Effects of Metabolic Modifiers Used in Animal Production on Meat Quality

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Introduction

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, or improve meat palatability. Most metabolic modifiers have been developed and researched to improve growth performance and carcass composition, and fewer specifically to improve meat quality. Research 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 pigs. Several in-depth review papers could be written on specific categories or types of metabolic modifiers; however, my review will be somewhat general because of time constraints and space constraints in the RMC Proceedings. Ellis and McKeith (1999) reviewed the effects of nutrition on the quality of meat from nonruminants, and Owens and Gardner (1999) reviewed the effects of ruminant nutrition on meat quality at the 1999 RMC. Therefore, the effects of type of feed, energy source, dietary protein/energy ratio, feed withdrawal prior to slaughter, and several other topics on beef and pork meat quality are not included in my paper.

My review will emphasize those metabolic modifiers that are approved for use in cattle and pigs or those likely to be approved for use in the U.S. and other developed countries. Because the sheep industry is so small, only minimal attention will be given to the effects of metabolic modifiers on lamb meat quality. Furthermore, the effects of metabolic modifiers on poultry meat quality will not be included. My discussion of meat quality will include those 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 characteristics related to human nutrition. Carcass composition or meat yield percentage will be discussed only briefly.

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

Antibiotics

Beermann (1995) stated that the primary benefit of subtherapeutic 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 in situations where bacterial contamination otherwise would have been a problem. This benefit is particularly true for poultry. Other than this benefit, subtherapeutic levels of antibiotics in diets for livestock virtually have no affect on carcass composition or meat quality.

Ionophores

Ionophores are defined as organic substances that bind polar compounds and act as ion transfer agents to facilitate movement of monovalent ions (sodium and potassium) and divalent ions (calcium) through cell membranes (Beermann, 1995). These changes affect the transport of nutrients and metabolites across cell membranes. Monensin® is the most common ionophore for cattle, and ionophores are fed to over 90% of all feedlot cattle, with doses ranging from 6 to 33 ppm of the diet. The changes in transport of nutrients and metabolites across cell membranes consistently improve feed efficiency in cattle. Generally, this results from reduced feed intake without a change in rate of gain, but may also be a result of 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. Beermann (1995) concluded that the effects of ionophores on dressing percentage and carcass composition are too small to be of economic importance. I did not find any research report that studied the 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). In addition, most anabolic steroid implants significantly increase live and carcass weights. Meat yield percentage generally is not altered significantly because cattle are slaughtered at heavier weights at a constant time on feed. 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 problem has been traced to approved anabolic steroid implants used properly.

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 is dependent on the gender of cattle, stage of growth, and potential impact on marbling deposition and subsequent USDA quality grades. Beermann (1995) reported that the live weight required to attain "small" marbling necessary to grade USDA Choice is increased by 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, and delay fattening to the greatest extent.

No major research reports have demonstrated that anabolic steroid implants improve visual meat quality or meat palatability. The majority of research reports show some reduction in marbling and tenderness in comparison to nonimplanted 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 obtained. Some research reports have raised questions regarding possible negative effects of aggressive implants on meat quality. Morgan (1997) and Belk and Cross (1988) reported that the "aggressive" use of anabolic implants commonly compromises beef carcass quality grades and increases the incidence of dark cutting carcasses. Furthermore, Morgan (1997), Foutz et al. (1990), Samber et al. (1996), and Roeber et al. (1999) indicated that some aggressive implanting strategies have been implicated as possible causes 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. In addition, Warner-Bratzler shear force values generally are lower for steaks from nonimplanted controls than for those from implanted cattle (Table 1). However, because at least 90% of all fed cattle are implanted, it is not very meaningful for most fed cattle to evaluate the effects of various implants and implant strategies on marbling and palatability in comparison to nonimplanted controls. For the cattle that are implanted, it would be more important to evaluate whether or not differences occur among implants or implant strategies in their effects on the incidence of dark cutters, reduced marbling, or decreased meat palatability. The goal for the pharmaceutical and beef cattle industries would be to utilize implants and implant strategies to capitalize on their very positive effects on production efficiency without **any** negative effects on visual meat quality or tenderness.

TABLE 1. Warner-Bratzler shear force value change stratified by implant strength and type[a].

First Implant	Second Implant	Third Implant	WBS[b], lb.
Non-implanted			8.00
ME[d]	—	—	+.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]WBS: Warner-Bratzler shear force value, lb.
[c]Change in WBS compared to nonimplanted controls.
[d]Implant classification: ME, SE, A, MC and SC are mild estrogen, strong estrogen, androgen, mild combination and strong combination, respectively.
From Morgan (1997).

Roeber et al. (1999) utilized 298 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 2-5). Cattle were implanted at the beginning of the feedlot phase with Encore and Component T-S®, Ralgro®, Revalor-S®, or Synovex Plus®, or not implanted. Cattle were then re-implanted after 59 d with the same or different implants or not implanted, resulting in seven implant strategies and a nonimplanted control group. The cattle were fed to a high degree of finish. Mean fat thicknesses and USDA yield grades were not different among the various implant strategies (Table 2), although some differences occurred in the percentage of Choice carcasses (Table 3). 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® and a higher percentages of carcasses grading USDA Choice than those implanted with Ralgro®/Synovex Plus®, Revalor-S®/Revalor-S®, Revalor-S®/no implant, or Synovex Plus®/no implant. The

