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What Will HACCP Mean to My Business?

Abstract

This paper reviews the literature relating to the potential impact of swine nutrition on pork quality attributes. Supra-nutritional levels of vitamin E have been shown to increase muscle vitamin E content E and reduce lipid oxidation; however, the impact on muscle color and water holding capacity has been variable. Selenium is also potentially involved in reducing lipid oxidation; there is no evidence, however, that supplying additional selenium above the requirement improves pork quality. Recent research has suggested that the feeding of high levels of vitamin D3 in the final 10 days prior to slaughter improves pork color and reduces drip loss; these results require validation. Feeding ingredients with relatively high levels of unsaturated fatty acids increases the degree of unsaturation of the fat tissue, decrease fat firmness, and can negatively impact fat quality. The potential to produce "healthier" pork by feeding ingredients rich in omega-3 fatty acids and to improve fat firmness by including conjugated linoleic acid in the diet is discussed. There is evidence that restricted feeding of growing-finishing pigs can negatively impact pork tenderness and juiciness. The marbling fat content of pork has been positively associated with eating quality and feeding protein-deficient diets in the final 5 weeks prior to slaughter has been shown to increase marbling. Australian research has suggested that supplementation of diets with magnesium aspartate for 5 days prior to slaughter reduces the incidence of PSE and improves muscle color and water holding capacity. A range of other dietary compounds has been investigated; however, there is limited evidence on which to judge their efficacy for improving pork quality under commercial conditions.

Introduction

Historically, the formulation of diets for growing-finishing pigs has largely been based on meeting the animal's requirements for energy and protein to optimize growth performance and carcass lean content and supplying sufficient minerals and vitamins to prevent deficiency symptoms. Over recent years, however, there has been an increase in interest in improving pork quality and the potential for nutrition to improve attributes such as muscle color, water holding capacity and pork palatability has been more widely researched. The objective of this paper is to provide a broad overview of the current status of knowledge relating to potential links between swine nutrition and pork quality.

1. Vitamin and Minerals

1.1. Vitamin E and Selenium

A major cause of deterioration in the quality of meat during storage is lipid oxidation which can result in a number of undesirable changes and reduce the shelf-life of pork. These changes include the development of oxidative rancidity and the associated increase in unpleasant odors and flavors. In addition, the deterioration of fresh pork color during aerobic storage has been associated with oxidative changes in the chemical form of muscle pigments; myoglobin can be converted into metmyoglobin producing a dull brown muscle color which is less attractive to the consumer. This color change is particularly important for ground products, such as sausage, where a greater surface area is generally available for oxidation to take place. It has also been proposed that oxidation of the phospholipids in the cell membranes, which are rich in polyunsaturated fatty acids, disrupts cell wall integrity and can reduce water holding capacity. Polyunsaturated fatty acids are essential components of cell and intracellular membranes but are susceptible to oxidation. The unsaturated fatty acid content of fat depots is very closely related to the composition of the dietary fat ingested by the pig and can therefore be readily manipulated by altering the fat source fed (see section 2). One approach to reducing the impact of oxidation on product appearance is vacuum packaging, where air is removed from the package, or modified atmosphere packaging and storage, which uses gases such as carbon dioxide in packages to displace oxygen and limit oxidation.

Another widely investigated approach to reducing oxidation in pork and improving shelf-life and quality is to use antioxidants such as vitamin E. In growing-finishing pigs, the NRC (1998) recommended that the dietary requirements for vitamin E to prevent deficiency symptoms is 11 mg/kg of feed of DL-α-tocopherol; however, increased levels of 30 mg/kg or higher are recommended in situations where rela-

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tively high levels of unsaturated fatty acids are fed (Ullrey, 198l). The feeding of high levels of vitamin E to pigs to improve pork quality has recently been reviewed by a number of authors (Buckley et al., 1995; Cannon, 1995; Jensen et al.,1998). Jensen et al. (1998) summarized the results of 14 studies that investigated the impact of feeding high levels of vitamin E (within the range of 100 to 800 mg/kg of feed of DL-α-tocopherol) to growing-finishing pigs. These studies used chops, steaks and/or ground pork products and employed a range of storage times and conditions post mortem. All of the studies that measured muscle vitamin E levels showed a dose dependent increase and a significant reduction in lipid oxidation from feeding high vitamin E levels. The effects of vitamin E feeding on pork color and water holding capacity were, however, more variable. For example, Jensen et al. (1997) found no effect of feeding vitamin E at levels up to 700 mg/kg on muscle color and drip loss despite the fact that muscle vitamin E levels were increased and lipid oxidation was decreased by the elevated dietary vitamin E treatments. Asghar et al. (1991) found that the surface redness of the muscle (measured by Hunter a* values) was increased and the drip loss from frozen pork chops upon thawing was decreased by feeding 200 mg of "-tocopherol acetate per kg of feed compared to the controls that were fed diets containing 10 mg/kg of "-tocopherol acetate; the color and drip loss of muscle from pigs fed 100 mg/kg feed was intermediate between the other two treatments. These are similar to the results of Monahan et al. (1992). In addition, Monahan et al. (1994) also observed a reduction in lipid oxidation and drip loss from pork chops over an 8-day storage period for pigs fed 200 mg/kg "-tocopherol compared to controls.

