacking a common superscript letter differ (P<.01).
[d,e,f] Means across muscles lacking a common superscript differ (P<.01).
From Liu et al. (1996a).

Table 14. Impact of Dietary Vitamin E Supplementation in Pigs on Drip Loss from Longissimus Chops

Study	Supplementary Vitamin E Level (mg/kg)	Other Treatment	Drip Loss (%) Control	Drip Loss (%) Supplemented
		Halothane genotype		
Cheah et al., 1995	500	Negative Carrier	6.9	3.2
		Carrier	9.1	5.0
		Days of storage		
		0	5.01	4.76
Cannon et al., 1996	100	14	3.81	3.30
		28	2.96	2.68
		56	2.35	2.40

From Ellis and McKeith (1999).

Hoving-Bolink et al. (1998) reported vitamin E levels in the **longissimus** and **psoas major** muscles that were five times higher in pigs fed extra vitamin E than those fed the control diet without vitamin E. Color stability was improved in the **longissimus** muscle after 6 d, but not in the **psoas major**. However, these authors noted that the effect in the **longissimus** is too late to be of practical significance in the Netherlands because pork is usually sold well before that time. Monahan et al. (1994) reported that TBARS values were lower and Hunter a* values were higher in pork chops from pigs fed 100 and 200 mg %α-tocopherol acetate/kg diet compared to pigs fed 10 mg/kg diet after 2, 4, 6, and 8 d of refrigerated storage. This effect seemed to be more pronounced in previously frozen chops than in fresh chops. Cannon et al. (1996) reported that vitamin E significantly reduced TBARS after 3 and 5 d of retail display after 0, 14, 28, and 56 d of vacuum storage (Table 15). However, the effects of feeding vitamin E on sensory panel attributes were negligible.

These research reports on supplementing cattle and pig diets with supra-nutritional levels of vitamin E consistently show an advantage in color display life and reduced oxidative deterioration of meat in various packages and chilled states. The effects in beef are more pronounced than in pork. In addition, there can be an advantage in reduced drip loss in pork, but results are variable. There do not appear to be any negative effects on feed intake, growth rate, feed efficiency, dressing percent, or meat yield percentage. Thus, it seems that the beef cattle and swine industries should be routinely feeding supra-nutritional levels of vitamin E. Williams et al. (1992) conducted a blind study of consumers regarding beef from cattle fed 500 IU/steer of vitamin E for 100 to 120 d and beef from cattle not fed vitamin E. They found 3.6 percentage points reduction in losses in retail value from the vitamin E fed cattle. Liu et al. (1995) described the cost/benefit ratio of this technology for the U.S. beef industry. The cost of supplementing 500 IU of vitamin E for 126 d is estimated to be $3 per animal. If retailers could improve their receipts by 3.6% (Williams et al., 1992), this suggests a financial gain to the beef industry of $792 million annually. The benefit/cost ratio for the packing, fabrication, distribution, and retail marketing segments of the beef industry would be 10.4:1. The only issue that needs to be worked out is for cattle feeders and swine producers to be compensated for the additional cost of feeding higher levels of vitamin E. It may also require a method to rapidly verify that cattle actually received adequate vitamin E supplementation when marketed with that guarantee. The entire production, processing, and retail segments of the meat industry would gain from this practice.

Somatotropin

Average daily gain is increased by 20% with 150 µg porcine somatotropin (pST)/kg body weight per day and feed conversion efficiency is improved throughout an even greater dose range (Beermann, 1994). Carcass protein accretion rates are increased up to 74% coincident with an 82% decrease in lipid accretion rate when pST was administered from 30 to 90 kg body weight. Growing ruminants also respond to exogenous ST administration in a dose-dependent manner, but responses are generally of lesser magnitude than those observed in pigs (Crooker et al., 1990). Boles et al. (1992) found that chops from stress carrier and normal pST-treated (4 mg/d) pigs had higher shear force values and lower sensory panel juiciness scores than those from pigs injected with a placebo (Table 16).

Table 15. Thiobarbituric Acid Reactive Substances Values of Fresh Longissimus Chops from Control Pigs and Pigs Supplemented with Vitamin E

Storage Period and Treatment	Day of Retail Display		
	1	3	5
0 d			
Control	.30	.51^{x}	.74^{x}
Vitamin E	.32	.30^{y}	.41^{y}
14 d			
Control	.50	.72^{x}	.75^{x}
Vitamin E	.50	.52^{y}	.49^{y}
28 d			
Control	.38	.59^{x}	.92^{x}
Vitamin E	.36	.43^{y}	.60y
56 d			
Control	.40	.72^{x}	.93^{x}
Vitamin E	.37	.53^{y}	.60^{y}

^{x,y} Means in the same column within each storage period lacking a common superscript letter differ (P<.05).
From Cannon et al. (1996).

However, stress-positive pigs treated with pST had higher juiciness scores than those not treated with pST. In that study, intramuscular lipid was reduced in the pST-treated normal and stress-carrier pigs, but not in the stress-positive pigs. McKeith et al. (1994) concluded that somatotropin decreases intramuscluar lipid content in both pork and beef in a dose-dependent manner by 20 to 50%. Table 17 presents a summary of ST effects on quality of pork and beef. From these studies, it appears that pST administration in pigs decreases intramuscular fat and slightly decreases muscle color and firmness. However, shear force was increased in eight of the 10 studies cited (Table 18), whereas sensory panel tenderness decreased in a majority of the studies. These studies show that tenderness generally is negatively affected by pST administration in pigs. Processing of bellies into bacon also can be a problem because of the thicker skin of pST treated pigs and because of thinner bellies. However, the sensory properties of cured products from pST treated pigs do not appear to be affected.

Thiel (1991) treated pigs with 0, 50, 100, 150, or 200 $\mu g \cdot d^{-1} \cdot kg^{-1}$ pST. He found that all pST treatments decreased untrained sensory panel tenderness scores, with the maximum effect at the highest dose (Table 19). In addition, shear force values were also increased by somatotropin treatment, with a difference of 2.27 kg in the mean values between the controls and the highest pST dose (Table 20).

Growing sheep also respond to exogenous bovine somatotropin (bST) and ovine somatotropin (oST), but the responses generally are not as great as those observed in pigs. Beermann et al. (1990) demonstrated a 12 to 19% increase in growth rate and a 22% response in feed efficiency with oST treatment. However, the improvement in feed efficiency did not result from a decrease in feed intake as generally has been observed in pigs. These authors reported a 36% increase in carcass protein content and a 33% decrease in lipid accretion rates. Beermann et al. (1990) found that ewe lambs exhibited greater reductions in fat accretion and greater responses in growth rate than wethers when oST was administered over an 8-week period prior to slaughter. Ewe lambs generally have slightly slower growth rate and deposit more fat at the same weight or age as wethers.

Prolonged release delivery of bST in an oil-based formulation (formulated sometribove) was injected at 50, 100, or 150 mg as a single treatment once every 2 weeks or as two equal treatments once per week by McLaughlin et al. (1994). Feed conversion efficiency improved by 9 and 10% in lambs injected once and twice/2 weeks, respectively. Fat thickness was reduced by 17, 30, and 42% with increasing dosages. Percentage of muscle increased, and weight of fat decreased.

Clearly, oST would have to be effective in an implant or prolonged release form before the sheep industry would adopt this technology. Sheep often graze or run in larger lots than pigs and their quick, flighty nature would make it extremely impractical to inject them daily with oST. An implant release form of oST might be accepted readily by the sheep industry, because no really effective anabolic steroid implant currently is available for use in sheep.

In general, ST administration does not significantly alter growth or composition in avian species (Beermann, 1994).

There is no scientific data to prevent the approval of somatotropin for use in swine, sheep, and beef cattle production. Somatotropin is extremely effective in improving growth performance and meat yield percentage. It will decrease marbling significantly and decrease tenderness a majority of the time. It has a neutral to slightly negative effect on color and firmness and a negative effect on commercial bacon production because of the thicker skin and thinner bellies. It is not likely that somatotropin will be approved for use in the near future.

Table 16. Subclass Means for Sensory Values[a] and Intramuscular Lipid of Loin Chops by Porcine Somatotropin (pST) Treatment and Stress Classification

Stress Classification	pST Treatment	Sensory Attribute					Fat, %
		Initial Tenderness[b]	Sustained Tenderness[b]	Initial Juiciness[bcd]	Sustained Juiciness[cd]	Flavor[c]	
Negative	Control	77.9±3.1	81.0±3.2	59.1±2.8	61.8±3.0	75.5±2.9	2.6±.6
Negative	pST	69.7±3.1	69.4±3.1	56.6±2.8	59.8±3.0	80.7±2.8	1.2±.6
Carrier	Control	83.4±3.3	83.7±3.4	62.2±3.0	63.4±3.2	79.7±3.0	3.6±.6
Carrier	pST	64.2±3.0	67.6±3.4	47.4±3.0	46.9±3.2	78.7±3.0	2.5±.8
Positive	Control	70.7±3.0	74.1±3.1	45.1±2.8	49.1±3.0	76.0±2.8	1.7±.7
Positive	pST	65.3±4.2	66.3±4.3	52.1±3.8	51.9±4.1	67.3±3.9	1.9±.9

[a] Least squares means and standard errors for sensory values based on score sheet with 0=least intensity of juiciness, tenderness, or pork flavor; 150=greatest intensity of juiciness, tenderness, or pork flavor.
[b] Effect of pST was significant (P<.05).
[c] Effect of stress classification was significant (P<.05).
[d] Interaction between stress classification and pST was significant (P<.05).
From Boles et al., 1992.

Table 17. Effects of Somatotropin on Color, Firmness, and Marbling of the Longissimus Muscle

Reference	Trait	Response
Swine		
Chung et al. (1985)[a]	Marbling	0.8↑
	% lipid	0.6↑
Novakofski (1987)[a]	Color	0.42↓
	Firmness	0.34↓
	Marbling	0.7↓
	% Lipid	1.4%↓
McLaughlin et al. (1989)[a]	Color	ND[c]
Beermann et al. (1990)[a]	Color	0.1↓
	Firmness	0.2↓
	Marbling	0.5↓
Bidanel et al. (1991)	% Lipid	1.3%↓
Knight et al. (1991)[b]	Study 1: Color	ND
	Marbling	ND
	Study 2: Marbling	Up to 0.22↓
Miller et al. (1991)[a]	Color	0.7↑
	Firmness	0.2↓
	Marbling	1.0↓
Thiel et al. (1993)	Myoglobin concentration	ND
	Color	Slightly darker
	Rate of pH decline	ND
	% Lipid	50 to 80%↓
Clark et al. (1992)[a]	Color	ND
	Marbling	0.3↓
Goodband et al. (1993)[a]	Color	0.4↓
	Firmness	0.2↓
	Marbling	0.9↓
Cattle		
Dalke et al. (1992)	Marbling	0.7 degree↓
	Quality grade	2/3 grade↓
Moseley et al. (1992)	Marbling	↓8 to 70%
Vestergaard et al. (1993)	Color	ND
	Marbling	20%↓

[a] Using a 5-point scale.
[b] Using a 3-point scale.
[c] ND, no difference.
From McKeith et al. (1994).