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	Marb.*	QG**
No Implant/No Implant	737.4[b]	.66	3.51[ab]	524.3[a]	523.8[a]
Encore & Component T-S/ No Implant	777.2[ab]	.65	3.47[ab]	511.6[ab]	515.1[ab]
Ralgro/Synovex Plus	798.8[a]	.69	3.59[ab]	459.2[bc]	460.7[c]
Ralgro/Synovex-S	796.8[a]	.64	3.40[ab]	482.7[abc]	487.5[abc]
Revalor-S/Revalor-S	809.5[a]	.67	3.45[ab]	449.6[c]	454.1[c]
Revalor-S/No Implant	795.9[a]	.71	3.70[a]	467.0[bc]	474.0[abc]
No Implant/Synovex Plus	791.0[a]	.64	3.35[b]	458.3[c]	463.4[bc]
Synovex Plus/No Implant	794.1[a]	.71	3.61[ab]	470.4[bc]	471.4[bc]

[a,b,c]Means in the same column with different superscript letters are different (P < .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. Distribution of calculated quality grades and yield grades by implant strategy group.

	Quality Grade (No.)				
Implant Strategy	Prime	Choice	Select	Standard	% Prime/Choice
No Implant/No Implant	2	49	2	1	94.44[a]
Encore & Component T-S/No Implant	0	41	3	0	93.18[ab]
Ralgro/Synovex Plus	0	41	12	0	77.36[c]
Ralgro/Revalor-S	0	39	9	0	81.25[abc]
Revalor-S/Revalor-S	0	32	16	0	66.67[c]
Revalor-S/No Implant	1	39	12	0	76.92[c]
No Implant/Synovex Plus	1	40	11	0	78.85[bc]
Synovex Plus/No Implant	0	39	12	1	75.00[c]

	Yield Grade (No.)					
Implant Strategy	Y1	Y2	Y3	Y4	Y5	% Y1/Y2
No Implant/No Implant	0	10	31	13	0	18.52
Encore & Component T-S/No Implant	0	7	29	7	1	15.91
Ralgro/Synovex Plus	0	5	33	15	0	9.43
Ralgro-Revalor-S	0	8	37	3	0	16.67
Revalor-S/Revalor-S	0	6	33	9	0	12.50
Revalor-S/No Implant	0	2	32	18	0	3.85
No Implant/Synovex Plus	0	10	37	3	1	19.61
Synovex Plus/No Implant	0	7	31	12	1	13.73

[a,b,c]Means in the same column and for the same trait bearing different superscript letters differ (P < .05).
From Roeber et al. (1999).

TABLE 4. Least squares means and frequency distribution of Warner-Bratzler shear force values stratified by implant strategy (n = 298).

Implant Strategy	WBS 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 ($P < .05$).
From Roeber et al. (1999).

Revalor-S®/no implant treatment group resulted in steaks with higher Warner-Bratzler shear values than those from nonimplanted controls (Table 4). In addition, the percentage of steaks with shear values >3.86 kg was less ($P < .05$) 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, suggesting that this combination is less aggressive or not as potent as the other implants. A consumer panel found that steaks from nonimplanted controls were more tender than those from nearly all implant treatment groups (Table 5); however, only one difference occurred among implant groups. Steaks from the Encore and Component T-S® treatment group were more tender than steaks from all other groups, likely because this is a "less aggressive" implant. The various implant strategies involving either Revalor-S® or Synovex Plus® reduced marbling and tenderness compared with nonimplanted controls, but the differences among implant strategies involving these two implants were minimal.

TABLE 5. Least squares means for consumer sensory responses[a] by implant strategy.

Consumer Sensory Response	Implant Strategy							
	No Implant/ No Implant	Encore & Component T-S/No Implant	Ralgro/ Synovex Plus	Ralgro/ Revalor-S	Revalor-S/ Revalor-S	Revalor-S/No Implant	No Implant/ Synovex Plus	Synovex Plus/ No Implant
Overall L/D[a]	4.25	4.47	4.61	4.71	4.61	4.42	4.69	4.73
Flavor L/D[b]	4.14	4.34	4.47	4.52	4.34	4.33	4.71	4.47
Flavor Intensity[c]	5.23	4.97	4.95	4.83	5.10	5.20	4.80	5.14
Tenderness L/D[d]	3.94[h]	4.25[gh]	4.48[g]	4.42[g]	4.54[g]	4.27[gh]	4.48[g]	4.46[g]
Level of Tenderness[e]	3.90[h]	4.25[gh]	4.50[g]	4.49[g]	4.53[g]	4.45[g]	4.48[g]	4.54[g]
Juiciness Level[f]	4.87	5.06	5.01	5.27	5.26	4.94	5.28	5.21

[a]Overall like to dislike rating by consumers: 1 = like extremely, 9 = dislike extremely.
[b]Like to dislike rating of flavor by consumers: 1 = like extremely, 9 = dislike extremely.
[c]Intensity of flavor rated by consumers: 1 = none or extremely bland, 9 = extremely intense.
[d]Like to dislike rating of tenderness by consumers: 1 = like extremely, 9 = dislike extremely.
[e]Level of tenderness rating by consumers: 1 = extremely tender, 9 = extremely tough.
[f]Level of juiciness rating by consumers: 1 = extremely juicy, 9 = extremely dry.
[g,h]Least squares means within a row with common superscripts and those lacking superscripts do not differ ($P < .05$).
From Roeber et al. (1999).

TABLE 6. Effect of implant treatment on ribeye steak peak shear force values at 7 and 14 days of aging (least squares means).