Two recent studies that have investigated the effect of vitamin E on water holding capacity are summarized in Table 1. The study of Cheah et al. (1995) showed a significant reduction in drip loss from feeding 500 mg/kg of supplementary vitamin E for 46 days prior to slaughter for both Halothane negative and carrier animals. In contrast, Cannon et al. (1996) fed 100 mg/kg of feed of supplementary vitamin E for an 84 day period prior to slaughter and showed no effect on muscle color or drip loss for storage periods of up to 56 days post mortem. The obvious explanation for the difference in response observed in these two studies is the lower level of vitamin E used by Cannon et al. (1996) and these authors suggested that the lack of response may have resulted from the low α-tocopherol concentrations found in the muscle of treated pigs. Obviously, the response to dietary vitamin E supplementation will depend on the level fed and the time of feeding and may actually vary depending on the response criterion used.

Another nutrient that is involved in reducing lipid oxidation in the cell membrane is selenium, which is a component of the enzyme glutathione peroxidase. This enzyme can remove peroxides from cell membranes and has, therefore, a shared role with vitamin E in reducing cell membrane oxidation. However, there is little experimental evidence to suggest that providing pigs with additional selenium above that required to prevent deficiency symptoms (i.e. 0.15 to 0.30 ppm) shows any benefit in terms of meat quality. In addition, dietary inclusion levels above 5 ppm are generally considered toxic to pigs (NRC, 1998).

1.2. Vitamin D3

Recently, there has been considerable interest in feeding high levels of vitamin D3 to cattle to improve tenderness (Swanek et al., 1997). It has been suggested that such an approach results in an increase in muscle calcium levels which stimulate proteolytic enzyme activity post mortem and improve meat tenderness. A preliminary study conducted at the University of Illinois, which evaluated the impact of feeding high levels of vitamin D3 (331 vs 55,000 vs 175,000 IU/kg) to finishing pigs during the final 10 days prior to slaughter (Enright et al., 1998), failed to show any beneficial effects on palatability traits (Enright et al., 1998). However, drip loss was reduced and muscle color was improved for treated animals relative to controls. Research at Iowa State University has shown an increase in plasma calcium levels from feeding elevated vitamin D3 levels (up to 500,000 IU per day) prior to slaughter but no effect on pork quality has been reported (Beitz et al., 1998). Further research is required to validate the impact of feeding high levels of vitamin D3 on pork quality and animal performance.

2. Fat Nutrition and Fat Quality

Fat quality is largely defined in terms of physical and nutritive characteristics, aspects which are both closely related to the fatty acid composition of the fat depots. In the pig, many of the fatty acids in the diet are absorbed across the gut intact and are deposited directly into the fat. Thus, the composi-

Table 1. Impact of dietary Vitamin E supplementation 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	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

Table 2. Influence of backfat thickness on composition of backfat (%)

Components	Average P2 fat thickness (mm) 8	12	16	SE of difference	Significance
Water	22.36	17.08	14.06	0.560	***
Lipid	69.25	77.00	81.59	0.726	***
Collagen	4.49	2.98	2.04	0.140	***
Fatty acid:					
Myristic (C14:0)	1.49	1.51	1.49	0.021	ns
Palmitic (16:0)	24.55	25.41	25.87	0.181	***
Palmitoleic (C16:1)	2.78	2.66	2.69	0.065	NS
Stearic (C18:0)	13.15	13.83	13.91	0.215	***
Oleic (C18:1)	40.34	42.83	43.11	0.307	***
Linoleic (C18:2)	14.94	12.38	10.65	0.368	***
Linolenic (C18:3)	1.11	0.89	0.84	0.043	***

Wood et al., 1989
NS, *** = not statistically significant, P<0.00l, respectively.

tion of the fat depots, in terms of fatty acid profile, is closely related to the fatty acid composition of the dietary fat. If pigs are fed a diet with no added fats or oils they synthesize and deposit saturated fatty acids (principally palmitic and stearic) and mono-unsaturated oleic acid (Metz and Dekker, 198l). Deposition of polyunsaturated fatty acids (principally C18:2 and C18:3) occurs only if they are included in the diet.