Table 18. Effects of Somatotropin on the Sensory Properties of the Pork Longissimus

Reference	Trait	Response
Novakofski (1987)[a]	Tenderness	ND[e]
	Juiciness	ND
	Shear force	Up to 0.3 kg↑
Solomon et al. (1988)	Shear force	Up to 1.1 kg↑
Prusa et al. (1989)[b]	Tenderness	ND and ↓37%
	Juiciness	ND
	Shear force	ND
Beermann et al. (1990)	Shear force	Up to 0.6 kg↑
Boles et al. (1991a)[b]	Tenderness	ND
	Juiciness	↓15%
Knight et al. (1991)[d]	Study 1: Texture	ND
	Juiciness	ND
	Shear force	Up to 0.43 kg↑
	Study 2: Texture	Up to 0.12↓
	Juiciness	Up to 0.09↓
	Shear force	Up to 0.77 kg↑
Solomon et al. (1991)	Shear force	Up to 1.6 kg↑
Boles et al. (1992)[b]	Tenderness	7 to 15%
	Juiciness	ND in 2 of 3 Genotypes
	Shear force	Up to 0.41 kg↑
Goodband et al. (1993)[c]	Tenderness	Up to 0.7↓
	Juiciness	Up to 0.8↓
	Shear force	Up to 1.0 kg↑

[a] Using a 14-point scale.
[b] Using a 150-point scale.
[c] Using a 10-point scale.
[d] Using a 7-point scale.
[e] ND, no difference.
From McKeith et al. (1994).

β-Adrenergic Agonists

Only ractopamine hydrochloride (Paylean®) for use in pigs and zilpaterol hydrochloride (Zilmax®) for use in cattle will be discussed in this manuscript. The reasons that these two are discussed are that Ractopamine is approved for use as Paylean® in the U.S. and zilpaterol does not have the potency or pharmalogical activity of products like clenbuterol or cimaterol. Zilpaterol is a synthetic and is not a phenethanolamine like clenbuterol or cimaterol. Dikeman (1991) discussed significant negative effects of the $β-agonists clenbuterol and cimaterol on meat tenderness in ruminants and potential toxicity effects in humans from consuming meat or other edible organs from animals fed $β-agonistss.

Table 19. Effects of Somatotropin, Sex, and Genotype on the Sensory Characteristics of Pork[a]

Dose[b]	Sex	Genotype[c]	Aroma	Tenderness	Juiciness	Flavor	Overall Acceptability
0	Barrow	NEB	8.3	8.2	7.0	8.7	8.3
	Barrow	PIC	8.0	7.5	6.3	7.7	7.5
	Boar	PIC	7.6	7.2	6.0	6.9	6.6
50	Barrow	NEB	8.2	7.4	6.6	8.5	8.0
	Barrow	PIC	7.6	5.6	5.5	7.4	6.2
	Boar	PIC	8.3	7.2	6.6	7.7	7.4
100	Barrow	NEB	8.0	6.3	6.2	7.9	7.1
	Barrow	PIC	8.0	5.8	5.9	7.6	6.6
	Boar	PIC	8.1	6.6	6.6	7.4	6.8
150	Barrow	NEB	8.3	5.8	6.0	7.4	6.7
	Barrow	PIC	8.1	7.4	7.8	8.9	8.3
	Boar	PIC	8.2	6.2	6.1	7.3	6.8
200	Barrow	NEB	8.1	6.3	6.6	7.3	7.0
	Barrow	PIC	8.2	6.1	6.5	7.4	7.0
	Boar	PIC	7.8	5.7	5.6	7.0	6.2

[a] Sensory characteristics were evaluated on 15 point scales with the lowest values described as the least desirable feature and the highest values described as the most desirable feature for the characteristic evaluated.
[b] Somatotropin dose, $\mu g \cdot d^{-1} \cdot kg^{-1}$ BW.
[c] NEB = unselected Nebraska gene pool line. PIC = Pig Improvement Company high lean tissue growth line.
From Thiel (1991).

Table 20. Effects of Somatotropin, Sex, and Genotype on Longissimus Shear Values[a]

Genotype[b]	Sex	Somatotropin Dose, $\mu g \cdot d^{-1} \cdot kg^{-1}$ BW: 0	50	100	150	200
NEB	Barrows	6.56	6.79	8.00	8.82	8.07
PIC	Barrows	5.52	8.18	7.21	8.02	8.86
PIC	Boars	6.19	7.31	8.89	8.25	7.55
Standard Error of Mean:						
		Sex		.256		
		Genotype		.286		
		Dose		.346		
Analysis of Variance[c]:						
		Sex		NS		
		Genotype		NS		
		Dose		*		
		Sex × Dose		*		
		Genotype × Dose		*		

[a] Shear values in kg were averaged for each pig from three 1.3 cm cores from each of two pork boneless top loin chops, cooked to 70°C and cooled to room temperature, using an Instron Model 1122 Universal Testing Machine equipped with a Warner-Bratzler shearing device and a 50 kg load cell and operating in tension with a crosshead speed of 50 mm per minute.
[b] NEB = unselected Nebraska gene pool line. PIC = Pig Improvement Company high lean tissue growth line.
[c] NS = not significant, * = P<.05 for main effects or P<.20 for interactions.
From Thiel (1991).

Paylean® has positive effects on growth rate, feed efficiency, dressing percent, and carcass composition when fed 30 to 50 d before slaughter. Most of the research for approval was done in the 1980's and early 1990's on moderate-lean-growth pigs.

McKeith et al. (1994) summarized the few studies that have been conducted on the effects of ractopamine on visual meat quality and sensory traits of both beef and pork. The effects on marbling, color and firmness in either species are neutral to positive (Table 21). In one study, ractopamine increased shear force value, whereas another study showed no difference on shear force or sensory palatability (Table 21). Most studies show that dressing percent and hot carcass weight are increased and backfat thickness is decreased. **Longissimus** muscle area and percentage of lean are increased at dosages of 9.0 and 18.0 g of ractopamine/ton of feed.

Merkel (1988) summarized several studies on the effects of ractopamine on pork quality and found no meaningful differences in visual quality traits, proteolytic enzyme activity, shear force, or sensory panel characteristics. More recent studies have shown an increase (.85 and .49 kg) in WBSF when Paylean® was fed at its highest level (18 g/ton) (Aalhus et al., 1990; Uttaro et al., 1993). Paylean® effects on visual pork quality generally are neutral to positive, but shear force may be increased. However, sensory panelists may not detect the increase in shear force. In two studies by Jeremiah et al. (1994a,b), feeding ractopamine had no affect on sensory properties of either uncured or cured pork cuts. Paylean® will increase carcass leanness and should increase ham processing yields (Stites et al. 1991: Uttaro et al.. 1993).

Weldon and Armstrong (2001) reviewed the literature and stated that several studies have shown that the inclusion of ractopamine in the diet will increase growth rate by as much as 275 g/d during the early weeks of ractopamine feeding. However, the improvements decrease over time. Recommendations are to feed ractopamine for 28 d before slaughter. Schinckel et al. (2001) concluded from three main studies that, overall, ractopamine has a positive impact on barrows and gilts with substantially different genetic potentials for lean growth and carcass lean percentage. The ractopamine response to increase lean growth has been found to be proportional to the genetic potential for the populations. Stoller et al. (2003) reported that feeding ractopamine resulted in an increase in growth rate and **longissimus** muscle area but had no effect on visual meat quality, sensory attributes, or instrumental tenderness. It did, however, decrease intramuscular fat in the Berkshire pigs that have high propensity for marbling.

Schluter et al. (1991) studied the effects of feeding ractopamine at 0, 10, 20, or 30 p.p.m. for 46 days before slaughter on feedlot cattle. At 20 and 30 p.p.m., growth rate, feed efficiency, and final live and carcass weights were increased over the controls. However, the average daily gain of those steers was relatively low (1.05 kg/d). Ractopamine did not decrease USDA quality grade. It is likely that ractopamine will be approved for beef cattle as Optaflexx® by the time this manuscript is published.

Zilpaterol (Zilmax®) distinctly improves growth performance, dressing percent, and carcass muscling (Plascencia et al., 1999; Strydom et al., 1998). However, Strydom et al. (1998) reported that zilpaterol supplementation resulted in a decrease in **M. longissimus** dorsi muscle tenderness. The negative effect of zilpaterol

Table 21. Effects of Ractopamine on the Color, Firmness, Marbling, and Lipid Content of Porcine and Bovine Muscle

Reference	Compound	Trait	Response[b]
Watkins et al. (1990)[a]	Ractopamine (pigs)	Color	Up to 0.5↑
		Firmness	Up to 0.4↑
		Marbling	Up to 0.6↑
Stites et al. (1991)	Ractopamine (pigs)	Color	ND
		Firmness	ND
		Marbling	ND
Uttaro et al. (1993)	Ractopamine (pigs)	Color L*	ND
		a*	15%↓
		b*	23%↑
Stites et al. (1994)	Ractopamine (pigs)	Tenderness	ND
		Juiciness	ND
		Shear force	ND
Uttaro et al. (1993)	Ractopamine (pigs)	Shear force	0.5 kg↑
Anderson et al. (1989)	Ractopamine (cattle)	Quality grade	ND

[a] Using a 5-point scale.
Adapted from McKeith et al. (1994).
[b] ND, no difference.

on tenderness seemed to be a function of effective electrical stimulation and postmortem aging. Without high voltage electrical stimulation and 7 d of aging, shear force was 0.78 and 0.60 kg higher for the **longissimus** dorsi and **semitendinosus** muscles, respectively, from cattle supplemented with zilpaterol for 30 d than for control cattle (Figure 6). When electrical stimulation and adequate aging were used, the reduction in tenderness was minor. Strydom et al. (1999) supplemented diets with 0.15 mg Zilmax® for the final 15, 30 or 45 d of the feedlot period until 48 h before slaughter. Sensory evaluated tenderness and juiciness, and shear force of the **longissimus** muscle were negatively affected by feeding Zilmax® for 45 d but not for 15 or 30 d. Strydom et al. (2000) studied the effects of Zilmax® on color and discoloration of three muscle types during vacuum storage and subsequent display. The diet supplemented with Zilmax® for 30 or 50 d significantly enhanced the color shelf life of loin and rump steaks and topside mince during retail display at 4°C, at 0 and 28 d aging. Because of the negative effects of 45 d feeding, it appears that 30 d of Zilmax® supplementation would be optimum. Zilpaterol is approved for use in Mexico and South Africa.

