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Review

Effects of metabolic modifiers on carcass traits and meat quality

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Abstract

Much research has been conducted and published about metabolic modifiers that increase growth rate, improve feed efficiency, increase carcass leanness, and decrease carcass fatness. Most of these metabolic modifiers have been developed to improve efficiency and profitability of livestock production and to improve carcass composition, with fewer of them developed and researched specifically to improve meat quality. Some of the metabolic modifiers can have negative effects on visual and sensory meat quality, especially when not used as recommended. This review evaluates the various kinds of metabolic modifiers that have been researched for their effects on production efficiency, carcass composition, and meat quality. Nutritional composition of meat generally is improved from use of most of the metabolic modifiers, visual quality is improved by others, but some can have a negative effect on marbling and tenderness. Anabolic steroid implants are very cost effective and practical for beef cattle production but aggressive implants used within 70 days of slaughter or too frequent use of them will reduce tenderness and marbling. Somatatropin and approved β-agonists are very effective in improving growth performance and carcass leanness in pigs, and β-agonists are effective in cattle, but improper use of them can have negative effects on marbling and tenderness. Feeding supplemental levels of vitamin E is quite beneficial for improving meat color and shelf-life of beef, lamb, and pork, whereas not supplementing diets with vitamin A has potential for improving marbling in cattle. Immunocastration shows promise for capitalizing on the efficiency of muscle growth of young boars up to a few weeks before slaughter, at which time boar taint is prevented and marbling is improved by immunocastration. Potential exists for improving the fatty acid profile of lipids and increasing conjugated linoleic acid content in beef through dietary manipulation. Supplementing swine diets with conjugated linoleic acid can improve carcass composition of swine, but is not yet cost effective to use. Dietary inclusion of magnesium, manganese, or chromium in diets of pigs and sheep has potential to improve meat color and water-holding capacity. Although, not all of these metabolic modifiers are approved in all countries, proper use of the ones that are approved offers opportunities for economically improving production efficiency and carcass leanness while maintaining acceptable marbling and tenderness, while some provide opportunities to enhance meat color and quality.

Keywords: Metabolic modifiers; Growth performance; Meat quality; Dietary manipulation; Carcass traits

Contents

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1. Metabolic modifiers

Metabolic modifiers are defined as compounds that are either fed, injected, or implanted in animals to improve rate of gain, improve feed efficiency, increase dressing percent, increase carcass meat yield percentage, improve visual meat quality, extend shelf-life, improve meat's nutritional profile, 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. However, research activity on dietary manipulation of 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 on carcass composition and meat quality. Little data are presented in Tables because the review would be excessively long, even when only the most relevant data were presented for all metabolic modifiers. 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 and related topics on beef and pork meat quality will not be discussed extensively in this review. 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 lamb research.

Emphasis of this review is on those metabolic modifiers that are, or likely will be approved for use in cattle and pigs in the US 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 characteristics of meat that affect human nutritional quality. Meat quality will be emphasized more than carcass composition or meat yield percentage.

Metabolic modifiers will be categorized as: (1) anabolic steroids, (2) somatotropin, (3) phenethanolamines or beta agonists, (4) vitamins or vitamin-like compounds fed in supra-nutritional levels, (5) 'designer' lipids and (6) other modifiers.

2. Anabolic steroids

Implants containing various anabolic steroids are used widely by the beef cattle industry in the US in growing and finishing cattle because of economic incentives to increase growth rate and improve efficiency of feed utilization (Dikeman, 1997). Heifers and steers show the greatest response to steroid implants, whereas bulls show minimal response. In fact, bulls may deposit more, rather than less fat when implanted. Implanted steers often achieve a growth rate and feed efficiency similar to bulls (Fisher, Wood, & Whelehan, 1986). In general, estrogenic implants are more effective in steers and androgenic implants more effective in heifers. Combination implants generally produce an additive affect in both steers and heifers compared to implants containing only an estrogenic or androgenic compound.

A review of the literature shows that anabolic steroid implants increase growth rate 10–20% when cattle are slaughtered at the same age or time on feed. Preston (1999) stated that growth rates can be improved by as much as 30% and feed efficiency by as much as 15% when slaughtered at the same live weight. In addition, carcass leanness can be improved up to 8% when slaughtered at the same live weight, but most implanted cattle are slaughtered at heavier weights than non-implanted cattle. 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, Bergen, & Merkel, 1992).

Dikeman (2003) published an extensive review of research on the effects of anabolic steroid implants in cattle production and summarized that the effects of implants on meat quality show that some 'aggressive' 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 affect likely results in decreased consumer confidence and demand for beef, which has a significant long-term negative economic consequence. Dikeman (2003) concluded that 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(or) tenderness when compared to non-implanted controls, although not all reductions are statistically significant. Obviously, the type of implant or re-implant strategy, the type of cattle, and the length of time cattle are on feed can have significant effects on the results. 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, Gill, Dolezal, Gardner, and Botts (1990), Samber et al. (1996), Morgan (1997) and Roeber et al. (1999) indicated that some aggressive implanting strategies have been implicated as possibly causing 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. Warner–Bratzler shear force (WBSF) values generally are lower (more tender) for steaks from non-implanted controls than for those from implanted cattle (Morgan, 1997; Table 1). However, because at least 90% of all fed cattle in the US 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 is 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.

Table 1
Warner–Bratzler shear force value change stratified by implant strength and type[a]

First implant	Second implant	Third implant	WBSF[b] (*N*)
	Non-implanted		
ME[c]	–	–	+0.49
ME	ME	ME	+4.11
A	–	–	+5.78
ME/A	ME/A	–	+6.96
SE	–	–	+4.12
SE	SE	–	+4.31
SE/A	–	–	+4.80
SE/A	SE/A	–	+6.47
MC	–	–	+0.98
MC	MC	–	+7.54
SC	–	–	+7.54
SC	SC	–	+5.78

[a] Source: OSU Implant data base (From Morgan, 1997).

[b] WBSF: Warner–Bratzler shear force value, *N* change in WBSF compared to non-implanted controls.

[c] Implant classification: ME, SE, A, MC and SC are mild estrogen, strong estrogen, androgen, mild combination and strong combination, respectively; – = not implanted.