The major issues relating to fat quality are soft fat, oxidative rancidity, and the impact of the composition of pork fat on human health. These issues are receiving increasing attention in the US pork industry because of the significant changes in production practices and consumer requirements that have occurred over recent years.

Soft fat is of major concern to the meat processor because it can cause significant problems during cutting, grinding and slicing operations and can result in lower processing yields and reduced value. For example, Shackleford et al. (1990) fed corn-soy diets with 0 (control) or 10% of either beef tallow, safflower oil, sunflower oil, or canola oil and showed a significant reduction in fat firmness for pigs fed the oil containing diets relative to controls. In addition, belly slicing yields and flavor and overall palatability ratings for bacon were lower for pigs fed canola oil. The softness of fat is directly proportional to the amount of unsaturated fatty acids in the fat depot. This area is receiving increasing attention because of changes in the genetics of pigs and in feed ingredients used to formulate swine rations. Soft fat problems are relatively greater in leaner pigs which have a greater proportion of the fatty acids in the carcass fat derived from the diet and a smaller proportion from *de novo* synthesis of fatty acids by the animal. This is illustrated by the results of a study by Wood et al., 1989 (Table 2) that compared the composition of the backfat in pigs with different backfat depths) and showed that leaner pigs had a higher proportion of polyunsaturated fatty acids (C18:2 and C18:3).

The inclusion of fat supplements in corn-soy diets is increasing due to the economic competitiveness of certain fats relative to corn on a cost per unit of energy basis and also to suppress dust levels within swine buildings. The use of high-oil corn in swine rations is also increasing and there is concern over the potential impact of this change on fat quality. All of these developments will result in an increase in the proportion of unsaturated fatty acids in the fat depots of the pig and increase the likelihood of soft fat problems.

The unsaturated fatty acid that is of major concern is linoleic acid (C18:2), because it is at a relatively high concentration in conventional feedstuffs and fat sources used in pig diets. Linoleic acid is not synthesized by the pig or significantly modified before being deposited in the fat depot. This means that all of the C18:2 in pig fat is derived directly from the diet. Vegetable oils are generally higher in unsaturated fats than animals fats, particularly C18:2, and the inclusion of these in rations will obviously increase the degree of unsaturation in the fat depots and increase the likelihood of fat quality problems.

A measure of the degree of unsaturation of fats, both dietary and within the body, is the Iodine Value (IV), with higher values indicating a greater proportion of unsaturated fats. Boyd et al. (1997) investigated the relationships between dietary fatty acid profile and the fatty acid profile and IV of backfat. The relationship between dietary linoleic (C18:2) content and the IV of the backfat was linear, with IV's increasing from approximately 65 to 76 for diets containing 1.3 and 3.5% of C18:2, respectively.

Threshold levels for body fat composition for soft fat problems have not been clearly established for US pigs. The Danish Meat Research Institute has set a fairly rigid standard of a maximum body fat IV of 70 (Barton-Gade, 1987). Boyd et al. (1997) suggested that some pigs fed a corn-soy diet with no added fat would exceed this threshold. To prevent problems occurring, dietary specifications in Europe generally include a maximum inclusion level for C18:2 which is commonly set at around 1.6% of the diet for finisher rations. Boyd (1997) has suggested a less stringent IV threshold of 74 for US conditions and dietary linoleic maximum of 2.1% to be under this threshold.

An area that has received relatively little attention is the relationship between the composition of pig fat and the eating

quality of pork, particularly in terms of odor and flavor. Historically, major problems in this respect were experienced with feeding fish oils or fish meals with a relatively high oil content and the associated development of fishy taints in the meat. Fish oils are high in polyunsaturated fatty acids such as C20:5 and C22:6 (Irie and Sakimoto, 1992) that are very susceptible to oxidative rancidity and the development of off-flavors.

The relationship between fatty acid composition of intramuscular fat and the palatability of pork was investigated in a European study by Cameron and Enser (1991) who showed that the correlations between the concentration of specific fatty acids and eating quality traits were generally weak. However, correlations involving polyunsaturated fatty acids and palatability scores were generally negative and those for the saturated fatty acids were generally positive suggesting that the higher the degree of unsaturation in the IMF, the greater the incidence of abnormal flavors. A possible explanation for this is the increased level of oxidation and development of rancidity for fat that is high in unsaturated fatty acid.