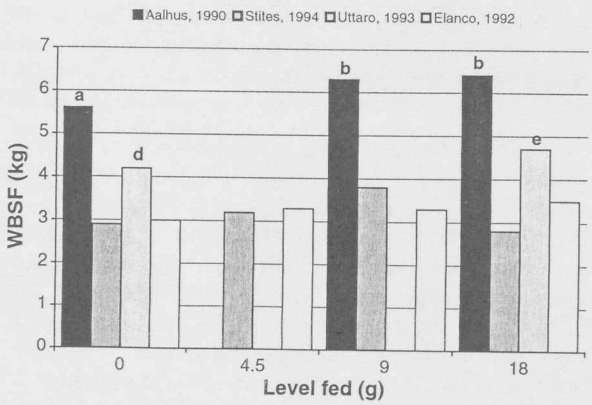

Figure 4. Effects of Paylean® on **Longissimus** WBS Force.

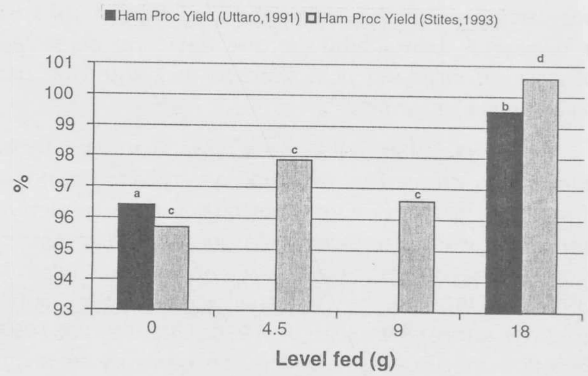

Figure 5. Effects of Paylean® on Ham Processing Yields.

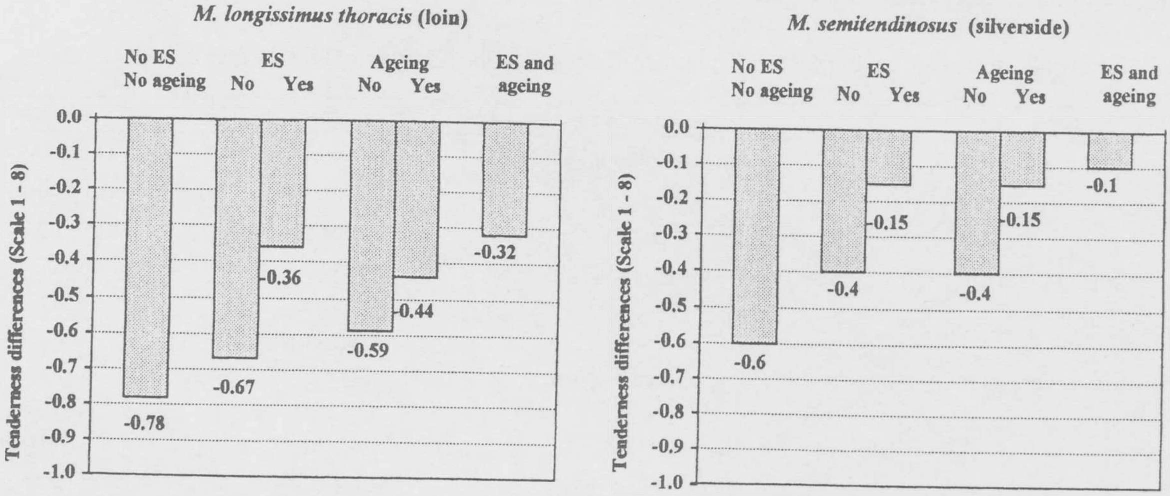

Figure 6. Effects of different slaughter and post-slaughter scenarios on tenderness of the M. **longissimus thoracis** and M. **semitendinosus** muscles from cattle fed zilpaterol for 30 days vs controls. (From Strydom et al., 1998).

Conjugated Linoleic Acid

Linoleic acid (C18:2) is at a relatively high concentration in typical feedstuffs and fat sources used in pig diets. It is not synthesized by pigs nor is it significantly modified before being deposited in fat. It contributes to soft, oily fat and is more susceptible to oxidative rancidity than saturated fat. Considerable research has been conducted in recent years on the effects of dietary conjugated linoleic acid (CLA) on growth, carcass traits, and meat quality in pigs. Part of this interest is because of the proposed human health benefits from consuming CLA. Cook (1999) stated that CLA is widely recognized as a potent anti-cancer fatty acid in many systems. It also reduces fatty streak formation in the aortas of arteriosclerosis models (Cook, 1999). Cook et al. (1998) demonstrated a 20% reduction in backfat in pigs fed CLA and about a 7% increase in lean muscle mass.

Dugan et al. (1997) found that CLA in the diet (2%) repartitions nutrients from carcass fat to lean. In a later study, Dugan et al. (1999) fed either CLA (2%) or sunflower oil (2%) from 61.5 to 106 kg live weight. Feed intake was reduced, feed efficiency was improved, and growth rate was not changed. Subcutaneous fat was reduced but **longissimus thoracis** shear force, drip loss, and color were not affected by diet, but objective chroma values were higher for pigs fed CLA (Table 23). The **longissimus thoracis** muscle had higher marbling scores and increased ether extractable lipid. Diet did not affect any meat palatability trait. Thiel et al. (1998) found an improvement in growth rate as well as an improvement in feed efficiency from feeding 0.12 and 1.0% CLA. An additional advantage found in that study was increased belly firmness as CLA was increased linearly in the diet.

O'Quinn et al. (1999b) studied the effects of modified tall oil, a rich source of CLA, and vitamin E on performance and carcass traits of finishing pigs. Pigs fed modified tall oil had increased ADG and reduced backfat, regardless of vitamin E level. In addition, pigs fed modified tall oil had firmer bellies, which would be an advantage to processors. Woodworth et al. (1999) found that modified tall oil decreased average daily feed intake, improved feed efficiency, and improved belly firmness.

Joo et al. (2002) fed pigs diets containing 0, 1, 2.5, or 5% CLA for 28 d before slaughter. They found that dietary CLA reduced the concentration of linoleic acid and increased CLA concentration in intramuscular fat of pork loins. Intramuscular fat was increased by the 5% level in the diet and less purge was observed with samples from CLA-fed pigs. In addition, dietary CLA improved the color stability of pork loin during cold storage, likely because of lower thibarbaturic acid reactive substances. These authors concluded that dietary CLA offers human health benefits and also improves pork color and water-holding capacity. These authors did not conduct palatability evaluations.

Although not all studies show all of the same benefits, the reported benefits of feeding CLA to pigs include improved feed efficiency, some reduction in backfat thickness, increased marbling and ether extractable lipid, increased fat firmness, improved muscle color, and reduced TBARS. No detrimental effects on performance, visual meat quality, or sensory traits have been reported. However, at the time this review was written, CLA **per se** was not approved for use in diets of pigs or other meat animals as a metabolic modifier. Some hydrogenated vegetable oils have a rather high content of CLA, but are not marketed as containing CLA. If CLA is approved and the benefit/cost ratio is proven favorable, all swine producers should strongly consider adding it to pig diets.

Table 22. Effects of Different Periods of Zilpaterol Intake on Meat Quality Characteristics of Two Muscles

Trait	M. semitendinosus					M. longissimus thoracis				
	Control[2]	Z15[2]	Z30[2]	Z45[2]	SEM	Control	Z15	Z30	Z45	SEM
Sensory attributes[1]										
Aroma	4.6	4.7	4.5	4.6	.099	4.9	4.8	4.7	4.9	.107
Initial juiciness	4.6[ab]	4.6[ab]	4.7[b]	4.2[a]	.109	4.8	4.8	4.9	4.7	.082
First bite	4.3[ab]	4.6[ab]	4.7[b]	4.0[a]	.149	4.8[b]	4.4[ab]	4.5[ab]	3.8[a]	.203
Sustained juiciness	3.9[ab]	4.1[b]	4.0[ab]	3.5[a]	.134	4.6[b]	4.3[ab]	4.3[ab]	3.9[a]	.137
Overall juiciness	4.3	4.7	4.6	4.1	.155	4.8[a]	4.4[ab]	4.5[ab]	3.9[b]	.169
Residual tissue	4.4	4.7	4.7	4.2	.138	4.9[b]	4.6[ab]	4.6[ab]	4.0[a]	.143
Flavour intensity	4.4	4.7	4.4	4.5	.070	4.9	4.7	4.7	4.5	.099
Shear force resistance (N/25 nn Ø)	93.7	90.8	92.6	100.8	3.230	97.9[a]	114.3[ab]	110.7[ab]	125.5[b]	5.600
Compression test (N): 20% level	16.6	16.4	21.1	21.1	.573	11.7[a]	16.9[b]	19.9[b]	19.4[b]	.483

[a,b] Means in the same row and within the same muscle with different superscript letters differ (P<.05; Bonferroni test).
[1] A score of 8 describes the sample as extremely intense in aroma/flavour, extremely juicy, extremely tender with no connective tissue residue, while a score of 1 describes it as extremely bland in aroma and flavour intensity; extremely dry, extremely tough with abundant connective tissue residue.
[2] Control received no zilpaterol; Z15, Z30, Z45 received zilpaterol for the final 15, 30 and 45 days in feedlot, respectively.
From Strydom et al. (1998).

Table 23. Effects of Diets Containing Conjugated Linoleic Acid (CLA) or Sunflower Oil on Longissimus Objective Color, Subjective Color, Structure Score, and Marbling Score (106-kg pigs)

Parameter	Diet	
	CLA	Sunflower
L*	53.2	52.8
Hue	41.0	41.1
Chroma	9.05[a]	8.21[b]
Color score	2.96	2.94
Structure score	2.97	2.95
Marbling score[x]	434[a]	390[b]
Wet Matter Basis (g kg^{-1})		
Intramuscular fat	19.2[a]	15.5[b]
Shear force (kg cm^2)	5.88	5.95
Drip loss (g kg^{-1})	50.3	45.1

[a,b] Means with different letters within row are different (P<.05).
[x] Interaction between diet and gender is significant (P<.01).
From Dugan et al. (1999).

Other Metabolic Modifiers with Potential to Improve Meat Quality

Chromium is an essential trace element for normal metabolism. Boleman et al. (1995) found that feeding elevated levels of chromium picolinate to pigs increased percentage of muscle, decreased backfat, and had no effect on tenderness or sensory traits. Carnatine is a vitamin-like compound that aids in the transport of long-chain fatty acids to the mitochrondial matrix. Supplementing swine diets with L-carnatine decreased backfat thickness without affecting growth performance (Owen et al., 1994; Smith et al., 1994) and increased lean deposition (Owen et al., 1994). O'Quinn et al. (1999a) evaluated the effects of modified tall oil, chromium nicotinate, and L-carnatine in growing-finishing pig diets. L-carnatine did not have any effect on any measure of growth performance or carcass measurements. Chromium nicotinate improved feed efficiency but had no effects on carcass or meat traits. Modified tall oil resulted in increased growth rate and firmer bellies. Waylan et al. (1999) evaluated meat traits from the pigs used in the study by O'Quinn et al. (1999a) and found no differences for **longissimus** color display, TBARS, or shear force. However, chops from pigs fed modified tall oil were less tender when evaluated by a trained sensory panel than those not fed modified tall oil. Bacon from pigs fed chromium had more aftertaste than bacon from pigs not fed chromium. The results of these studies in which chromium nicotinate and L-carnatine were included in diets suggest little advantage from including these metabolic modifiers in the diets of pigs. However, there does appear to be beneficial effects of including modified tall oil in diets to improve growth and(or) carcass traits and to improve the firmness of bellies. This is a practical technology that also has positive effects on human health.