Dikeman (2003) stated that cattle absolutely should not be re-implanted with aggressive (combination implants containing trenbolone acetate) 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.

In more recent research, Smith, Duckett, Asain, Sonon, and Pringle (2007) compared cattle fed a high-concentrate diet with no implant and those receiving two Synovex-Plus^{TM} (combination trenbolone acetate and estrogen) implants. Implanting did not have a direct effect on intramuscular lipid deposition. These authors did find that implanting reduced tenderness after 14 days of aging but shear values were still in an acceptable range.

Watson (submitted for publication, personal communication) conducted a meta-analysis of studies regarding the effects of hormone growth promotant use on beef palatability measured by objective testing and by consumer studies. These authors stated that a meta-analysis is a more rigorous alternative to the 'casual, narrative discussions' of research results. This analysis included 32 studies with 22 treatment-control comparisons for sensory tenderness evaluation; and 18 studies with 24 treatment-control comparisons for shear force. Their hypothesis included the assumption that there is little difference among the different hormone growth promotants in their effect on palatability. The abstract from this analysis stated "we present evidence that suggests strongly that growth promotant implants have a negative effect on beef palatability." Results from the meta-analysis showed that shear force was increased 2.55 N and sensory tenderness score was decreased by 5 units on a 100 point scale. In my opinion, however, the rather modest decrease in tenderness shown from this meta-analysis is not overly concerning. The review by Morgan (1997) presented in Table 1 shows that there are differences among hormone growth promotants in their effect on tenderness; some have a distinct negative effect, whereas others have a rather modest effect.

In a study by Thompson, Polkinghorne, Porter, and Hunter (in press), 509 Brahman and F_1 Brahman crossbred steers were either not implanted or implanted with 20 mg estradiol-17β, approximately every 100 days. Half were finished in a feedlot and half were finished on grass and slaughtered at one of three endpoints based on weight: 220 kg (Australian domestic), 280 kg (Korean), or 320 kg (Japanese). Small blocks of meat were cooked in a water bath for 1 h at 70 °C. Sensory tenderness scores for the domestic endpoint were lowered −7.0 (100 point scale) for feedlot and −12.7 for grass-fed cattle when compared to non-implanted cattle, whereas scores for the Korean and Japanese endpoints were only lowered from −1.3 to −4.5. In my opinion, the reduction in sensory tenderness scores for the two heavier slaughter groups is not concerning because there can be numerous things pre- and postmortem to decrease tenderness to a greater extent than in this study.

In a large study involving 2,748 *Bos indicus* crossbred cattle, Barham et al. (2003) reported that implanting with Synovex-S twice or Synovex-S followed by Revalor-S increased shear force values compared to non-implanted controls after only 14 days of aging, but not after 21 days of aging. These authors determined that consumers failed to detect any differences in steak samples related to implant treatment after 7 or 14 days of aging.

Limited research was found on the effects of anabolic implants in poultry, sheep, and pigs. Anabolic steroids are not approved for growth regulation in pigs in the US and numerous other countries. Even so, Lee et al. (2002) studied the effects of implanting castrate pigs weighing 59 kg with Revalor-H® (trenbolone acetate plus estradiol-17β) on performance, carcass composition and meat quality. Overall, pork quality was not affected by implantation, but backfat thickness was reduced with implantation.

3. Vitamin D_3

Feeding vitamin D_3 has received attention for its potential to improve meat tenderness. It has been shown to increase blood and muscle calcium levels. Dikeman (2003) summarized research on feeding vitamin D_3 and concluded that it may increase tenderness in beef early postmortem, and improve firmness and color and decrease drip loss in pork. However, feeding vitamin D_3 likely will not be adapted by the industry because it reduces feed intake and performance. Moreover, Puls (1994) suggested that supplementing cattle with at least 2×10^6 IU d^{-1} vitamin D_3 could result in cattle toxicity. 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 and it is proven consistently beneficial without any human health risks.

4. Vitamin A

Recently, the role of vitamin A in adipocyte differentiation and marbling development has been investigated. Steers finished on diets containing low levels of vitamin A have produced carcasses with increased marbling scores (Gorocica-Buenfil, Fluharty, & Loerch, 2005; Kruk et al., 2004; Nade, Hirabara, Okumura, & Fujita, 2003; Oka, Maruo, Miki, Yamasaki, & Saito, 1998). Marbling scores have been negatively correlated with concentrations of vitamin A in blood (Adachi et al., 1999; Nakai, Kita, Hasegawa, & Hiramitsu, 1992; Torri, Matsui, & Yano, 1996) and liver (Oka et al., 1998). Most of these studies have utilized Japanese Black or Wagyu cattle that have a very high propensity for marbling deposition. Furthermore, the effects of high levels of vitamin A seem to be dependent on age of cattle. In the published research by Oka et al. (1998), these authors stated that high vitamin A decreased marbling in 15-mo old cattle, but not in 21- or 23-mo old cattle. Serum vitamin A diverged more than 30 μg dl^{-1} over a 16-mo period in the 15-mo old steers, which was the only group with differences in marbling. Circulating vitamin A diverged only 19.6 and 23.2 μg dl^{-1} in treatment periods of only 10 and 6 mo for the 23- and 25-mo old cattle, respectively. This difference in circulating vitamin A was only observed in the last 30 days before slaughter in the 25-mo old cattle. This suggests that duration and(or) extent of vitamin A depletion or supplementation may be important factors that affect marbling development in addition to cattle age. Gorocica-Buenfil et al. (2005) demonstrated that marbling score and percentage of USDA Choice carcasses were 10% higher in steers fed diets with no supplemental vitamin A. Retinoic acid, a derivative of vitamin A, regulates adipose cell differentiation and, possibly proliferation (Pairault, Quignard-Boulange, Dugail, & Lasnier, 1988). This suggests that high vitamin A might negatively affect differentiation of adipocytes and, consequently, marbling.