	Implant Treatment[a]					
Trait	CONT	MGA	FINMGA	REV	REVMGA	Effect[b]
7-Day Aging:						
Shear force, lbs.	8.57[c]	8.88[cd]	8.60[d]	9.29[d]	9.26[d]	CI RF
Very tender steaks[f], %	57.00	44.90	59.10	39.10	41.20	
Tender steaks[f], %	23.70	32.20	23.50	24.30	31.10	
Tough steaks[f], %	19.30	22.90	17.40	36.60	27.70	
14-Day Aging:						
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	

[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 ($P < .05$) = 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.
From Nichols et al. (1996).

Kirchofer et al. (2000) evaluated six implant treatments with 240 steers that were fed for 194 d. Implant strategies involved different levels of trenbolone acetate/estradiol (Revalor®) or estradiol and progesterone (Synovex-S®) at day 0 and nonimplanted controls. All steers except the controls received Revalor-S® at re-implant time (d 84). Control steers had 40 points higher marbling (Small[20] vs Slight[80]) than the average of the implant treatments, but no differences occurred in USDA yield grades because the implanted cattle had 23.6 kg heavier carcasses. Shear force tended to be lower ($P < .09$) for the controls compared

TABLE 7. Effect of implant treatment on sensory panel ratings of ribeye steaks at 14 days of aging (least squares means).

Trait	Juiciness[a]	Tenderness[b]	Connective Tissue[c]	Flavor Intensity[d]
Implant Treatments[e]				
CONT	5.70	5.96[f]	5.87	5.33
MGA	5.75	5.88[fg]	5.81	5.32
FINMGA	5.68	5.87[fgh]	5.80	5.30
REV	5.67	5.72[h]	5.73	5.30
REVMGA	5.64	5.76[gh]	5.71	5.28
Effect[i]	—	CI RM	—	—

[a]8 = extremely juicy, 1 = extremely dry.
[b]8 = extremely tender, 1 = extremely tough.
[c]8 = none, 1 = abundant.
[d]8 = extremely intense, 1 = extremely bland.
[e]Implant treatments: CONT = control, MGA = Melangestrol Acetate, FINMGA = Finaplix-H plus MGA, REV = Revalor-H, REVMGA = Revalor-H plus MGA.
[f,g,h]Means in the same column within a main effect, with different superscripts differ ($P < .05$).
[i]Contrast effects: CI ($P < .05$) = Control vs all implants; RM ($P < .05$) = REV vs MGA.
From Nichols et al. (1996).

TABLE 8. Effect of implant treatment on sensory panel ratings of ribeye steaks at 14 days of aging (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[a]		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, %[b]		2.39	2.45	2.39	2.40	2.41
Backfat th., in.		.51[b]	.54[a]	.51[b]	.52[b]	.50[b]
Ribeye area, in^2 [c]		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 ($P < .05$).
[a]3 = slight, 4 = small, 5 = modest, 6 = moderate, 7 = slightly abundant.
[b]KPH fat as a % of hot carcass weight – estimated visually.
[c]Ribeye muscle area between the 12th and 13th ribs.
From Hoechst-Roussel Agri-Vet Company (1992).

with the average of the implant treatment strategies, which did not differ among themselves.

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, the percentage of Choice carcasses, muscle color score, or the 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 nonimplanted 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 ($P < .05$) peak Warner-Bratzler shear values than steaks from non-implanted controls (Table 6). Additionally, sensory panel ratings indicated that steaks from Revalor-H® and Revalor-H® X MGA treatments were less tender than steaks from nonimplanted controls (Table 7). However, no differences occurred in sensory panel ratings for tenderness among steaks from heifers in the Revalor-H®, Revalor-H® X MGA, and Finaplix® X MGA treatments. These authors concluded that the magnitude of the Warner-Bratzler shear differences were of questionable practical importance. 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.

A Technical Bulletin published by Hoechst-Roussel Agri-Vet Company (1991) presented data from 1,950 steers in five trials 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®

TABLE 9. Least squares means for beef carcass traits and shear force values as affected by implant treatment.

	Experimental Treatment Group						
Trait[a]	CON	RAL/ SYNREV	RAL/ REVREV	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]Abbreviations 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 ($P < .05$).
From Samber et al. (1996).

TABLE 10. Age-constant means for beef slaughter and carcass traits as affected by implant treatment.

Trait	Implant Treatment				
	Control	Synovex-S	Finaplix-S	Revalor-S	SEM
Live wt., kg	507.1[c]	534.9[b]	528.9[bc]	549.2[b]	8.81
Carcass wt., kg	327.2[c]	347.3[b]	342.1[bc]	359.5[b]	6.54
Dressing percentage	64.5	65.0	64.7	65.4	.55
Fat thickness, cm	1.42	1.83	1.37	1.65	.18
Preliminary YG	3.6	3.9	3.6	3.8	.14
Longissimus muscle area, cm^2	69.7	72.7	75.0	77.8	2.09
KPH fat, %	2.75	2.38	2.29	2.37	.12
Yield grade	4.0	4.1	3.8	3.9	.16
Marbling score[a]	507.8[bc]	458.1[c]	518.9[b]	538.6[b]	18.11
i.m. Lipid, %	5.28	4.92	5.48	5.00	.22

[a]Marbling scores: 400 to 499 = Small; 500 to 599 = Modest.
[b,c]Means in the same row with a common superscript or without superscripts do not differ ($P > .05$).
From Gerken et al. (1995).

resulted in a lower percentage of Choice carcasses (60% vs 69%) than the other implant strategies (Table 8). Neither Warner-Bratzler shear force values nor sensory panel evaluations were conducted in these experiments. Nichols et al. (1993) stated in another Technical Bulletin that "If high quality grade 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.