Apple et al. (2000) conducted two experiments on the effects of dietary supplementation of magnesium mica during the growing-finishing period on pig performance and pork carcass characteristics. Magnesium mica had no effect on performance but decreased fat thickness and increased muscle percentage in one study. However, color scores improved linearly with increasing levels of magnesium mica. Real et al. (2002) conducted two experiments to determine the effects of added dietary niacin on growth performance and meat quality in finishing pigs. Dietary treatments consisted of a corn-soybean meal-based control diet or the control diet with 13, 28, 55, 110 or 550 mg/kg of added niacin. In one experiment, increasing added niacin improved feed efficiency, carcass shrink, subjective color, and pH of meat.

SUMMARY

The inclusion of antibiotics and ionophores in livestock diets provides advantages for animal health and performance without any effects on meat quality. Anabolic steroid implants are very cost effective and improve the efficiency of cattle production. They are too effective for most of the beef industry not to use them. In general, the more 'aggressive' implants and implant strategies decrease marbling compared to non-implanted controls. In addition, aggressive implants or implant strategies may tend to make cattle more susceptible to stress and increase the incidence of dark cutters when other conditions are unusually stressful. Tenderness also usually is reduced in meat from implanted cattle compared with that from non-implanted cattle. In general, estrogenic plus trenbolone acetate combination implants repeated two or three times or used late in the finishing phase tend be more detrimental to marbling and tenderness than other implants. Not following the manufacturers' recommendations for implanting types and sequences certainly can cause negative effects. Cattle should not be implanted within 70 d of slaughter and special care should be used when handling cattle during hot weather.

Feeding vitamin D_3 to cattle or pigs will improve tenderness early postmortem, but the advantage in tenderness is minor after adequate aging. The depressions in feed intake and performance reported in some trials and the concerns about human toxicity from consuming too much vitamin D_3 likely will prohibit its use until more research is conducted. Including supranutritional levels of vitamin E in the finishing diets of both cattle and pigs appears to be very beneficial in extending shelf life and reducing oxidative rancidity of meat. The livestock industry should incorporate vitamin E in **all** finishing diets, and meat processors and retailers should reward the industry for this practice.

Feeding ractopamine (Paylean®) to pigs for 28 d before harvest will increase growth rate, dressing percent, and carcass leanness. It may also improve processing yields, but have a nuetral effect on meat palatability. Ractopamine will also improve growth performance of cattle and likely will be approved as Optaflexx® by the time these proceedings are published. Zilpaterol (Zilmax®) distinctly improves growth performance, dressing percent, and carcass muscling. When fed for only 15 to 30 d and when effective electrical stimulation and adequate aging are used, its negative effects on meat palatability will be minor. Meat color may be improved.

Somatatropin is extremely effective in improving growth performance and meat yield percentage. However, it negatively effects marbling, tenderness, and bacon production. It is not likely to be improved in the near future. Including conjugated linoleic acid in diets of pigs generally has positive effects on carcass composition, water-holding capacity, and lipid oxidation. In addition, healthfulness of pork is improved. It should be adapted by the industry if approved and proven cost effective.

No extensive study has evaluated the combined effects of ractopamine, conjugated linoleic acid, and vitamin E in pig diets on carcass composition and meat quality.

B. GENETIC EFFECTS ON CARCASS COMPOSITION AND MEAT QUALITY

In general, the estimates of heritability of carcass and meat quality traits in pigs and cattle range from moderately-low to high. There are some very distinct breed differences in carcass composition and quality traits, such as intramuscular fat (marbling) and tenderness. There is a genetic antagonism between intramuscular fat and percentage of meat yield, but there is little data to show that there are antagonisms between performance traits and meat quality.

Genetic Effects on Carcass Composition and Pork Quality

Genetic differences among pigs that affect meat quality include **major gene effects** and **polygenic effects**. Pork quality can be categorized into the quality-related traits of pH, color, intramuscular fat, tenderness, flavor, water-holding capacity, and oxidative characteristics.

Major gene effects

Three known major commercially important gene effects are: sex chromosome, stress (HAL) gene, and Napole (RN^-) gene. Sellier and Monin (1994) stated that a major gene is one in which the difference between the mean of individuals homozygous for the gene and that of individuals not carrying the gene is at least equal to one phenotypic standard deviation of the trait.

Sex effect. The sex-chromosome influence can be demonstrated as differences between barrows and gilts. The main quality difference of sex-linked traits is that barrow longissimus muscles have more marbling than those from gilts (Table 1). However, barrows have more backfat and are lower in meat yield percentage than gilts at constant market weights, suggesting a hormonal contribution to the onset of fattening.

Data on the sex differences between gilts and boars are included in Table 10. In that data set, the longissimus muscle from gilts contains significantly more intramuscular fat (2.62 vs. 2.24%) and a lower meat yield percentage (59.7 vs. 60.8%).

Stress gene effect. The stress (HAL) gene was first described as porcine stress syndrome (PSS). These hogs, when stressed physically, are more susceptible to death and typically produce pale, soft and exudative (PSE) meat. When triggered by physical stress, there is a defect in the Ca^{++} release channel of the sarcoplasmic reticulum of the muscle cell. In normal muscle, contraction is initiated by a release of Ca^{++} through this channel. For the muscle to relax, Ca^{++} is pumped from the cytoplasm by a Ca^{++} 'pump' back into the sarcoplasmic reticulum. However, in PSS hogs, a defect in the 'gate' of the channel protein prevents it from closing, allowing Ca^{++} to continue to leak. A continued high rate of metabolism associated with this disorder can lead to prolonged acidosis and fatal collapse. Shortly after harvest, muscles from stress-susceptible pigs will have a significantly reduced pH value and greater light reflectance.

Table 1. Influence of Sex (Barrows vs. Gilts) on Pork Loin Quality Traits[a]

Trait	NGEP[b] Barrow	NGEP[b] Gilt	NBS[c] Barrow	NBS[c] Gilt
Minolta Reflectance[d]	23.3	23.1	24.5*	23.3
Visual Color	3.0	3.0	2.8	2.8
Ultimate pH	5.86	5.83	5.68	5.68
Drip Loss, %	2.95	2.75	–	–
Lipid Content, %	2.65*	2.23*	3.24*	2.56*
Marbling Score	2.7*	2.6*	2.6	2.5

[a]Adapted from Goodwin, 1997.
[b]1995 National Genetic Evaluation Program, National Pork Producers Council.
[c]1991/96 National Barrow Show Sire Progeny Tests.
[d]A lower value equates to a paler color.
*Pairs of means within program are statistically different (P<.05).

Halothane screening has been used as a tool to detect PSS pigs (Eikelenboom and Minkema, 1974). Live pigs that have muscle stiffening when exposed to halothane gas are halothane-positive and most likely have two copies of the recessive allele (nn). Using halothane-screening generally does not detect the carriers (Nn) of the PSS gene. However, blood typing can be used to segregate pigs into normal (NN), carriers (Nn), and stress susceptible (nn) pigs. This detects the mutation of the Ca^{++} release protein named ryanodine (RYR1). While stress susceptible (nn) pigs can result in 90-95% incidence of PSE, they produce carcasses that are 3-4% leaner with less backfat and larger loin eyes and hams. Live weight gains are similar to NN pigs (Table 2), but stress susceptible pigs are slightly more efficient in converting feed into carcass weight. The carriers (Nn) are intermediate for several of these traits. Carriers have 1 to 2% leaner carcasses than normal pigs and a higher percentage of unacceptable quality characteristics. In an excellent review by Rosenvold and Anderson (2003), these authors stated that Denmark, The Netherlands, Sweden and Switzerland have eliminated the presence of the HAL gene from their selection lines. More recently, most of the large breeding companies are working to remove the HAL gene from their selection lines.

Napole effect. The Napole (RN^-) gene has its origin in the Hampshire breed. This gene causes is a lower ultimate muscle pH and associated PSE pork and greater cooking loss (Table 3). The low pH values are dependent on high 'glycolytic potential'and extended pH decline postmortem (Monin and Sellier, 1985; Estrade et al., 1993), which is believed to result from a single gene with two alleles.

Table 2. Influence of Normal and Stress Gene Carriers on Selected Performance, Carcass, and Muscle Quality Traits[a]

Units	NBS[b] NN	NBS[b] Nn	NBS[b] Diff	NGEP[c] NN	NGEP[c] Nn	NGEP[c] Diff
No. of pigs	2,763	243		2,863	391	
Average daily gain, lb/d	1.69	1.68	.01	1.87	1.88	-.01
Lean gain on test, lb/d				.667	.685	.017*
Tenth rib backfat, in	1.08	1.03	.05*	1.13	1.13	0.00
Last rib backfat, in	1.23	1.22	.01	1.16	1.20	-.04*
Loin area, sq in	5.68	6.02	-.34*	5.94	6.23	-.29*
Carcass length, in	31.67	31.62	.05	32.6	32.4	.18*
Carcass yield, %	72.0	72.5	-.5*	73.5	73.9	-.4*
Hunter loin color, L*	44.2	46.4	-2.2*	47.0	48.7	-1.7*
Loin drip loss, %	2.46	3.16	-.70*	2.61	3.09	-.48*
Loin intramuscular fat, %	3.07	2.72	.35*	2.60	2.28	.32*
INSTRON tenderness, kg	6.22	6.52	-.30*	5.66	6.16	-.5*
Loin quality disqualifications, %				22.5	36.8	

[a] Adapted from Christian, 1997.
[b] National Barrow Show Sire Progeny Tests.
[c] National Genetic Evaluation Program, National Pork Producers Council.
* Difference is statistically significant (P<.05).

The dominant allele (RN^I) is believed to be responsible for the high glycolytic potential. This would suggest that the homozygous dominant (RN^IRN^I) and heterozygous (RN^Irn^+) express the trait while the homozygous recessive (rn^+rn^+) is normal. Milan et al. (2000) stated that the causative mutation for the RN- gene is PRKAG3 gene encoding for a muscle specific isoform of the regulatory(γ subunit of adenosine monophosphate-activated protein kinase.

In genetic evaluation studies, the Hampshire breed and their crosses often have a lower ultimate pH, partially due to the occurrence of this RN^I gene in the population (Table 4). In addition to a lower ultimate pH, the RN^I gene is associated with a lighter (paler) color and reduced water binding capacity. However, the RN^I genotype, compared with rn^+ genotype, may have more tender meat. Le Roy et al. (2000) stated that the processing yield of meat from carriers of the RN- gene is reduced by five to six percentage points compared with non-carriers. A reduction of the frequency of the gene would improve fresh meat quality of the Hampshire population and allow producers to more fully take advantage of genetic diversity and the high meat yield characteristics offered by Hampshire genetics.