Pigs fed a diet with no supplemental vitamin A had higher percentages of *longissimus* intramuscular fat without having detrimental effects on growth performance (D'Souza, Pethick, Dunshea, & Mullan, 2003). In contrast to the published results for cattle and pigs, Arnett, Dikeman, Spaeth, Johnson, and Hildabrand (2006) reported that lambs fed diets with 1,365 IU vitamin A kg^{-1} diet during the growing and finishing phases to slaughter had higher percentages of intramuscular fat in the *longissimus* muscle than those fed diets with no supplemental vitamin A. Lambs fed no supplemental vitamin A during the 56-day growing phase and finished on high vitamin A, and lambs fed diets with high A during the growing phase and finished with no supplemental vitamin A were intermediate in *longissimus* intramuscular fat. Lambs fed no supplemental A also had the greatest increase in serum fatty acids. There were no differences in circulating retinol levels from day 0 to day 56, but then became higher at 84 days for lambs on the high vitamin A diet. These results suggest that there may be a species interaction on the effects of supplemental vitamin A on intramuscular fat deposition. Seibert, Pitchford, Kuchel, Kruk, and Bottema (2000) reported that adipose tissue from lambs fed a diet containing low β-carotene had decreased C18:0 (stearate) and increased C18:1 *n*-9 *cis* (oleate), resulting in 14.9 percentage points reduction in saturated fat. In addition, there was a 10 °C lower melting point for fat from lambs on the diet with low β-carotene than those on the high β-carotene diet. Seibert et al. (2000) stated that this contradiction with results from cattle might simply be that cattle do not metabolize β-carotene as well as sheep.

In all of these studies, there have been no significant effects of vitamin A supplemental level on growth rate, feed intake, or carcass composition. However, retinoic acid, a form of vitamin A, regulates growth hormone gene expression (Bedo, Santisteban, & Aranda, 1989). Dalke et al. (1992) demonstrated reduced marbling scores in steers treated with growth hormone. Therefore, vitamin A may be affecting marbling development indirectly by regulating growth hormone secretion. Color shelf-life of beef could be negatively affected by not supplementing diets with vitamin A. Muramoto, Nakanishi, Shibata, and Aikawa (2003) reported that 7500 mg hd^{-1} d^{-1} of β-carotene supplementation for 28 days extended the color shelf-life of *semimembranosus* and *longissimus lumborum* muscles by 1.5 and 3 days, respectively, based on a threshold value of 20% metmyoglobin.

5. Vitamin E

Numerous studies have shown that feeding supra-nutritional levels of vitamin E improves meat color and can extend shelf-life of beef, lamb, and pork. There have been no reports of negative effects on feed intake or performance of cattle or pigs fed vitamin E, unlike supplemental feeding of vitamin D_3. Therefore, this metabolic modifier is practical and effective, but feeding high levels of vitamin E should not increase costs of production to the point of not being cost effective.

Dikeman (2003) and Dunshea, D'Souza, Pethic, Harper, and Warner (2005) published reviews on effects of feeding high levels of vitamin E on meat quality. Dikeman (2003) summarized the research showing that dietary vitamin E supplementation in cattle results in accumulation of α-tocopherol in muscle tissue, which acts as an antioxidant to delay lipid and myoglobin oxidation. Consequently, color stability and retail shelf life of beef are prolonged (Faustman et al., 1989; Figs. 1 and 2). Asghar et al. (1991) and Monahan, Asghar, Gray, Buckley, and Morrissey (1992, 1994) published data showing that vitamin E decreases lipid oxidation and drip loss while improving the color of pork cuts.

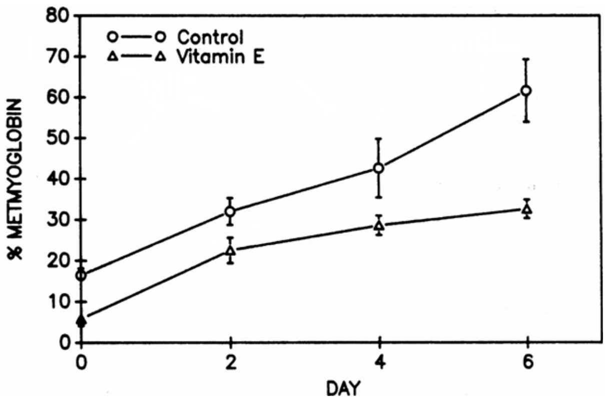

Fig. 1. Metmyoglobin accumulation during storage at 4 °C for fresh ground sirloin patties from control and vitamin E-supplemented Holstein steers. $N = 11$ for each group; standard error bars are indicated. (From Faustman et al., 1989).

Arnold et al. (1992) reported that color stability during retail display of *longissimus lumborum* steaks from Holstein steer calves supplemented with vitamin E was extended by 2.5–4.8 days (Fig. 3); color stability for *gluteus medius* steaks was extended 1.6–3.8 days. Liu, Scheller, Arp, Schaefer, and Frigg (1996) fed Holstein steers 0, 250, 500

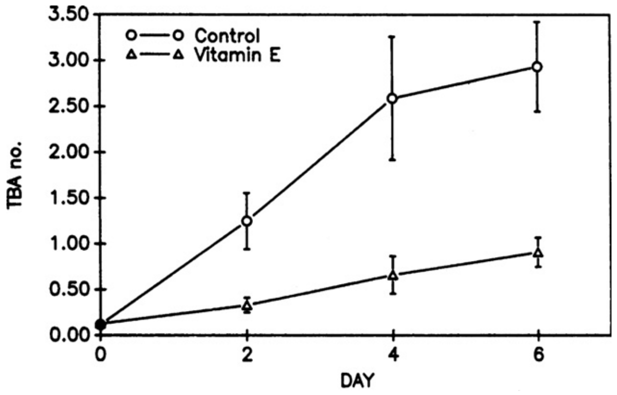

Fig. 2. TBA numbers of fresh ground sirloin from control and vitamin E-supplemented Holstein steers during storage at 4 °C. $N = 11$ for each group; standard error bars are indicated. (From Faustman et al., 1989).