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. No reduction in the percentage of Choice carcasses occurred with the use of Synovex-S®/Revalor-S® or Revalor-S®/Revalor-S® (Table 9). However, all treatments receiving three successive implants had lower percentages of Choice and Prime carcasses than the nonimplanted 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 nonimplanted control calves (Table 9). 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 implanting cattle twice with a combination implant, possibly accentuated with delayed initial implanting, may be more detrimental to marbling and tenderness than other implants or strategies.

Revalor-S® administered late in the finishing period (Thonney et al., 1991), Revalor-S® or Finaplix-S® administered late in the finishing period (Foutz et al., 1990), and Synovex-S® or trenbolone acetate administered twice (Foutz et al., 1997) adversely affected shear force values compared with nonimplanted controls. Apple et al. (1991) implanted Holstein calves from about 4 months of age to slaughter with Ralgro®, Synovex-S®, Finaplix-S®, or a combination of Synovex-S® and Finaplix-S®. Only 50% of the steers implanted with Finaplix-S® plus Synovex-S® graded USDA Choice compared with 75 to 90% for the other implant treatments. Longissimus steaks from Synovex-S® and Finaplix-S® plus Ralgro® implanted cattle tended to have decreased tenderness in comparison to steaks from nonimplanted cattle. Kuhl et al. (1993), Huck et al. (1991), and Belk and Savell (1992) found no detrimental effects on longissimus 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 a study supported by the former National Live Stock & Meat Board conducted at Colorado State University (Gerken et al., 1995), 24 cloned Brangus calves were utilized in an implant study. Implanting steers with an estrogen implant resulted in lower ($P < .05$) marbling than implanting with androgen or a combination implant (Table 10). In addition, implanting once with estrogen resulted in lower tenderness scores and higher Warner-Bratzler shear force values than implant-

TABLE 11. Main effect means showing the effects of implant treatment and aging period on Warner-Bratzler shear force values (WBS) and sensory panel tenderness ratings[a] (SPT) of strip loin, top sirloin, and top round steaks.

		Strip Loin		Top Sirloin		Top Round	
Effect	**n**	**WBS**	**SPT**	**WBS**	**SPT**	**WBS**	**SPT**
Implant treatment							
Control	6	3.98	4.89	3.69	4.97[b]	4.82	3.06
Synovex-S	6	4.56	4.47	3.93	4.60[c]	5.20	3.01
Finaplix-S	6	3.93	4.81	3.70	5.14[b]	4.67	3.46
Revalor-S	6	4.65	4.59	3.85	4.82[bc]	4.95	3.11
Aging period							
7 d	24	4.83	4.53	3.83	4.72	5.11	3.08
14 d	24	4.13	4.70	3.92	4.93	4.90	3.17
21 d	24	3.88	4.84	3.63	5.01	4.73	3.24
Orthogonal effect	—	Linear	NS	NS	NS	NS	NS
RSD[d]	—	.53	.42	.74	.50	1.06	.57

[a]Rated using an 8-point rating scale (5 = slightly tender, 4 = slightly tough).
[b,c]Means in the same column sharing a common superscript, or without superscripts, do not differ ($P > .05$).
[d]Residual standard deviation. Standard errors of subclass means can be calculated as 1 =n × RSD for a trait, where n = number of observations in the subclass.
From Gerken et al. (1995).

ing once with androgen for top sirloin steaks but not for strip loin or round steaks (Table 11). These results demonstrate a clear disadvantage in implanting steers with an estrogen implant compared to implanting with an androgen or combination implant, which somewhat contradicts the results of Samber et al. (1996).

In a survey involving over 2.6 million cattle over 3 yr on the factors contributing to the incidence of dark cutting beef, Scanga et al. (1998) classified implants as androgenic

TABLE 12. 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 ($P < .05$).
From Scanga et al. (1998).

TABLE 13. 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.

	Mean Percentage of Dark Cutters per Pen	
Implant Treatment	**<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[v] ± .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 < .05).
From Scanga et al. (1998).

(Synovex-H®, Finaplix-H/S®); estrogenic (Synovex-S®, Ralgro®); combination (Revalor-H/S®); double androgens (Finaplix® and Synovex-H®); and estrogen/combinations (Synovex-S®/Revalor®). All heifers were fed MGA. Implanting steers with combination/combination implants resulted in more dark cutters than implanting with estrogen/estrogen or estrogen/combination (Table 12). In addition, implanting less than 100 d before slaughter increased the incidence of dark cutters (Table 13). Temperatures exceeding 35 C increased the incidence of dark cutting carcasses for the combination/combination strategy. In heifers, estrogen/estrogen caused more dark cutters than combination implants. Again, implanting less than 100 days before slaughter and temperatures greater than 35 C increased the incidence of dark cutters in heifers for most implants. These authors concluded that the use of estrogenic re-implants before slaughter in heifers and the use of combination implants singly in steers, either as the initial implant or as re-implants before slaughter, or the use of combination on-feed, combination re-implantation strategies increased the risk of incurring dark cutting beef. These authors concluded that using good handling facilities, good animal handling practices, and proper shipping practices and "moderate" growth-promoting implants can minimize nonconformance due to 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's 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. They just need to be managed extremely well.

Vitamin D_3

Feeding vitamin D_3 has received much attention recently for potentially improving meat tenderness. Dietary vitamin D_3 has been shown to increase calcium levels in blood and muscle. Wheeler et al. (1997) showed that elevated levels of calcium in muscle increase 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 days 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 lower Warner-Bratzler shear values at 10 d postmortem for inside round steaks from continental steers fed vitamin D_3 than for round steaks from cattle not fed vitamin D_3. However, vitamin D_3 reduced only 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 produce tough beef but will have no impact on cattle that produce tender beef. Karges et al. (1999) reported a decrease in Warner-Bratzler shear force of both longissimus and gluteus medius steaks at 14 and 21 d postmortem but also a decrease in hot carcass weight when cattle were fed 6 x 10^6 IU/hd/d for 4 or 6 d. The decrease in carcass weight likely was due to decreased feed intake and reduced growth rate. Swanek et al. (1999) observed 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 either vitamin D_3 (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 Warner-Bratzler shear value of < 3.86 kg, which was considered to be "very tender." However, steaks from cattle fed the vitamin D_3 treatment alone and those from control cattle had higher TBA values than those fed the vitamin D_3 and E combination.