Frequency of the RN- gene is almost nonexistent in the Duroc, Landrace, and Yorkshire breeds, but very high in the Hampshire breed. The frequency of the HAL gene is nearly 25% in the Poland China breed and extremely low in the Duroc breed (Table 4).

Hamilton et al. (2000) stated that the detrimental effects of the HAL gene and the RN^- gene are additive for both color and water-holding capacity.

The Napole gene has negative effects on firmness, drip loss, purge loss, cooking loss, pH, and cooked meat juiciness, and has a positive effect on tenderness (Tables 3 and 6). There are also negative effects of the RN- gene on reflectance and intramuscular lipid content of several muscles (Table 5).

Intramuscular fat and androstenone. Van Arendonk and Brascamp (1997) have indicated that there may be a single gene for intramuscular fat. However it is my interpretation that in cattle, intramuscular fat appears to be controlled by polygenic effects rather than by a single major gene. Fouillaux et al. (1997) have suggested that a major gene affects androstenone levels, which is a major cause of boar taint.

Table 3. Quality, Water Holding Capacity, and Sensory Characteristics of the longissimus lumborum of Pork from RN^- and rn+ Animals (n=62)[a]

Traits	RN^-[b]	rn+	Significance[c]
Color[d]	2.52	2.71	*
Firmness[d]	1.89	2.26	***
Marbling[d]	2.18	2.13	NS
L*[e]	41.40	39.83	*
A*[e]	7.28	6.60	**
B*[e]	4.04	3.88	*
pH_u	5.52	5.63	*
Napole yield[f]	91.65	95.28	**
48 hr drip	7.50	4.97	***
Loin-purge (%)[g]	4.47	3.55	*
Ham-purge (%)[h]	6.29	4.99	**
Cooking loss (%)[i]	24.09	20.56	***
Juiciness[j]	8.63	8.04	**
Tenderness[k]	5.71	5.85	NS
Warner-Bratzler shear (kg)[l]	2.06	2.33	**

[a]Adapted from Ellis et al., 1997.
[b]Animals with gycolytic potential greater than 150μ moles/g were classified as RN^-.
[c]* = (P<0.05); ** = (P<0.01); *** = (P<0.01).
[d]Subjective color, firmness, and marbling scores where 1 = pale, soft and devoid of marbling and 5 = dark, firm and moderately abundant marling.
[e]Objective color score where L* = lightness, a* = redness, b* = yellowness.
[f]Cooked yield of 100 g of LL cured with $NaNO_2$ and NaC1.
[g]Moisture lost from the loin after 10 days of vacuum packaged storage.
[h]Moisture lost from cured ham slices after 4 weeks of vacuum packaged storage.
[i]Cooking loss of a 2.5 cm chop cooked to an endpoint temperature of 70°C.
[j]Juiciness, 0 = dry and 15 = juicy.
[k]Tenderness, 0 = tough and 15 = tender.
[l]Kg of force required to shear a 1.3 cm diameter core.

Table 4. Pigs from National Barrow Show and Genetics of Lean Efficiency Project with Known Rendement Napole and HAL 1843 (NN) Genotypes[a]

Breed	Number pigs	Number sires	Freq of RN-, %	Freq of n (HAL), %
Berkshire	981	133	.024	.021
Chester White	326	43	.017	.014
Duroc	820	117	.003	.004
Hampshire	114	18	.590	.018
Landrace	253	34	.004	.079
Poland China	219	30	.096	.235
Spot	79	12	.038	.146
Yorkshire	641	106	.005	.011

[a]Adapted from Goodwin (2003).

Table 5. Least Squares Means for Reflectance and Intramuscular Lipid Percentage of Rendement Napole (RN) and HAL 1843 (NN) Genotypes (Pigs from National Barrow Show and Genetics of Lean Efficiency Project)

Genotype	Loin L	Inside ham L*	Outside ham L*	Loin lipid, %	Inside ham lipid, %	Outside ham lipid, %
rn+/rn+	51.6^a	55.0	55.5	2.50^a	6.1	8.8
RN-/rn+	53.0^b	55.4	56.1	2.27^b	6.0	6.8
RN-/RN-	52.7^b	54.4	54.9	2.22^b	5.8	6.8
N/N	49.7^a	54.9	54.7^a	2.40^a	6.2	7.5
N/n	51.5^b	55.0	56.3^b	2.19^b	5.8	7.4

Adapted from Goodwin (2003).
[ab]Means within a column with different superscript letters differ (P<.05). Traits without superscripts do not differ (P>.05).

Table 6. Least Squares Means for Cooking Loss, Drip Loss and pH for Rendement Napole and HAL 1843 (NN) Genotypes (Pigs from National Barrow Show and Genetics of Lean Prediction Project

Genotype	Loin cooking loss, %	Inside ham drip loss, %	Outside ham drip loss, %	Loin pH	Inside ham pH	Outside ham pH
rn+/rn+	21.6^a	9.7	7.8^a	5.70^a	5.68	5.67^a
RN-/rn+	24.2^b	10.6	9.5^b	5.51^b	5.58	5.56^b
RN-/RN-	23.8^b	11.4	10.3^b	5.51^b	5.64	5.56^b
N/N	22.3^a	10.6	9.3	5.60^a	5.64	5.60
N/n	23.8^b	10.6	9.1	5.56^b	5.63	5.60

Adapted from Goodwin (2003).
[ab]Means within a column with different superscript letters differ (P<.05). Traits without superscripts do not differ (P<.05).

Polygenic Inheritance

Differences among breeds and hybrids offer genetic diversity and opportunities for producers to select from different populations and to optimize heterosis (hybrid vigor) of lowly heritable traits. Within breeds, there is genetic variability and selection pressures that continually change their populations. The National Genetic Evaluation Program (Tables 7 and 8) offers some insights into different breeds and their influence on production, carcass and meat quality traits. While no one sire line excels in all traits, certain lines can be selected to meet desired objectives. When focusing on quality-related traits, the Berkshire breed appears to have a superior combination of desirable loin quality traits; the Duroc breed appears to excel in intramuscular fat (marbling), whereas the Hampshire breed appears to have lower ultimate pH and higher drip losses, yet desirable tenderness evaluations (characteristics of the RN^- gene).

Table 7. Least Squares Means for Breed Effects on Lipid Percentage of Loin and Ham Muscles (Pigs from National Barrow Show and Genetics of Lean Efficiency Project)

Breed	Loin lipid, %	Inside ham lipid, %	Outside ham lipid, %	Loin cooking loss, %	Inside ham drip loss, %	Outside ham drip loss, %
Berkshire	2.58^{b}	8.4^{a}	8.7^{a}	21.4^{a}	8.9^{a}	8.1^{a}
Chester White	2.46^{b}	5.7^{cd}	6.9^{bc}	22.7^{b}	10.7^{bc}	9.5^{bc}
Duroc	3.12^{a}	6.8^{bc}	7.8^{ab}	23.6^{c}	11.5^{bc}	10.0^{c}
Hampshire	2.08^{c}	4.1^{d}	7.8^{ab}	23.4^{bc}	10.7^{bc}	8.4^{ab}
Landrace	1.99^{c}	4.2^{d}	7.1^{b}	24.4^{d}	11.5^{c}	9.7^{c}
Poland china	2.18^{c}	6.2^{c}	7.5^{ab}	23.0^{bc}	10.0^{b}	9.2^{bc}
Spot	2.44^{b}	7.7^{ab}	8.2^{ab}	23.4^{bc}	10.9^{bc}	9.8^{c}
Yorkshire	1.77^{d}	4.8^{d}	5.7^{c}	24.0^{cd}	10.3^{b}	9.0^{b}

Adapted from Goodwin (2003).
abcdMeans within a column with different superscript letters differ (P<.05).

Table 8. Least Squares Means for Breed Effects on Ultimate Loin and Ham Muscle pH (Pigs from Nation Barrow Show and Genetics of Lean Prediction Project)

Breed	Loin pH	Inside ham pH	Outside ham pH
Berkshire	5.67^{a}	5.74^{a}	5.71^{a}
Chester White	5.70^{a}	5.69^{ab}	5.62^{b}
Duroc	5.58^{b}	5.63^{b}	5.59^{b}
Hampshire	5.59^{b}	5.55^{b}	5.53^{b}
Landrace	5.47^{c}	5.62^{b}	5.59^{b}
Poland China	5.59^{b}	5.68^{b}	5.60^{b}
Spot	5.52^{c}	5.60^{b}	5.57^{b}
Yorkshire	5.49^{c}	5.57^{b}	5.57^{b}

Adapted from Goodwin (2003).
abcMeans within a column with different superscript letters differ (P<.05).

Genetic correlations. Correlations among production traits such as daily gain, backfat and loin eye area and most quality traits such as color, muscle pH, and Instron shear force are usually low (NPPC, 1995). Only external fat (10th rib fat depth and last rib backfat) and fat within the muscle (lipid and marbling) have a moderate relationship. This suggests that breeding programs can be developed to improve meat yield percentage and still maintain or improve quality at the same time. However, selection for production and meat yield percentage without selecting for quality can result in decreased meat quality. Even though the relationship of fatness and meat palatability is not strong, pork from extremely lean carcasses and/or carcasses with low marbling tends to be less tender and less juicy than pork from carcasses with 0.6 in. (17mm) or more fat over the loin. Therefore, selection considerations should be placed on quality attributes as well as production and meat yield percentage to optimize efficient production of lean, high quality pork.

Goodwin (2003) reported heritability estimates for pork quality traits (Table 9). The heritability estimates for the traits of intramuscular fat and water holding capacity for both the loin and inside ham range from 0.36 to 0.50. Heritability of pH for the loin is high at 0.48, but somewhat low at 0.25 for the inside ham. Table 9 also contains genetic correlations among quality traits. Intramuscular fat percentage of the loin and inside ham are highly correlated at 0.8, and pH of the loin is highly correlated with pH of the inside ham (0.68). Loin pH is highly correlated with loin cooking loss (-0.67) and moderately correlated with water holding capacity (-0.36). Goodwin (2003) concluded that selection for loin quality would have favorable effects on ham quality.