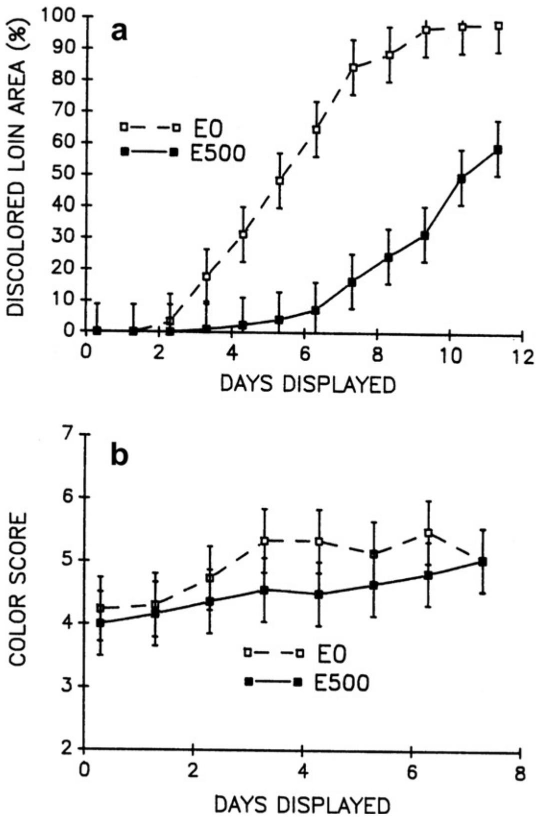

Fig. 3. Effect of level of vitamin E supplementation on area of discoloration (a) and color score (b) of *longissimus lumborum* (loin) steaks ($n = 34$ steers). Color scores were associated with the following descriptive terms: 3 = moderately light cherry red, 4 = cherry red, 5 = slightly dark red, and 6 = moderately dark red. $E_0 = 0$ IU d^{-1} of supplemental vitamin E; E500 = 300 IU d^{-1} of actual supplemental vitamin E. (From Arnold et al., 1992).

Table 2
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^{-1})	*Longissimus lumborum*		*Semimembranosus*		*Gluteus medius*		Dose
	42 days	126 days	42 days	126 days	42 days	126 days	
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}		

$^{a–c}$ Means across durations within muscle or among doses lacking a common superscript letter differ ($P < 0.01$).
$^{d–f}$ Means across muscles lacking a common superscript letter differ ($P < 0.01$). (From Liu et al., 1996).

or 2000 IU d^{-1} vitamin E for durations of 42 or 126 days and reported that color display of fresh beef was extended 0.9–1.8 days from the lowest to highest feeding level (Table 2). Liu et al. (1996) determined that color display life across the *longissimus lumborum*, *semimembranosus* and *gluteus medius* muscles stored under vacuum until 14 days and then displayed under simulated retail conditions was extended 2.0 days (E250) to 5.0 days (E2000). 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 days, or essentially 100%. Lynch, Kerry, Buckley, Faustman, and Morrissey (1998) reported that supplementing Friesan steers with 2000 IU α-tocopherol acetate kg^{-1} feed d^{-1} for 50 days resulted in greater color and lipid oxidative stability for *longissimus lumborum, gluteus medius* and *psoas major* muscles than steaks from steers fed the basal diet after 7 days of retail display.

Supplementation of lamb diets containing at least 1000 μg g^{-1} α-tocopherol has also been proven effective for improving lamb meat color and shelf-life stability (Guidera, Kerry, Buckley, Lynch, & Morissey, 1997; Wulf et al., 1995). Supplementing diets for pigs with at least 200 IU kg^{-1} of feed reduced lipid oxidation (Jensen et al., 1997), reduced drip loss (Cheah, Cheah, & Krausgril, 1995), and enhanced color stability (Lanari, Schaefer, & Scheller, 1995), whereas drip loss and color stability in other studies were not affected (Cannon et al., 1995; Jensen et al., 1997). Hoving-Bolink, Eikelenboom, van Diepen, Jongbloed, and Houben (1998) reported that color stability was improved in the *longissimus* muscle after 6 days, but not in the *psoas major* for pigs fed extra vitamin E. Cannon et al. (1996) reported that vitamin E significantly reduced TBARS of pork after 3 and 5 days of retail display after 0, 14, 28 and 56 days of vacuum storage. However, the effects of feeding vitamin E on sensory panel attributes were negligible. 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.

In more recent research since the review published by Dikeman (2003), Guo et al. (2006a) showed that drip loss was decreased with increased vitamin E (200 and 400 vs. 40 IU Vitamin E kg^{-1} of feed) and that both drip loss and pH were improved with 6 or 9 weeks of feeding vs. 3 weeks. Also, less lipid oxidation was detected in fresh ground pork from pigs fed greater concentrations of vitamin E after 4 days of storage, and in pork chops after 6 months of freezer storage. In another study, Guo et al. (2006b) evaluated the effects of 200 IU vitamin E kg^{-1} of feed and three levels of fat in the diet. These authors stated that meat quality characteristics did not differ among treatments, but the high level of vitamin E had a beneficial effect on the oxidative stability of pork as indicated by TBARS values. Also, adding vitamin E acetate led to greater monounsaturated and total unsaturated fatty acid proportions in neutral lipids of muscle and adipose tissues.

Supplementing cattle and pig diets with supra-nutritional levels of vitamin E consistently shows an advantage in color display life and reduced oxidative deterioration of meat in various packages and chilled states but the effects in beef are more pronounced than in pork. Williams, Frye, Frigg, Schaefer, and Scheller (1992) conducted a blind study of consumers regarding beef from cattle fed 500 IU $steer^{-1}$ d^{-1} of vitamin E for 100–120 days and beef from cattle not fed vitamin E. They found 3.6 percentage points reduction in losses in retail value from the cattle fed supplemental vitamin E. Liu, Lanari, and Schaefer (1995) described the cost/benefit ratio of this technology for the US beef industry. The cost of supplementing 500 IU of vitamin E d^{-1} for 126 days 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 US 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 including vitamin E in the diets of livestock.