Duckett et al. (1998) administered a calcium gel as a drench 3 to 6 hr before slaughter instead of including D_3 in the diet.

The gel consisted of 150 g of calcium, 630 g propionate, and 600 g propylene glycol (Dr. Larson's Up and Over 1000™) in a 1.5 L dose. The oral calcium propionate gel increased μ-calpain and m-calpain activites but did not change calpastatin activity. Steaks from steers that received the gel had lower shear values after 4 and 7 d of aging, but not after 14 or 28 d of aging. Results of these authors and others cited indicate that when steaks are aged for 10 to 14 d or longer, the advantages of D_3 are rather small.

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 14). Furthermore, visual color scores of the longissimus muscle increased as the amount of vitamin D_3 in the diet increased. However, meat palatability traits did not improve. A negative aspect of their research was that feeding high levels of vitamin D_3 reduced feed intake in pigs from 3.82 to 2.90 kg/d and, consequently, reduced ADG from 0.77 to 0.07 kg/d for low and high vitamin D_3 levels, respectively, in the diet. Enright et al. (1999) incorporated both vitamin E and D_3 in the diets of pigs, with the vitamin E being fed at two levels for 42 d and the vitamin D_3 fed at three levels (1,000, 90,000 or 180,000 IU/kg of feed) for 6 or 9 d before slaughter. Feeding the high level of vitamin D_3 for 9 d reduced ADG, G/F ratio, live weight, and carcass weight compared to the other vitamin D_3 x time of feeding treatment combinations. Feeding the two high levels of vitamin D_3 improved muscle visual quality traits and reduced purge loss. Karges et al. (1999) found that dry matter intake in cattle was reduced by feeding vitamin D_3 for 2 d at 7.5 x 10^6 IU/d; 4 d at 15 x 10^6; 5 d at 7.5 x 10^6 IU/d; and 6 d at 5 x 10^6 IU/d. These findings raise questions about the practicality of feeding vitamin D_3 to improve tenderness, because livestock feeders are not likely to use this practice if it reduces performance and efficiency.

High levels of vitamin D_3 can be toxic to humans. The U.S. RDA is 400 IU/d 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 than normal in liver and muscle when cattle were fed 5 x 10^6 IU/hd/d of vitamin D_3. These results suggest that more research needs to be conducted on the safety of feeding vitamin D_3.

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

Vitamin E

Numerous studies have shown that feeding supranutritional levels of vitamin E improves meat color and can extend shelf life of both beef and pork. No reports have indicated negative effects on feed intake or performance of cattle or pigs fed vitamin E. Therefore, this metabolic modifier is practical and effective. The economic benefits to the beef cattle and meat industries would seem clear, if case life of meat could be extended by 1 to 3 d. However, the economic incentive may not be passed back to cattle feeders or pig producers.

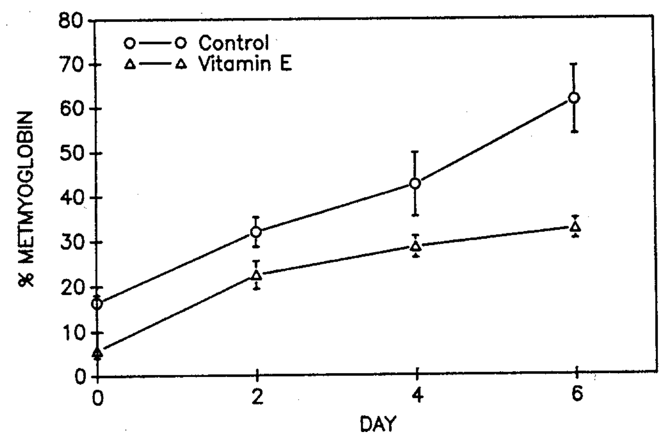
Several studies indicate that dietary vitamin E supplementation to steers results in accumulation of α-tocopherol in muscle tissue, and that this antioxidant delays lipid and myoglobin oxidation. Consequently, color stability and retail shelf life of beef are prolonged (Faustman et al., 1989ab; Arnold et al., 1992). Figures 1and 2 show the effects of vitamin E on the percentage of metmyoglobin and TBA number, respectively, in ground sirloin patties from the research reported by Faustman et al. (1989b). Ashgar et al. (1991) and Monahan et al. (1990a,b; 1992) stated that vitamin E has been demonstrated to decrease lipid oxidation, decrease drip loss, and improve the color of pork cuts. According to Cannon et al. (1995), inadequate color and water holding capacity are two major quality concerns in pork. Furthermore, vitamin E supplementation has been shown to improve growth rate and feed efficiency of pigs.