Hovenier (1993) summarized heritability estimates from the literature and reported a high heritability estimate for intramuscular fat percentage (0.50); moderate heritability estimates for color, tenderness, and pH (all 0.30); and a relatively low estimate for water holding capacity (0.20). These heritability estimates were obtained from both halothane-positive and halothane-negative pigs. Hovenier stated that selection against the halothane gene will have only a minor influence on heritabilities of meat quality parameters. Table 10 contains data from a halothane-negative population (Duroc and Dutch-Yorkshire pigs) and

Table 9. Heritabilities on the Diagonals and Genetic Correlations Above the Diagonals Among Pork Quality Traits (Pigs from National Barrow Show and Genetics of Lean Prediction Project)

	Loin					Inside ham			
	IMP[a]	HUNT[b]	_PH[c]	WHC[d]	CLSS[e]	IMF[a]	WHC[d]	_PH[c]	HUNT[b]
LOINIMF	**0.50**	0.09	0.22	-0.17	-0.14	0.81	-0.29	0.04	0.14
LOINHUNT		**0.34**	-0.17	0.02	0.10	0.30	-0.34	-0.18	-0.07
LOIN_PH			**0.48**	-0.36	-0.67	0.02	0.23	0.68	-0.53
LOINWHC				**0.44**	0.34	-0.30	-0.23	-0.28	-0.36
LOINCLSS					**0.20**	-0.01	0.01	-0.55	0.42
IHAMIMF						**0.50**	-0.02	0.07	0.43
IHAMWHC							**0.36**	0.10	0.25
IHAM_PH								**0.25**	-0.48
IHAMHUNT									**0.21**

Adapted from Goodwin (2003).
[a]Intramuscular lipid percent.
[b]Hunter L* color score.
[c]Ultimate pH.
[d]Loin filter paper exudate or ham drip loss.
[e]Percent cooking loss.

Table 10. Number of Pigs per Trait, Generalized Least Squares Means for Breeds and Sexes, and Heritabilities (h^2) of Growth, Carcass, and Meat Traits[a]

		Breed		Sex		
Trait[1]	n	Dutch-Yorkshire	Duroc	Boars	Gilts	h^2
LWG (gd^{-1})	1,110	621.2[b]	599.8[c]	624.4[b]	596.7[c]	0.29
BF (mm)	1,110	11.27[b]	12.42[c]	11.56[b]	12.12[c]	0.51
LMC (%)	1,106	60.95[b]	59.49[c]	60.78[b]	59.67[c]	0.63
INTMF (%)	1,075	1.65[b]	3.20[c]	2.24[b]	2.62[c]	0.61
DRIP (%)	1,086	4.40	4.81	4.44	4.77	0.30
PHLD	1,110	5.52	5.59	5.56	5.55	0.39
PHSM	1,100	5.61	5.64	5.62	5.62	0.20
COLOR	1,111	2.91[b]	3.25[c]	3.07	3.09	0.29

[a]Adapted from Hovenier (1993).
[bc]Means within breed or sex with different superscript letters differ (P<0.01).
[1]LWG = average daily live weight gain; BF = ultrasonic backfat thickness; LMC = lean meat content; INTMF = intramuscular fat; DRIP = drip loss; PHLD = $pH_{24hours}$ in M. longissimus dorsi; PHSM = $pH_{24hours}$ in M. semimembranosus.

illustrates that the heritability estimates are similar to those for the population that contained both halothane-positive and negative pigs. These data also show that backfat thickness and lean meat percentage are highly heritable (0.51 and 0.63, respectively).

Monin and Sellier (1994) reported ranges and average heritability estimates of meat quality traits from the literature (Table 11). The heritability estimates for tenderness and intramuscular fat averaged 0.30 and 0.48, respectively. Oksbjerg et al. (2001) reported a moderately high heritability estimate for muscle glycogen content (0.37) and pH (0.30) (Table 12). In addition, a* and b* values had high and moderately-high heritability estimates (0.60 and 0.34, respectively). The genetic relationship between backfat thickness and rate of live weight gain is positive (0.57) and the genetic relationship between intramuscular fat percentage and lean meat percentage is negative (-0.44) (Table 13). However, genetic correlations between live weight gain and meat quality traits are favorable. Without selection for meat quality, selection for reduced backfat thickness and increased meat yield percentage generally will have a detrimental effect on meat quality. These published results illustrate that several pork quality traits of importance are moderately-high to highly heritable and that progress could be made through a structured selection program.

Table 11. Average Values of Heritability (h^2) of Some Meat Quality Criteria[a]

Trait	Average h^2 (1)	No. of estimates	Range of estimates
pH1 (2)	0.18	11	0.11 - 0.41
pH_u (2)	0.22	23	0.07 - 0.34
Reflectance	0.28	25	0.15 - 0.57
Water-holding capacity	0.12	12	0.01 - 0.43
Subjective quality score	0.22	5	0.10 - 0.37
Tenderness (shear force)	0.30	7	0.21 - 0.46
Tenderness (taste panel)	0.32	5	0.23 - 0.70
Juiciness (taste panel)	0.06	5	0.00 - 0.28
Intramuscular fat content	0.48	14	0.26 - 0.86

[a]Adapted from Sellier and Monin (1994).
(1) Weighted mean of the h^2 estimates.
(2) pH1 = pH at 45-60 min postmortem; pH_u = pH at 24 h postmortem.

Table 12. Number of Observations, Means of Traits, Standard Deviations, and Heritabilities (h^2) of Traits in Danish Pure Breed Pigs[a]

Item	n	Mean	SD	h^2
Glycerol, mg/g	967	1.18	0.23	0.14
Glycogen, Fmoles/g wet weight	1646	87.5	12.0	0.37
Pigment, mg myoglobin residues/g	1651	1.41	0.34	0.19
Colour	902	3.31	0.88	0.16
L*	902	52.4	3.45	0.15
A*	902	5.82	1.23	0.60
B*	902	5.47	1.27	0.34
pH (loin and ham)	821	5.63	0.09	0.30

[a]Adapted from Oksbjerg et al. (2001).

Table 13. Genetic Correlations Among Pig Growth, Carcass, and Meat Quality Traits[a]

	LWG[1]	BF[1]	LMC[1]	INTMF[1]	DRIP[1]	PHLD[1]	PHSM[1]	COLOR[1]
LWG		0.55						
BF	0.57		-0.75					
LMC	-0.27	-0.71		0.11				
INTMF	0.19	0.37	-0.44		-0.03			
DRIP	-0.06	-0.07	0.11	-0.07		-0.46		
PHLD	0.12	0.15	-0.11	-0.18	0.80		0.45	
PHSM	0.26	0.25	-0.05	0.36	-0.60	0.64		0.33
COLOR	0.46	0.00	0.17	-0.33	-0.73	0.71	0.80	

[a]Adapted from Hovenier (1993).
[1]LWG = average daily live weight gain; BF = ultrasonic backfat thickness; LMC = lean meat content; INTMF = intramuscular fat; DRIP = drip loss; PHLD = $pH_{24hours}$ in M. longissimus dorsi; PHSM = $pH_{24hours}$ in M. semimembranosus.

Genetic 'Markers' and Candidate Genes for Pork Carcass Composition and Meat Quality Traits

Rothschild (2001) suggested three approaches have been employed to find genes that affect pork carcass composition and meat quality. The first has been to find that "major" genes such as HAL and RN- are segregating in a population. The second approach is the "genomic scan" method, which uses specialized crossbred resource families and random genetic markers to scan regions of the genome that are associated with meat quality traits. The final approach is the candidate gene approach and uses genes that, by their nature, are expected to be associated with certain physiological functions.

Ciobanu et al. (2001) demonstrated the presence of new, economically important alleles of the PRKAG3 gene affecting the glycogen content in muscle. They concluded that the potential applications of the alleles of this gene for the pig industry and consumers are considerably greater than the original discovery of the RN^- mutation. These genes are segregating in all of the commercial lines in contrast to the RN- mutation, which is associated only with the Hampshire breed. Ciobanu et al. (2002) reported that a suggestive QTL for average Instron shear force was revealed for chromosome 2 in a population of Berkshire x Yorkshire pigs. They considered the calpastatin gene to be a good candidate for the QTL.

Genetic Effects on Beef Carcass Composition and Meat Quality

The genetic effects on beef carcass composition and meat quality include polygenic effects, individual gene effects, and DNA 'markers.'

Differences among and within cattle breeds largely are caused by polygenic effects. The most extensive data set for the effects of breed of cattle on carcass composition and meat quality traits is from the U.S. Meat Animal Research Center (USMARC) in Clay Center, Nebraska, USA. I was fortunate to cooperate on much of the research on the Germ Plasm Evaluation and Germ Plasm Utilization projects at USMARC. Data in Table 14 are from steer progeny sired by twelve breeds out of Angus and Hereford dams. There are some distinct breed differences in carcass weight, meat yield percentage, and marbling. In addition, the **longissimus thoracis** muscles from the **Bos indicus** breeds of Brahman and Sahiwal were less tender than for most other breeds. **Bos indicus** cattle also have below average marbling. Steers sired by the Jersey dairy breed and South Devon dual-purpose breed produced steaks that possessed an excellent combination of tenderness, flavor and juiciness. Sire breed differences in trained sensory-panel evaluated flavor and juiciness were small.

Table 15 shows breed differences in dressing percent, marbling score, tenderness, and meat yield (retail product) percentage and weight from cattle in Cycle IV of the Germ Plasm Evaluation project at USMARC. The **Bos indicus** Nellore breed and the muscular hypertrophy Piedmontese breed excelled in dressing percent. The British breeds of Angus, Hereford, and Shorthorn excelled in marbling. The Nellore breed produced longissimus steaks that were inferior in tenderness; steaks from Salers-sired steers were intermediate in tenderness. The Piedmontese breed excelled in meat yield percentage and was superior to several sire breeds in meat yield weight. The Charolais breed excelled in meat yield weight.

Table 16 contains data from progeny of seven sire breeds in Cycle V of the Germ Plasm Evaluation project at USMARC. The two muscular hypertrophy breeds of Piedmontese and Belgian blue excelled in both meat yield percentage and weight, and had an advantage in dressing percent. On the other hand, these two breeds were inferior in marbling to all breeds except the Brahman breed. There were wide differences in the percentage of carcasses that graded U.S. Department of Agriculture (USDA) Choice. As in Cycle IV data, steaks from Brahman-sired steers were inferior in tenderness to all other sire breeds. Steaks from Angus sired steers had the highest sensory panel evaluated tenderness and juiciness scores, whereas steaks from Brahman-sired steers had the least desirable tenderness and juiciness scores. The Boran breed is a **Bos indicus** breed, and the Tuli breed is a **Bos taurus** breed that is also a heat tolerant breed. Yet, steaks from the Tuli breed were more tender than those from the Brahman breed.

Data from Cycle VI of the Germ Plasm Evaluation project at USMARC (Cundiff et al., 2001) are not presented. However, it is worth noting that Waygu-sired progeny had marbling equal to Angus-sired progeny, even though the Waygu breed is known for exceptionally high marbling. They also were similar in sensory panel traits to Angus. Although they had a higher meat yield %, they produced less meat yield weight than Angus at the same age.