6. Somatotropin

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

(Beermann, 1994). Recombinantly produced porcine somatotropin (rpST) has been approved for use in swine production in several countries, but not in the US. It is delivered as an injection one to three times per week. Average daily gain is increased by 20% with 150 μg rpST kg^{-1} 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% concurrent with an 82% decrease in lipid accretion rate when rpST is administered from 30 to 90 kg body weight. The increase in protein deposition generally is considered a result of increased protein synthesis instead of decreased protein degradation. On the other hand, dressing percentage is not increased with rpST administration, primarily because of increased organ weights. Growing ruminants also respond to exogenous rbST administration in a dose-dependent manner, but responses are generally of lesser magnitude than those observed in pigs (Crooker et al., 1990). Currently, rbST and roST are not approved for beef cattle or lamb production.

Dunshea et al. (2005) conducted a meta-analysis of the literature and concluded that rpST decreased intramuscular fat an average of 12%, increased shear force an average of 9%, but reduced drip loss by 6%. In addition, the limited literature on consumer preferences suggests that there is a 9% decrease in tenderness. However, the increases in shear force and decreases in consumer sensory tenderness can be as much as 35%, depending on dosage, genotype, and other management variables. There were no negative effects on consumer-evaluated flavor, but consumer-evaluated juiciness was decreased in a majority of the studies; as much as 20% in some studies.

Dikeman (2003) concluded that the large majority of studies show that shear force is increased and sensory panel tenderness is reduced for chops from pigs treated with rpST. Thiel (1991) reported a rather dramatic difference of 2.27 kg in the mean values between the controls and the highest rpST dose.

McKeith, Lan, and Beermann (1994) concluded that ST decreases intramuscular lipid content in both pork and beef in a dose-dependent manner by 20–50%. Processing of bellies into bacon also can be a problem because of the thicker skin of rpST treated pigs and because of thinner bellies. However, the sensory properties of cured products from rpST treated pigs do not appear to be affected.

Growing sheep also respond to exogenous bovine somatotropin (rbST) and ovine somatotropin (roST), and carcass fatness is significantly reduced (Beermann et al., 1990; McLaughlin et al., 1994). Beermann et al. (1990) found that ewe lambs exhibited greater reductions in fat accretion and greater responses in growth rate than wethers when roST was administered over an 8-week period prior to slaughter.

Clearly, roST 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 or bi-weekly with oST. An implant release form of roST might be accepted readily by the sheep industry, because no effective anabolic steroid implant is currently available for use in sheep.

There are no scientific data to justify preventing 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.

7. β-agonists

Only ractopamine hydrochloride for use in pigs (Paylean®) and cattle (Optaflexx®) and zilpaterol hydrochloride (Zilmax®) for use in cattle will be discussed in this manuscript. Only these two are discussed because they are approved for use in the US and several other countries, and zilpaterol does not have the potential negative potency or pharmalogical activity of products like clenbuterol or cimaterol. Zilpaterol is 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 these β-agonists.

Ractopamine hydrochloride for pigs has positive effects on growth rate, feed efficiency, dressing percent, and carcass composition when fed at dosages of 5.0 and 9.9 mg of ractopamine kg^{-1} of feed for 30–50 days before slaughter, but most of the research for approval was done in the 1980s and early 1990s on moderate-lean-growth pigs. McKeith et al. (1994) summarized the few studies that have been conducted on the effects of ractopamine hydrochloride on visual meat quality and sensory traits of both beef and pork and stated that the effects on marbling, color and firmness in both species are neutral to positive. However, some studies have shown an increase (8.33 and 4.80 N) in WBSF when ractopamine was fed at its highest level (20 mg kg^{-1}) (Aalhus et al., 1990; Uttaro et al., 1993). Stites et al. (1991) and Uttaro et al. (1993) stated that feeding ractopamine hydrochloride will increase carcass leanness and should increase processed ham yields.

Schluter, Preston, Davis, Ramsey, and Miller (1991) studied the effects of feeding ractopamine (marketed as Optaflexx™ in the US) at 0, 10, 20 or 30 ppm 46 days before slaughter on feedlot cattle. At 20 and 30 ppm, 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^{-1}). Ractopamine did not decrease USDA quality grade. Avendano-Reyes et al. (2006) evaluated the

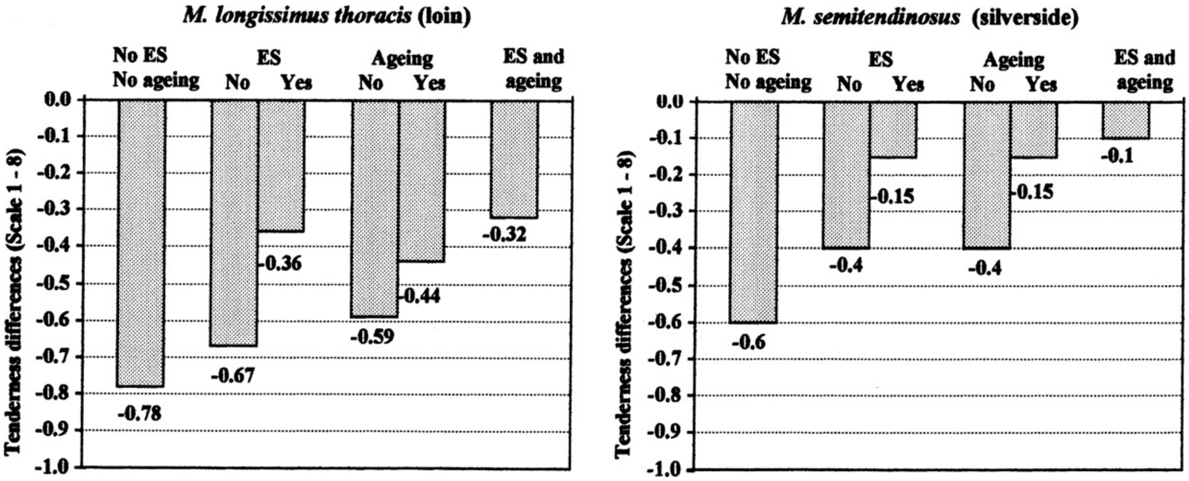

Fig. 4. Effects of different slaughter and post-slaughter scenarios on tenderness of the *longissimus thoracis* and *semitendinosus* muscles from cattle fed zilpaterol for 30 days vs. controls. (From Strydom et al., 1998).

effects of feeding ractopamine at 300 mg steer^{-1} d^{-1} for the last 33 days on feed and reported decreased ($P < 0.05$) feed intake, improved ($P < 0.01$) gain/feed ratio, increased ($P < 0.05$) dressing percent and carcass weight, and increased ($P < 0.05$) shear force (46.6 vs. 42.3 N) compared to controls.