TABLE 14. 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	SIG1
Vitamin D_3 ('000 IU/kg)	.331	50.040	175.000	
Ultimate pH	5.50	5.53	5.47	NS
Subjective color	2.08^{a}	2.72^{ab}	3.08^{b}	**
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}	**
Drip loss, %	4.39^{a}	3.21^{ab}	2.04^{b}	0

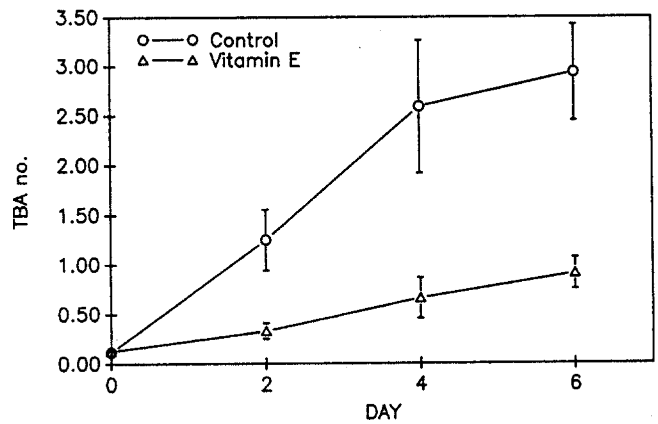
[1]NS, *, ** = not statistically significant, P < .05, P < .01, respectively.
[a,b]Means in some row with different superscripts differ (P < .05).
From Enright et al. (1998).

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. (1989).

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. (1989).

Arnold et al. (1992) fed Holstein calves diets containing 300 IU/d of vitamin E for 266 d; 1,140 IU/d for 67 d; or 1,200 IU/d for 38 d and a control diet with no vitamin E. They found that color stability during retail display of longissimus lumborum steaks from cattle fed vitamin E 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.

Liu et al. (1996b) fed Holstein steers 250, 500 or 2,000 IU/d of vitamin E or a diet with no vitamin E for durations of 42 or 126 d and evaluated the effects on meat quality. Color display of fresh beef was extended by .9 to 1.8 d from the lowest to highest feeding level when the "metmyoglobin threshold method" was used to determine when beef reached the end of its shelf life (Table 15). In addition, lipid oxidation as measured by TBARS was delayed in beef from cattle fed vitamin E. When estimation

TABLE 15. Dose and duration effects of supplemental vitamin E on time to first detectable discoloration for longissimus lumborum (LL), semimembranosus (SM), and gluteus dedius (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**
	d						
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.
[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 16. Dose and duration effects of supplemental vitamin E on color display life for three bovine muscles held in vacuum storage for 14 days.

Vitamin E, mg/d	Longissimus lumborum 42 d	Longissimus lumborum 126 d	Semimembranosus 42 d	Semimembranosus 126 d	Gluteus medius 42 d	Gluteus medius 126 d	Dose
	d						
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]
2000	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[c]	6.6[d]		4.4[e]		2.9[f]		

[a,b,c]Means across durations within muscle or across 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).

of display life was based on "hue angle measurements", Liu et al. (1996a) determined that color display life of the longissimus lumborum, semimembranosus, and gluteus medius muscles stored under vacuum until 14 d and then displayed under simulated retail conditions was extended by 2.0 (250 IU/d) to 5.0 d (2,000 IU/d) (Table 16). 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 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 dorsi, gluteus medius, and psoas major muscles showed greater color and lipid oxidative stabilities than meat from the basal group after 7 d of retail display. Stubbs et al. (1999) incorporated vitamin E at 500 IU/hd/d for at least 100 d in the diets of cattle and found that lipid oxidation was markedly reduced across the display period for top loin steaks and ground chuck patties compared with controls. Maximum display life increased with vitamin E by approximately 3 d and 1.3 d for top loin steaks and ground chuck patties, respectively.

Vitamin E supplementation in pigs also has been studied by numerous researchers. Jensen et al. (1997) fed 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 m. longissimus dorsi and psoas

TABLE 17. 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
Cheah et al., 1995	500	Halothane genotype		
		Negative Carrier	6.9	3.2
		Carrier	9.1	5.0
Cannon et al., 1996	100	Days of storage		
		0	5.01	4.76
		14	3.81	3.30
		28	2.96	2.68
		56	2.35	2.40

From Ellis and McKeith (1998).

TABLE 18. Thiobarbituric acid values of fresh longissimus chops from control pigs and pigs supplemented with vitamin E.

Storage Period and Treatment[a]	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]	.60[y]
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).

major were related linearly 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 17). 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), i.e., 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 -tocopherol supplementation was not as profound as that reported for beef muscle.

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. 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 usually is sold well before that time. Monahan et al. (1994) reported that TBARS values were lower and Hunter ‘a’ values higher in pork chops after 2, 4, 6, and 8 d of refrigerated storage from pigs fed 100 and 200 mg α-tocopherol acetate/kg diet compared to pigs fed 10 mg/kg diet. This effect seemed to be more pronounced in previously frozen chops than in

TABLE 19. 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: Initial Tenderness[b]	Sustained Tenderness[b]	Initial Juiciness[bcd]	Sustained Juiciness[cd]	Flavor[c]	Fat, %
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 20. 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	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 21. 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. (1989a)[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).

fresh chops. Cannon et al. (1996) reported that vitamin E significantly reduced TBARS after 3 and 5 d of retail display either without aging or after 14, 28, and 56 d of vacuum aging (Table 18). However, the effects of feeding vitamin E on sensory panel attributes were negligible.

These research reports on supplementing cattle and pig diets with supranutritional 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. An additional advantage of reduced drip loss can occur 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 from feeding high levels of vitamin E. Williams et al. (1992) conducted a blind study of consumers on 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 a 3.6 percentage point 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 compensating cattle feeders and swine producers for the additional cost of feeding higher levels of vitamin E. It may also require a method to rapidly verify

TABLE 22. Effects of somatotropin, sex, and genotype on the sensory characteristics of pork[a].