The data in Tables 14, 15, and 16 are from sire breeds mated to Angus, Hereford, or composite MARC III dams. Therefore, differences among sire breeds in these data are approximately 50% of what differences would be between pure breeds. Data in Table 17 are from pure breeds evaluated in the Germ Plasm Utilization project at USMARC. Consequently, the magnitude of the differences in some traits among some breeds are greater than when sire breeds are mated to common dam breeds like Hereford, Angus or MARC III. The Limousin breed excelled in dressing percent and meat yield percentage; the Gelbvieh and Simmental breeds were intermediate in meat yield percentage. The Continental breeds of Limousin, Simmental, Charolais and Gelbvieh ranked highest for meat yield weight. Angus and Red Poll excelled in marbling, whereas Herefords and Pinzgauers were intermediate. The Limousin and Gelbvieh breeds were inferior in marbling and generally had the lowest sensory panel scores. Angus and Pinzgauer breeds had a distinct advantage in shear force and sensory panel tenderness.

Table 14. Breed Group Means for Carcass Traits - Cycles I, II, and III[1]

Sire breed	Carcass weight (lb)	Retail product (%)	Marbling score[2]	Percent Choice	Warner-Bratzler shear force (lb)	Flavor[3]	Juiciness[3]	Tenderness[3]
	Adjusted to a constant age of 458 days							
Jersey	593	65.5	13.3	85	6.8	7.5	7.5	7.4
Hereford-Angus	637	66.3	11.3	76	7.3	7.3	7.3	7.3
South Devon	655	67.7	11.3	76	6.8	7.3	7.4	7.4
Sahiwal	611	69.1	9.7	44	9.1	7.1	7.0	5.8
Brahman	663	69.4	9.3	40	8.4	7.2	6.9	6.5
Brown Swiss	677	69.1	10.4	61	7.7	7.4	7.2	7.2
Gelbvieh	687	69.8	9.7	43	7.8	7.4	7.2	6.9
Simmental	673	71.0	9.9	60	7.8	7.3	7.3	6.8
Maine-Anjou	704	70.2	10.2	54	7.5	7.3	7.2	7.1
Limousin	652	72.4	8.9	37	7.7	7.4	7.3	6.9
Charolais	691	71.8	10.3	63	7.2	7.4	7.3	7.3
Chianina	690	73.0	8.5	24	7.9	7.3	7.2	6.9

[1]Adapted from Koch et al. (1982).
[2]Marbling scores: traces = 4, 5, 6; slight = 7, 8, 9; small = 10, 11, 12; modest = 13, 14, 15.
[3]9 = extremely flavorful, juicy, and tender; 1 = extremely bland, dry, and tough.

Table 15. Breed Group Means for Dressing Percent and Carcass Traits of Steers, Cycle IV (Phase 2)[1]

Sire breed group of steers	Dressing percent (%)	Marbling Score[a]	Shear force (lb)	Fat thickness (in)	Retail product 0.3 in trim (%)	Retail product 0.3 in trim (lb)
Original Hereford x Angus	62.0	531	11.8	0.65	67.8	447
Current Hereford x Angus	62.1	523	12.3	0.61	68.2	487
Charolais	61.8	496	13.0	0.37	71.2	522
Gelbvieh	61.8	498	12.5	0.36	71.6	503
Shorthorn	61.9	548	12.9	0.47	68.0	484
Nellore	64.2	486	15.8	0.47	70.2	495
Piedmontese	63.6	492	11.9	0.29	74.4	512
Salers	62.3	496	14.0	0.38	71.0	503

[1]Adapted from Cundiff et al. (1993).
[a]400-499 = Slight; 500-599 = Small.

Table 16. Breed Group Means for Carcass and Meat Traits of Steers (447 Days of Age)[1]

Sire breed of steer	Dressing Percent (%)	0.3 in trim retail product %	0.3 in trim retail product lb	Marbling Score[a]	USDA Choice (%)	Warner-Bratzler shear, lb.	Sensory panel (7 days aging)[a] Tenderness score	Flavor score	Juiciness score
Hereford	60.4	67.6	491	520	70.3	10.6	5.13	4.94	5.19
Angus	60.5	67.9	495	556	84.6	8.9	5.38	4.89	5.36
Brahman	61.6	69.6	482	476	29.9	13.2	4.00	4.83	4.78
Boran	61.3	68.4	438	504	47.2	11.3	4.48	4.77	5.04
Tuli	61.3	69.0	440	525	63.8	10.1	5.00	4.86	5.17
Piedmontese	62.3	75.3	514	472	31.8	10.1	5.04	4.84	5.02
Belgian Blue	62.2	74.0	542	464	23.8	10.7	4.93	4.85	5.02
LSD 0.05[b]	0.9	1.5	1.9	30	22.2	1.3	0.47	0.15	0.20

[1]Adapted from Cundiff et al. (1996).
[b]400-499 = Slight; 500-599 = Small.
[a]8 = extremely tender, intense or juicy; 1 = extremely tough, bland, or dry.
[b]LSD0.05 is the approximate difference between means of parental breeds required for significance.

Currently, marbling in beef cattle is very important economically in the U.S. and seedstock producers are selecting to improve marbling by obtaining ultrasound data on progeny of sires and(or) obtaining actual carcass data on progeny. When progeny tests are properly conducted so that several sires are compared in the same contemporary group, genetic differences in marbling among sires can be used to develop Expected Progeny Differences (EPDs) by breed associations for use in selection. EPDs are'user friendly' tools for cattle producers to use in selection. Most U.S. beef cattle breed associations publish EPDs for marbling and several other carcass traits in addition to performance traits such as weaning or yearling weight. EPDs are expressed as deviations in marbling score or percentage of intramuscular fat from the breed average.

An example of the marbling EPDs of four Simmental sires are presented in Table 18. The EPD of 0.27 for Nichols Legacy means that he would be expected to sire progeny that would have 0.27 higher marbling score than breed average. If breed average was 'Small^{20}', his progeny would be expected to average 'Small^{47}'. Progeny from 3C Pasque would be expected to average 0.35 marbling score lower than breed average, or 'Slight^{85}' (Slight is the degree of marbling below Small).

The average heritability estimate for longissimus muscle tenderness in cattle is 0.30. Unfortunately, the only accurate method at present to measure tenderness is to retrieve sections of meat from carcasses, cook them, and then conduct a trained sensory panel or use an instrumental method such as the Warner-Bratzler Shear Instrument or MIRINZ Tenderometer to measure tenderness. Whatever the method of measurement used, it is difficult and expensive to obtain tenderness data for genetic improvement. Animals have to be identified at the time of slaughter, sections of meat have to be retrieved, and the meat then transported to a laboratory where tenderness assessment can be made. Because trained sensory panels can only evaluate a few samples at one time, most tenderness measurements are made by using an instrumental procedure.

Expected Progeny Differences for Warner-Bratzler shear force have been published by the American Simmental Association, which are the first EPDs developed and published for tenderness. The EPDs ranged from -0.87 lb. to +0.60 lb among the 102 sires tested. Seedstock producers can use this information to make selection decisions to genetically improve tenderness (Table 18).

Breeds are not identified in these data because the study was not a breed comparison study, but rather a study to generate data to allow breed associations to develop EPDs and to validate DNA markers for meat quality traits. The range for Warner-Bratzler shear force means from the most to the least tender breed is quite wide at 8.9 lb., or 4.1 kg (Table 19). The range among progeny means of sires across breeds was dramatic at 14.4 lb. or 6.6 kg. These data also show that there is considerable range among progeny means of sires within breeds. These data clearly indicate that there is a very significant beef tenderness problem. The cattle in this large study were young and managed in a near optimum way; therefore, the variability in tenderness when cattle are older and not managed in an optimum way likely will be even greater.

The correlation between Warner-Bratzler shear force and trained sensory panel evaluated tenderness for the data in Tables 19 and 20 was -0.82. The ranking of the 11 breeds that had at least 100 progeny evaluated was slightly different than the ranking for Warner-Bratzler shear force, but the two most tender and two least tender breeds were the same for both methods of evaluating tenderness (Table 20).

Table 17. Pure Breed Least Squares Means for Carcass and Meat Palatability Traits[a]

Breed	Dressing percent	Marbling score[b]	Percentage USDA Choice&Prime	Retail product 8 mm, %	Retail product 0 mm, %	Retail product 8 mm, kg	Shear force, kg	Sensory panel[c] Tenderness	Sensory panel[c] Juiciness	Sensory panel[c] Flavor
Red Poll	60.0	5.30	71	67.8	62.6	202.5	4.72	5.15	5.25	4.96
Hereford	60.3	5.21	60	66.0	60.1	192.3	5.06	5.10	5.25	4.80
Angus	61.3	5.41	77	67.1	61.5	201.2	4.50	5.55	5.38	4.92
Limousin	63.4	4.43	14	76.5	72.3	239.8	5.62	4.88	5.01	4.82
Braunvieh	59.7	4.84	42	71.9	67.3	232.1	5.09	5.06	5.12	4.90
Pinzgauer	59.5	5.16	55	71.5	66.8	225.0	4.47	5.43	5.20	4.96
Gelbvieh	59.9	4.53	15	74.2	70.0	240.1	5.78	4.63	5.04	4.75
Simmental	59.8	4.80	34	72.8	68.4	239.3	5.48	4.80	5.14	4.83
Charolais	60.7	4.71	24	73.2	68.7	241.3	5.16	4.95	5.12	4.88
D.05[d]	.8	.28	19	1.3	1.5	8.2	.45	.27	.19	.13

[a]Adapted from Gregory et al. (1994a, 1994b).
[b]4.00 - 4.90 = slight; 5.00 - 5.90 = small.
[c]8 = extremely tender, juicy, or flavorful; 1 = extremely tough, dry, or bland.
[d]D.05 is the approximate difference between means of parental breeds required for significance.

Table 18. Example Warner-Bratzler Shear Force and Marbling Expected Progeny Differences (EPDs) for Four Simmental Sires[1] from Data Generated in the Carcass Merit Traits Project[2]

Sire Name	Warner-Bratzler shear force EPD (lb.)	Accuracy	Marbling EPD	Accuracy
GW Lucky Break 047G	-0.87 (1st)	0.26	-0.01	0.41
Circle S Leachman 600U	-0.36	0.45	0.14	0.66
GW Lucky Strike 147G	-0.02	0.26	0.47 (2nd)	0.43
Nichols Shannigan F5	0.60 (100th)	0.38	-0.16	0.47

1 From Dikeman et al. (2003).
2 The Carcass Merit Traits project was funded in part by beef and veal producers and importers through their $1/hd checkoff and was produced for the Cattlemen's Beef Board and state councils by the National Cattlemen's Beef Association.

Table 19. Carcass Merit Traits Project[1] Warner-Bratzler Shear Force Ranges of Sires Within Breeds Ranked on WBSF from Most Tender to Least Tender Breed[2]

Breed #1	3.45 lb	Breed #8	3.68 lb.
Breed #2	5.20 lb	Breed #9	1.90 lb
Breed #3	3.74 lb	Breed #10	3.99 lb
Breed #4	2.29 lb	Breed #11	2.33 lb
Breed #5	2.79 lb	Breed #12	6.62 lb
Breed #6	2.66 lb	Breed #13	4.49 lb
Breed #7	4.32 lb	Breed #14	6.41 lb

Breed range = 8.9 lb; Sire range across breeds = 14.44 lb.
1 From Dikeman et al. (2003).
2 The Carcass Merit Traits project was funded in part by beef and veal producers and importers through their $1/hd checkoff and was produced for the Cattlemen's Beef Board and state councils by the National Cattlemen's Beef Association.