Zilpaterol hydrochloride (Zilmax®) distinctly improves growth performance, dressing percent, and carcass muscling in cattle (Dikeman, 2003). However, Strydom, Osler, Nel, and Leeuw (1998) reported that zilpaterol supplementation resulted in a decrease in M. *longissimus* dorsi muscle tenderness, but the negative effect seemed to be a function of ineffective electrical stimulation and inadequate postmortem aging. When electrical stimulation and adequate aging were used, the reduction in tenderness was minor (Fig. 4). Strydom and Nel (1999) supplemented diets with 0.15 mg zilpaterol for the final 15, 30 or 45 days 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 zilpaterol for 45 days but not for 15 or 30 days. Strydom, Buys, and Strydom (2000) studied the effects of zilpaterol on color and discoloration of three muscle types during vacuum storage and subsequent display. The diet supplemented with zilpaterol for 30 or 50 days significantly enhanced the color shelf life of loin and rump steaks and topside mince during retail display at 4 °C, at 0 and 28 days aging. However, the negative effects of 45 days feeding on tenderness suggest that 30 days of zilpaterol supplementation would be optimum.

Avendano-Reyes et al. (2006) evaluated the effects on performance, carcass traits, and meat quality of including 60 mg steer^{-1} d^{-1} zilpaterol for 33 days before slaughter of steers fed a high grain diet. Zilpaterol improved ($P < 0.01$) gain/feed ratio and ADG by 26% compared to control steers. In addition, hot carcass weight was increased ($P < 0.05$) as well as *longissimus* area. Meat from the zilpaterol fed steers had greater ($P < 0.01$) shear force values than meat from controls (49.6 vs. 42.6 N) but meat color was not affected. In contrast, O'Neill (2001) reported that there were no differences in tenderness between steers fed zilpaterol and controls. Avendano-Reyes et al. (2006) compared the effects of ractopamine and zilpaterol and reported that steers fed ractopamine consumed less feed than control steers, and tended to have greater fat thickness than steers fed zilpaterol. Shear values were similar between steers fed zilpaterol and those fed ractopamine. Zilpaterol is approved for use in Mexico, South Africa, and the US (for weight gain, feed efficiency, and carcass leanness).

Including either ractopamine or zilpaterol in finishing diets of cattle for a maximum of 30 days before slaughter would be a very cost effective, convenient, and efficient way to increase growth rate, improve feed efficiency, increase dressing percent, and improve carcass meat yield. However, meat tenderness could be reduced unless proper electrical stimulation and aging or other mechanical means are used to counter the potential negative effects on tenderness.

8. 'Designer' lipids

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. 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 that is more susceptible to oxidative rancidity than saturated fat. Cook et al. (1998) demonstrated a 20% reduction in backfat for pigs fed CLA and about a 7% increase in lean muscle mass.

Part of the interest in feeding increased levels of conjugated linoleic acid 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 and it also reduces fatty streak formation in the aortas of arteriosclerosis models. The main isomers of CLA in meat are *cis*-9, *trans*-11 and *trans*-10, *cis*-12, and both have human health benefits. Rumen biohydrogenation of linoleic acid was originally believed to be the source of CLA *cis*-9, *trans*-11 (Hartfoot & Hazelwood, 1998), but Griinari et al. (2000) and Palmquist (2001) have shown that the primary source of CLA is through Δ^9-desaturase acting on *trans* vaccenic acid during rumen biohydrogenation. Scollan et al. (2006) stated that it is recognized that *trans* vaccenic acid (*trans*-11, 18:1) is the precursor for tissue synthesis of beneficial CLA in both humans and animals. McGuire, Duckett, Andrae, Giesy, and Hunt (1998) showed that increasing both forage level and high-oil corn in feedlot diets of cattle increased CLA content by 24% in intramuscular fat. Enser et al. (1999) added 60 g linseed oil kg^{-1} diet dry matter to the diet of finishing steers and increased CLA content in *longissimus* muscle three-fold (35.6 vs. 11.3 mg 100 g^{-1} muscle) compared to Megalac supplement (calcium salts of palm oil fatty acids, mainly palmitic, oleic and linoleic). Lorenzen et al. (2007) found CLA content to be higher in cooked muscles from cattle fed on pasture than those fed a feedlot diet and the CLA content varied among the three muscles studied.

Dugan, Aalhus, Schaefer, and Kramer (1997) found that CLA in the diet (2%) of pigs repartitions nutrients from carcass fat to lean. In a later study, Dugan, Aalhus, Jeremiah, Kramer, and Schaefer (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. Objective chroma values for subcutaneous fat were reduced but *longissimus thoracis* shear force, drip loss, and color were not affected by diet for pigs fed CLA. The *longissimus thoracis* muscle had higher marbling scores and increased ether extractable lipid (Table 3). Diet did not affect any meat palatability trait. In a review of the literature, Dunshea et al. (2005) stated that the greater the initial backfat depth, the greater the reduction in backfat in response to dietary CLA supplementation. For the already extremely lean, hybrid genotypes now used in many countries, the use of dietary CLA may be limited, unless the improvements in quality and value of pork with higher CLA content is rewarded. In a meta-analysis of published studies, Dunshea et al. (2005) showed an average reduction in backfat of 6% and an increase in intramuscular fat and marbling score by 7% and 11%, respectively. However, consumer perception of juiciness was reduced by 12%. Thiel, Sparks, Wiegand, Parrish, and Ewan (1998) found an improvement in growth rate as well as 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.

Table 3
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[c]	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

From Dugan et al. (1999).

[a,b] Means with different letters within row are different ($P < 0.05$).

[c] Interaction between diet and gender is significant ($P < 0.01$).