Dose	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 points 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 23. Effects of somatotropin, sex, and genotype on longissimus shear values[a].

		Somatotropin Dose, $\mu g \cdot d^{-1} \cdot kg^{-1}$ BW				
Genotype[b]	**Sex**	**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).

TABLE 24. Effects of the ractopamine on the color, firmness, marbling, and lipid content of porcine and bovine muscle.

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

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

that cattle actually received adequate vitamin E supplementation when marketed with that guarantee. The entire production, processing, and retail segments of the livestock and meat industry would gain from cattle feeders and swine producers feeding supranutritional levels of vitamin E.

Somatotropin

The advantages in production efficiency and carcass composition from injecting pigs with somatotropin have been dramatic. Average daily gain in pigs was increased by 20% with 150 µg porcine somatotropin (pST)/kg body weight per day and feed conversion efficiency was improved throughout an even greater dose range (Beermann,

TABLE 25. Effects of different periods of zilpaterol intake on meat quality characteristics of two muscles.

	M. semitendinosus					M. longissimus thoracis				
Trait	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 superscripts differ significantly ($P < .05$; 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).

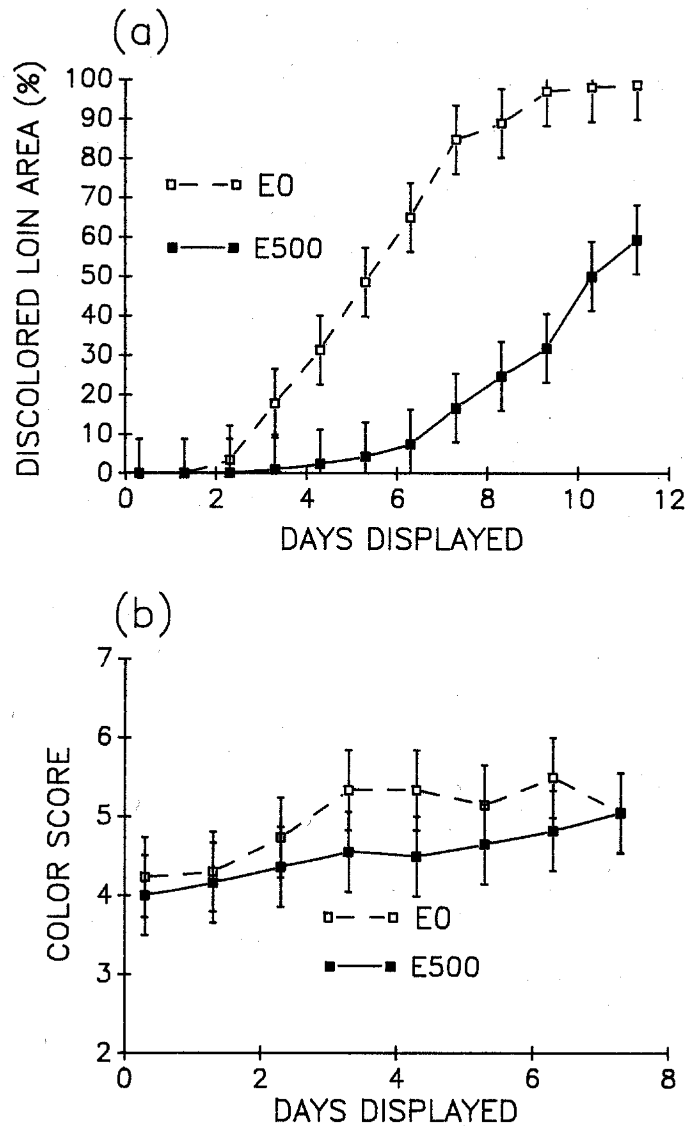
TABLE 26. Effects of diets containing conjugated linoleic acid (CLA) or sunflower oil on longissimus objective color, subjective color, structure score, and marbling score (106-kg pigs).

	Diet	
Parameter	**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).

1994). Carcass protein accretion rates were 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 (Enright et al., 1998; 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 19). However, chops from stress-positive pigs treated with pST had higher juiciness scores than those from pigs not treated with pST. 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 ST clearly decreases intramuscluar lipid content in both pork and beef in a dose-dependent manner by 20 to 50%. Table 20 presents a summary of ST effects on the quality of pork and beef. These results indicate that pST administration in pigs decreases intramuscular fat and slightly decreases muscle color and firmness. Table 21 shows that shear force was increased in eight of the 10 studies cited, whereas sensory panel tenderness was decreased in only some studies. Processing of bellies into bacon also can be a problem because of the thicker skin and thinner bellies of pST treated pigs. However, the sensory properties of cured products from pST-treated pigs do not appear to be affected.

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.

Thiel (1991) treated pigs with 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 for pork, with the maximum effect at the highest dose (Table 22). In addition, shear force values also were increased by ST treatment, with a difference of 2.27 kg in the mean values between pork from the controls and that from pigs receiving the highest pST dose (Table 23).

No scientific data exists to justify the prevention of the approval of somatotropin for use in swine and beef cattle production. It is extremely effective in improving growth performance and meat yield percentage. Daily or frequent injection is not a practical delivery system, but Dikeman (1997) reported in a review of technologies to reduce fat in meat animals that implants to allow the slow release of ST appear to be promising. Somatotropin will decrease marbling significantly and increase shear force most of the time. However, sensory panelists have not consistently detected a depression in tenderness. It also has a neutral to slightly negative effect on color and firmness but a negative effect on commercial bacon production because of the thicker skin and thinner bellies. Somatotropin is not approved for use in beef cattle and swine production. It is not known whether or not ST will be approved for use in either species in the future.