Table 20. Carcass Merit Traits Project[1] Ranges of Sires for Tenderness Scores* Within Breeds Ranked 1st to 11th**[2]

Breed #2	0.75	Breed #11	0.55
Breed #3	0.56	Breed #10	0.81
Breed #4	0.84	Breed #13	1.13
Breed #7	1.11	Breed #14	1.05
Breed #9	0.80		
Breed #6	1.11		
Breed #8	0.52		

* 8 = extremely tender; 1 = extremely tough.
** Only breeds with $100 progeny (11 of the 14 breeds) are presented; Avg. tenderness score = 5.63; Breed range = 2.55; Sire range across breeds = 3.03.
1 From Dikeman et al. (2003).
2 The Carcass Merit Traits project was funded in part by beef and veal producers and importers through their $1/hd checkoff and was produced for the Cattlemen's Beef Board and state councils by the National Cattlemen's Beef Association.

The rankings of breeds for flavor intensity as evaluated by a trained sensory panel was considerably different than the ranking for tenderness, which suggests that there is not much relationship between tenderness and flavor intensity. The range of means of breeds, and progeny means of sires within breeds were quite small. These results suggest that there may be little opportunity to genetically improve beef flavor intensity.

The range of means of breeds, the range of progeny means of sires across breeds, and the range of progeny means of sires within breeds for juiciness were intermediate to those of tenderness and flavor intensity. Except for the two breeds with the least juicy steaks, the ranking of breeds on juiciness was much different than how the breeds ranked for tenderness.

Minick et al. (2001) conducted genetic analyses of tenderness and marbling differences among sires within four breeds of beef cattle that were part of the larger Carcass Merit Traits project reported by Dikeman et al. (2003) and Pollak et al. (2001). The heritability estimates of tenderness as measured by Warner-Bratzler shear force were 0.11 in Hereford, 0.13 in Simmental, 0.34 in Angus, and 0.43 in Charolais cattle. In the analyses by Minick et al. (2001), genetic correlations between marbling and Warner-Bratzler shear force were -0.18 for Angus, -0.34 for Charolais, -0.43 for Hereford, and +0.64 in Simmental cattle. For Angus, Hereford, and Charolais cattle, selection for increased marbling would be expected to result in a small to moderate decrease in Warner-Bratzler shear force (improved tenderness). However, in Simmental cattle, an increase in marbling alone would be expected to result in an increase in Warner-Bratzler shear force (decreased tenderness). Therefore, single trait selection for marbling may or may not result in an improvement in tenderness. To improve both marbling and tenderness, there would need to be selection for each trait simultaneously.

Table 21 presents heritability estimates for carcass compositional traits that are very representative of other data in the literature. All of these estimates are moderately-high to high. Ribeye area and fat thickness data can be obtained from actual carcasses of progeny or by ultrasound evaluations of progeny of sire groups. Ultrasound data can be obtained on breeding bulls and heifers as well as on slaughter steers and heifers. When progeny tests are properly designed and conducted, ultrasound and(or) actual carcass data can be used by beef cattle breed associations to develop EPDs. Percentage of retail product (meat yield) can be predicted from weights, fat thicknesses, and ribeye area data.

Table 21. Estimates of Direct Heritability (h^2) for Carcass Traits

Trait	
Hot carcass weight	0.49
Retail product percentage	0.58
Fat percentage	0.49
Bone percentage	0.48
Ribeye area	0.58
Adjusted fat thickness	0.46
Kidney, pelvic and heart fat percentage	0.60
Marbling score	0.35
Warner-Bratzler shear force	0.34

Adapted from Splan et al. (2002).

Single Gene Effects

There is now a GeneSTAR® test for marbling and for tenderness marketed by Genetic Solutions (Genetic Solutions, 2003). This is the first commercial test for a meat quality trait. The marbling test distinguishes alleles of the thyroglobulin gene. Results from studies on the relationship between the frequency of the GeneSTAR® gene for marbling were presented but not published in the proceedings at the 2001 and 2002 Beef Improvement Federation meetings in the U.S. In a population of Simmental, Angus, Red Angus, and Wagyu cattle, there were twice as many cattle homozygous for the GeneSTAR® gene for marbling in Waygu cattle as for Red Angus cattle, and approximately four times as many as for Angus and Simmental cattle. However, the frequency of heterozygotes for the GeneSTAR® gene was nearly equal for the Wagyu and Red Angus breeds. The frequency of the GeneSTAR® gene (homozygotes and heterozygotes) was almost the same for Angus and Simmental cattle, but marbling is considerably higher in Angus than in Simmental cattle. Furthermore, Angus and Red Angus cattle are very similar in marbling, but the frequency of the GeneSTAR® gene was higher in Red Angus than in Angus cattle. In another study in the U.S. involving yearling steers and heifers, marbling increased almost linearly from cattle having zero, one or two GeneStar® genes for marbling. In contrast to these results, in 'calf-fed' steers and heifers, marbling score was not related to the frequency of the GeneSTAR® gene for marbling.

The frequency of the GeneSTAR® gene for marbling was generally different among 'biological types' of cattle that generally differ in marbling (Table 22). For example, 'British' type cattle, such as Angus and Red Angus (relatively high marbling), had a higher frequency than 'Continental' type cattle, such as Gelbvieh, Simmental and Limousin (moderately low marbling). **Bos indicus** cattle (low marbling) had a very low frequency of the GeneSTAR® gene for marbling. The advantage of a test like the GeneSTAR® marbling gene is that DNA can be analyzed as early as birth to measure the frequency of the gene. For seedstock producers who are intensively selecting for marbling, it can be used as tool to screen potential sires early in their life and avoid the expense of progeny testing so many sires.

Table 22. Limited U.S. Data on the Frequency of the GeneSTAR® Gene for Marbling Among Different Biological Types of Cattle (Unpublished Data)

Biological Type of Cattle	Frequency
Angus, Red Angus, Shorthorn	25-60%
Hereford, Polled Hereford, Red Poll	0-15%
Simmental, Limousin, Charolais, Salers	20-45%
Bos indicus	0-5%
Bos indicus composite	10-17%
Dairy	15-25%

Marbling most likely is controlled by numerous genes, rather than just the GeneSTAR® gene. Therefore, additional methods to genetically improve marbling will need to be implemented in countries where marbling is economically important. Currently, marbling in beef cattle is very important economically in the U.S.

Genetic Solutions has also commercialized a GeneSTAR® test for tenderness. This gene test is for 'variants' of the calpastatin gene on chromosome 7. The 'variants' do not inhibit calpain enzyme activity like calpastatin does. The DNA test determines whether cattle have zero, one or two variant genes ('stars') for calpastatin. In results that have not yet been published in refereed journals, the frequencies of '2-stars' was approximately 85% in British cattle, 43% in Brahman cattle, and 67% in Santa Gertrudis (a composite breed developed from Brahman and Shorthorn cattle). Conversely, the frequencies of '0-stars' were 2% in British, 11% in Santa Gertrudis, and 22% in Brahman cattle. Genetic Solutions reports that cattle with 2-stars compared to 0-stars averaged 0.37 kg less shear force; cattle with 1-star were intermediate in tenderness. They further predicted that cattle with 2-stars would reduce the number of steaks rated unacceptable in tenderness by consumers by 50%. The cost of the test at the time that this manuscript was written was 60 to 90 U.S. dollars, depending on the volume of business.

Page et al. (2002) discovered that single nucleotide polymorphisms of the micro-molar calcium-activated **calpain** gene exist, and are 'markers' for tenderness. The allele encoding isoluecine at position 530 and glycine at position 316 was associated with increased shear force values relative to the alleles encoding valine at position 530 and alanine at position 316. This test has not yet been commercialized, but these authors stated that this DNA test could represent a valuable tool for cattle breeders to improve tenderness.

Just as is true for marbling, it is most likely that several genes are related to tenderness and that selection for only one gene may not be sufficient to make significant genetic improvement in tenderness. However, DNA tests for the two genes discussed, the discovery of other genes, and simultaneous selection for marbling in some breeds have potential for genetic improvement of tenderness. Although the Carcass Merit Traits project partially funded by the Cattlemen's Beef Board and managed by the National Cattlemen's Beef Association in the U.S. generated tenderness data on nearly 8,500 progeny, it is not likely that retrieving steak sections in meat processing plants for tenderness evaluation can be sustained. Pollak et al. (2001) reported that the Carcass Merit Traits Project will validate the segregation of 11 quantitative trait loci for carcass and meat traits discovered in the Texas A&M Angleton Project

Genetics of Poultry Composition and Meat Quality

In a review presentation at the International Animal Agriculture and Food Science Conference, Fletcher (2001) stated that, other than for breast meat yield and fat content, the only other area of selection relative to meat quality in poultry has been in attempting to reduce the PSE-like condition that is common in turkeys. Fletcher further stated that with the dramatic changes in the marketing of broilers from a predominantly whole carcass market to further processed meat products, the issues relative to traditional quality attribues have almost completely disappeared.

SUMMARY

The heritability of pork carcass composition and several meat quality traits are moderately-high to highly heritable and can be improved through traditional genetic selection procedures. In addition, the stress gene can be eliminated from populations through blood-typing for the ryanodine receptor gene. Until a gene is identified for the Napole gene, muscle samples can be tested for glycolytic potential (µ moles of lactate equivalent per gram of fresh tissue) to segregate pigs with the Napole gene (RN^{I}) from those with the normal gene (rn^{+}). Genetic markers and(or) specific genes may be identified in the future to select directly for specific quality traits.

The heritability of carcass compositional traits, marbling, and tenderness in cattle are moderately-high to high and would respond to selection in a structured selection program. Selection for carcass composition and marbling can be effective by ultrasound evaluation by highly trained technicians and(or) by obtaining actual carcass data from progeny groups of cattle. Rapid progress is being made in identifying DNA 'markers' or specific genes that can be used to select directly for meat quality traits.

There is little information to determine whether or not metabolic modifiers affect the assessment of genetic differences among progeny groups when the latter is the primary goal. It is likely that some of the more potent metabolic modifiers affect the accurate assessment of genetic differences and subsequent genetic predictions for growth performance, carcass composition, and meat quality. Research needs to be conducted to evaluate the interaction of metabolic modifiers and genetics on these traits. Researchers and the livestock industry need to emphasize more the genetic improvement of carcass composition and meat quality because these improvements are permanent and because there is much potential for improvement.

The author is grateful for the assistance of Janeal Stephens, Jeannine Grobbel, Ersel Obuz, and Val Stillwell for their assistance in preparing this manuscript.

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