Dunshea et al. (2005) summarized the literature to conclude that dietary supplementation also results in modified fatty acid composition of pork tissue, mostly in subcutaneous fat. 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. Woodworth et al. (1999) found that modified tall oil decreased average daily feed intake and improved feed efficiency. In addition, pigs fed modified tall oil (O'Quinn et al., 1999b; Woodworth et al., 1999) or dietary CLA (Thiel et al., 1998) had firmer bellies, which would be an advantage to processors.

Joo, Lee, Ha, and Park (2002) fed pigs diets containing 0, 1, 2.5 or 5% CLA for 28 days 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% CLA in the diet and less purge was observed with samples from CLA-fed pigs. In addition, dietary CLA improved the color stability of pork loins during cold storage, likely because of lower TBARS. These authors concluded that dietary CLA offers human health benefits and it also improves pork color and water-holding capacity. These authors did not conduct palatability evaluations.

According to Gillis et al. (2004), feeding rumen protected CLA offers a potential means of increasing the CLA content of meat from ruminants. In an excellent review, Scollan et al. (2006) concluded that, despite the high levels of ruminal biohydrogentation of dietary PUFA, nutrition is the major route for increasing the content of beneficial fatty acids in beef. Scollan et al. (2006) stated that finishing cattle on grass or on concentrates containing linseed (rich in α-linolenic acid, 18:3*n*3) increases the content of 18:3*n*3 and its longer chain derivative eicosapentaenoic acid (EPA, 20:5*n*3) in beef muscle and adipose tissue, resulting in a lower *n*6:*n*3 ratio (Table 4). These authors further stated that feeding PUFA-rich lipids that are protected from ruminal biohydrogentation result in further enhancement of the PUFA in meat with concomitant beneficial improvements in the ratio of PUFA:SFA (P:S ratio) and *n*6:*n*3 ratio (Table 5). However, Scollan et al. (2006) further stated that as the content of *n*3 PUFA increases,

Table 4
Influence of forage on the fatty acid composition (mg 100 g^{-1} tissue) of beef *longissimus* muscle

(i) Grass vs. concentrate (Dunshea et al., 2005; adapted from Warren et al. (2003))

Fatty acids	Grass	Concentrate	SED	Significance
Total	2581	1724	139.3	***
$18{:}2n{-}6$	62.0	146.9	6.68	***
$18{:}3n{-}3$	32.0	7.2	1.60	***
$20{:}5n{-}3$	17.7	4.5	1.05	***
$22{:}5n{-}3$	10.8	10.8	1.28	***
$22{:}6n{-}3$	5.0	1.3	0.30	***
$n{-}6{:}n{-}3$	1.2	8.9	0.24	***
P:S	0.09	0.24	0.010	***

(ii) Proportion of grass (g kg^{-1} DM) in the diet (Dunshea et al., 2005; adapted from French et al. (2000))

Fatty acids	Grass (g kg^{-1} DM)				SED	Significance
	0	510	770	1000		
Total	3410	4490	4020	4360	650.5	NS
$18{:}2n{-}6$	120.5	105.8	94.4	85.9	6.05	**(linear)
$18{:}3n{-}3$	29.3	35.4	41.1	46.0	1.78	**(linear)
$20{:}5n{-}3$	4.9	11.0	9.8	9.4	1.32	*(quadratic)
$22{:}6n{-}3^{A}$	–	–	–	–		
$n{-}6{:}n{-}3$	4.15	2.86	2.47	2.33	0.197	**(linear)
P:S	0.09	0.10	0.11	0.13	0.010	**(linear)

NS, not significant.
* $P < 0.05$.
** $P < 0.01$.
*** $P < 0.001$.

sensory attributes such as grassy, greasy, and fishy are increased and color shelf life may be reduced. High levels of vitamin E are then necessary to help offset these negative sensory attributes, either in the form of specific grasses or concentrates supplemented with vitamin E. Scollan et al. (2006) concluded that opportunities exist to enhance the content of health promoting fatty acids in beef, which results in opportunities to add value and product differentiation. However, it is imperative that these approaches to deliver "functional" attributes do not compromise on the health value (lipoperoxidation) or the taste of beef.

It should be remembered that the amount of CLA in meat is small relative to the amount recommended daily for health benefits, which is approximately 3500 mg d^{-1} (exraploated from studies with animals) (Ha, Grimm, & Pariza, 1989). Except for low values found for bulls, the range of CLA in meat from steers from several published manuscripts summarized by Scollan et al. (2006) is from 35 to 134 mg 100 g^{-1} of fresh muscle. Nevertheless, meat and dairy products are the primary sources of CLA in human diets.

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 or visual meat quality have been reported. The effects of CLA on meat palat-

Table 5
Influence of fat sources on the fatty acid composition (mg/100 g tissue) of beef *longissimus* muscle

(ii) Plant oils supplement (PLS) protected from ruminal biohydrogenation (Scollan et al., 2006; adapted from Scollan et al. (2004))

Control		PLS (g d^{-1})			SED	Significance
		400	800	1000		
Total	4685	4976	4880	4895	737.0	NS
$18{:}2n{-}6$	120	255	279	305	23.4	***
$18{:}3n{-}3$	29^{a}	102^{b}	$118^{b,c}$	139^{c}	13.1	***
$20{:}5n{-}3$	13^{a}	15^{a}	14^{a}	16^{a}	1.1	*
$22{:}5n{-}3$	$23^{a,b}$	24^{b}	20^{a}	20^{a}	1.7	*
$22{:}6n{-}3$	1.9	1.8	1.5	1.6	0.272	NS
$n{-}6{:}n{-}3$	2.27^{c}	2.02^{b}	2.00^{b}	1.88^{a}	0.055	***
P:S	0.07^{a}	0.18^{b}	0.20^{b}	0.22^{b}	0.018	***

NS, not significant.
* $P < 0.05$.
** $P < 0.01$.
*** $P < 0.001$.

ability appear to be minimal. However, at the time this review was written, the use of CLA *per se* in diets of pigs or other meat animals as a metabolic modifier was minimal. Some hydrogenated vegetable oils have a rather high content of CLA, but are not marketed as containing CLA. If the benefit/cost ratio of feeding CLA is proven favorable, swine producers should consider adding it to pig diets.