ß-Adrenergic Agonists

Only ractopamine hydrochloride (Paylean®) for pigs and zilpaterol hydrochloride (Zilmax®) for cattle will be discussed. Ractopamine is a phenethanolamine that was approved very recently for use in pigs. The synthetic zilpaterol does not have the potency or pharmalogical activity of phenethanolamine products like clenbuterol or cimaterol. The manufacturer of zilpaterol currently is seeking approval for use in beef cattle production. Dikeman (1991) discussed significant negative effects of the ß-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 ß-agonists.

Ractopamine generally has a positive effect on growth rate, feed efficiency, and carcass composition when fed for 40 to 50 days before slaughter. However, most of the research on ractopamine was done in the 1980's and early 1990's on moderate-lean growth pigs and its effect on carcass composition and meat quality of high-lean growth pigs is not as well established. 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 were neutral to positive (Table 24). In one study, however, ractopamine increased shear force value, whereas no effects on shear force or sensory palatability occurred in the other study (Table 24). Most studies show that dressing percent and hot carcass weight are increased and backfat thickness is decreased from feeding ractopamine. Longissimus muscle area and percentage of lean are increased at dosages of 9.0 to 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, shear force, or proteolytic enzyme activity. (Data tables not presented because of no effect of ractopamine on these traits.) In addition, his summary showed no effect of feeding ractopamine on palatability characteristics determined by a sensory panel.

Zilpaterol distinctly improves dressing percent and carcass muscling but reduces tenderness of the longissimus muscle when fed as long as 45 d. Strydom et al. (1998) reported an improvement in dressing percentage as well as feed efficiency as the feeding period for 0.15 mg zilpaterol/kg live weight was increased from 0 to 45 d; however, fatness score was altered only to a minor degree. Feeding zilpaterol for 45 d decreased sensory panel scores for tenderness and sustained juiciness, and increased shear force of the longissimus thoracis muscle compared with the controls (Table 25). However, tenderness and shear force of the m. semitendinosus were not affected by feeding zilpaterol. Strydom and Nel (1999) also reported a toughening effect for longissimus thoracis steaks evaluated at 3 d postmortem when zilpaterol was fed for 30 or 50 d and carcasses were not electrically stimulated. However, electrical stimulation and 10 d of aging negated these differences, because these postmortem treatments seemed to have a greater effect on steaks from zilpaterol treated cattle than those from controls. The authors further stated that the effects of zilpaterol on meat quality seem to be muscle specific.

The effects of feeding ractopamine on pork quality generally are neutral. It has positive effects on growth performance and carcass composition but the benefit/cost ratio of feeding it to pigs has not been established. Zilpaterol appears to have significant potential to improve production efficiency and carcass composition and will only have a slight negative effect on tenderness of the longissimus and possibly other muscles of cattle when fed for only 30 d. However, muscles from cattle fed zilpaterol appear to respond well to postmortem tenderization enhancement such as electrical stimulation and proper aging.

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 either not synthesized by pigs or significantly modified before being deposited in fat depots. 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 due to 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 and that it also reduces fatty streak formation in the aortas of arteriosclerosis models. 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. (1997a) also found that CLA in the diet (2%) repartitioned nutrients from carcass fat to lean. In a following study, either CLA (2%) or sunflower oil (2%) was fed from 61.5 to 106 kg live weight (Dugan et al., 1999). Feed intake was reduced, feed efficiency was improved, and growth rate was not changed by feeding CLA. Subcutaneous fat was reduced by feeding CLA. Longissimus thoracis shear force, drip loss, and color were not affected by diet, but objective chroma values were higher for muscles from pigs fed CLA (Table 26). The longissimus thoracis muscle from pigs fed CLA had higher marbling scores and increased ether extractable lipid. Diet did not affect any meat palatability trait. Thiel et al. (1998) actually 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 in that study was increased belly firmness as dietary CLA increased linearly. Research results from Wiegand et al. (1999, 2000), Thiel-Cooper et al. (1999), and Larsen et al. (1999) demonstrated several positive benefits from including CLA in the diets of pigs and no real negative effects.

O'Quinn et al. (1999a,b) 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.

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 feed it!

Other Metabolic Modifiers for Pigs

Chromium is an essential trace element for normal metabolism. Bolemen et al. (1995) found that feeding elevated levels of chromium picolinate to pigs increased percent muscle, decreased backfat, and had no effect on tenderness or sensory traits. Carnitine is a vitamin-like compound that aids in the transport of long-chain fatty acids to the mitochondrial matrix. Supplementing swine diets with L-carnitine 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. (1999) evaluated the effects of modified tall oil, chromium nicotinate, and L-carnitine in growing-finishing pig diets. L-carnitine 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. (1999) 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 from pigs not fed modified tall oil. Bacon from pigs fed chromium nicotinate had more aftertaste than bacon from pigs not fed chromium. The results of these studies with chromium nicotinate show a distinct advantage in feed efficiency, whereas the results with L-carnitine suggest little advantage from including it as a metabolic modifier in the diets of pigs.

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 to not use them. In general, the more "aggressive" implants and implant strategies decrease marbling compared to nonimplanted 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 nonimplanted cattle. However, this is not a very realistic comparison for most fed cattle because of the extremely high percentage of cattle that are implanted. In general, estrogenic plus trenbolone acetate combination implants repeated two or three times or used late in the finishing phase tend to 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 calcium likely will limit 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 conjugated linoleic acid to pigs appears to improve composition and quality simultaneously and should be adapted by the industry if approved and proven cost effective.

Several metabolic modifiers appear to have good potential to improve efficiency of production and carcass composition without detrimental or with positive effects on meat quality.

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