9. Chromium, carnatine, magnesium, niacin, manganese and betaine

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. Reduced purge loss was observed in the loin muscle by Mathews, Southern, Bidner, and Persica (2001).

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 affect on growth performance or carcass measurements. Chromium nicotinate improved feed efficiency but had no effects on carcass or meat traits. 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. Bacon from pigs fed chromium had more after taste 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.

Apple, Maxwell, deRodas, Watson, and Johnson (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, but color scores improved linearly with increasing levels of magnesium mica. Magnesium aspartate supplementation was shown by D'Souza, Warner, Leury, and Dunshea (1998) to increase muscle pH in the *longissimus* muscle at 40 min and 24 h after slaughter. In addition, pigs fed the magnesium aspartate supplemented diet had lower percentages of drip loss, lower surface lightness L^*, and had no PSE carcasses compared to pigs fed the control diet. However, little is known about the effects of supplemental magnesium on palatability of pork. According to Gardner, Jacob, and Pethick (2001), 1% magnesium oxide supplementation in sheep 4 days before commercial slaughter resulted in higher muscle glycogen concentrations in muscle and reduced ultimate pH in 2 of 3 trials. They concluded that magnesium oxide supplementation is a viable option for reducing the stress associated with commercial sheep slaughter.

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^{-1} of added niacin. In one experiment, increasing niacin content improved feed efficiency, subjective color, and pH of meat, and reduced carcass shrink,

Apple et al. (2007) evaluated the effects of dietary manganese inclusion level on pork quality traits during retail display. They found that chops from pigs fed 80 ppm manganese received higher ($P < 0.05$) American and Japanese color scores than pigs fed 0 or 40 ppm but TBARS values did not differ among dietary manganese levels.

Betaine is used quite widely in some countries to improve growth performance of pigs, but little data exists regarding its effect on pork meat quality.

10. Immunocastration

Dunshea et al. (2005) gave an excellent review of the mechanisms and effects of immunocastration with Improvac$^{\text{TM}}$ on growth performance, carcass composition, and meat quality of pigs. Improvac contains a modified form of GnRF in a low reactogenic adjuvant system, which allows pigs to receive a secondary immunization relatively close to slaughter. He reviewed original work in which he was involved (Dunshea et al., 2001) that demonstrated a reduction in the production and accumulation of both androstrenone and skatole in pork carcasses. Taint substances already present are metabolized and this allows boars to be slaughtered at heavier weights without taint, but still allows boars

Table 6
Effect of sex and immunocastration on eating quality of pork loin steaks (D'Souza et al., 1999)

Sex	Boar	Barrow	Immunocastrate	LSD[b]	*P*-value
Odor[a]	56	62	62	6.13	0.093
Flavor[a]	58	62	66	7.01	0.101
Tenderness[a]	52	59	62	7.44	0.016
Juiciness[a]	60	59	64	7.05	0.304
Overall acceptability[a]	58	62	67	6.41	0.025

[a] Acceptability score (line scale) for all attributes, 0 = dislike extremely and 100 = like extremely.

[b] Least significant difference.

to benefit from testicular testosterone on growth and carcass composition before they are immunized.

Dunshea et al. (2005) cited the work of Oliver et al. (2003) who reported that Improvac-treated boars had up to 35% increased feed intake from 2 to 4 weeks after the second immunization, but feed efficiency was not different. This contrasts a reduction in feed intake of pigs administered rpST. These results support real benefits from immunocastration with Improvac by increasing feed intake, capitalizing on the growth and leanness advantages of boars before immunocastration, and may have potential to improve marbling. In the original work by Dunshea et al. (2001), most boars treated with either Improvac or a placebo had appreciable levels of testosterone (>2 nM) at the time of the second immunization. However, within 2 weeks the placebo treated boars had fat androstenone levels almost eight times higher than the Improvac treated boars, which in turn, were not significantly different from the barrows. In addition, these researchers concluded that 99% and 100% of the Improvac-treated boars had skatole and androstenone levels below a recommended threshold of 0.22 and 1.0 $\mu g\ g^{-1}$ established by the European Union. D'Souza, Hennessy, Danby, McCauley, and Mullan (2000) reported that immunocastrated boars had higher marbling scores than non-immunocastrated boars. Dunshea et al. (2005) cited work from D'Souza, Hagan, Hooper, Nicholls, and Mullan (1999) showing that flavor, tenderness, and overall acceptability of pork loin steaks for immunocastrates were superior to those from intact boars and not different from barrows (Table 6). These results suggest that immunocastration is very effective at preventing boar taint and it may improve marbling, with meat palatability equal to meat from barrows.

11. Summary

In a thorough review by Dunshea et al. (2005), the authors stated that conservative use of each of the metabolic modifiers used to increase carcass leanness will result in a 5–10% increase in shear force and a similar reduction in the perception of tenderness. The authors did not, however, state whether there were any additive negative effects if two or more metabolic modifiers were used simultaneously. 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 and marbling also usually are reduced in meat from cattle implanted with aggressive combination implants late in the finishing phase, or implanted several times. Not following the manufacturers' recommendations for implanting types and sequences certainly can cause negative effects.

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 supra-nutritional 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. A low level of vitamin A in cattle diets shows potential to increase marbling in cattle but may decrease shelf-life of meat.

Feeding ractopamine hydrochloride (Paylean®) to pigs for 28 days before harvest will increase growth rate, dressing percent, and carcass leanness. It may also improve processing yields, and have a neutral effect on meat palatability. Ractopamine hydrochloride (Optaflexx®) will also improve growth performance of cattle. Zilpaterol (Zilmax®) distinctly improves growth performance, dressing percent, and carcass muscling. When fed for only 15–30 days and when effective electrical stimulation and adequate aging are used, its negative effects on meat palatability should be minor. Meat color may be improved.

Somatatropin is extremely effective in improving growth performance and meat yield percentage of pigs. However, it negatively affects marbling, tenderness, and bacon production. 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.

Immunocastration shows very good potential for preventing boar taint and improving marbling and still capitalize on the growth, feed efficiency and carcass leanness of boars up to the point of immmunocastration. Inclusion of magnesium in the diets of pigs shows potential to improve pH and color of pork.

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