One of the consequences of the close relationship between the composition of dietary and body fat is that it is relatively easy to manipulate fat composition by changing the fat source fed to the pig. In the human, the consumption of high levels of saturated fat has been associated with an increasing incidence of coronary heart disease and a number of studies have investigated the potential for increasing the concentrations of "healthier" fatty acids in pig fat by including them in the diet.

Of particular interest have been the so-called omega-3 fatty acids that have been associated with a beneficial effect on cardiovascular diseases. Feed sources that are rich in omega-3 fatty acids include fish oils and certain vegetable oils such as flaxseed and linseed. Including these feedstuffs in diets for pigs has led to an increase in omega-3 fatty acid concentrations in the fat depots of the animal but has also been associated with an adverse effect on flavor in some studies probably as a result of lipid oxidation (Romans et al., 1995a, 1995b).

Another issue receiving increasing attention is that of the effects of dietary conjugated linoleic acid (CLA) on growth, carcass and meat quality characteristics. This fatty acid is found at a relatively high level in dairy products and has been shown to increase feed conversion efficiency and decrease carcass fat content in laboratory animals (Chin et al., 1994). There has been little published on the effects of CLA on growth and meat quality in pigs. Duggan et al. (1997) fed diets containing either 2% CLA or 2% sunflower oil from 61.5 to 106 kg liveweight and found a reduction in feed intake (-5.2%), improved feed efficiency (5.9%), reduced subcutaneous fat levels (-6.8%) and similar growth rates for pigs fed CLA compared to those fed sunflower oil. Thiel et al. (1998) showed improvements in daily gain, feed efficiency and carcass fat levels from feeding between 0.12 and 1.0% CLA to pigs between 26.3 and 116 kg liveweight. In addition, belly hardness increased linearly as the concentration of CLA in the diet increased, suggesting an improvement in fat quality due to CLA inclusion. Further research is required to validate the effect of CLA on fat quality, including evaluation of palatability traits.

3. Feeding Level and Dietary Protein:Energy Ratio Effects

A number of studies carried out in the United Kingdom have shown an eating quality advantage for pigs reared under ad libitum compared to restricted feeding. The results from two of these studies are presented in Table 3. The feeding regimes were imposed between approximately 30 kg liveweight and 80 to 85 kg in the case of the Warkup et al. (1990) and from 30 kg to between 80 and 120 kg in the study of Ellis et al. (1996). The degree of feed restriction imposed was similar in both trials at approximately 82% of ad libitum intake. The results of these studies (Table 3) suggest a small but significant improvement in tenderness and juiciness from ad libitum feeding. The mechanism for any improvement in palatability observed with from ad libitum feeding has not been established but could result from the improved growth rate and/or increased intramuscular fat levels in ad libitum compared to restrict fed animals. Warkup and Kempster (1991) proposed a theoretical model in which increases in intramuscular fat levels and/or lean growth rates are associated with improvements in tenderness and juiciness. This model has not been validated but raises an issue over the extent to which eating quality can be improved by manipulating the growth curve of the animal.

In contrast to these positive associations between growth performance and palatability, other research has shown little effect of either feeding level or growth rate on eating quality. In a recent study, Wood et al. (1995) found no effect of ad libitum compared to restricted feeding (80% of ad libitum intake between 25 and 95 kg liveweight) on eating quality characteristics. In addition, a recent collaborative study carried out by Purdue University and the University of Illinois found little difference in tenderness and juiciness between pigs of the same genotype that were grown at widely different rates (A. Schinckel, personal communication) . This calls into ques-

Table 3. Effect of ad libitum and restricted feeding regimens on eating quality

	Advantage of ad libitum over restricted feeding[1]	
Trait	**Trial A[a]**	**Trial B[b]**
Tenderness	0.30***	0.47*
Juiciness	0.26***	0.19*
Flavor	.00	-0.05
Odor	0.12	0.02
Overall acceptability	0.19***	

1 8-point scale; lower values = poorer quality
*, *** = P<.05, P<.00l, respectively
a Source: Ellis et al., 1996
b Source: Warkup et al., 1990

Table 4. Influence of feeding protein deficient diets on intramuscular fat content of the longissimus

Dietary protein/lysine level (%)		Intramuscular fat (%)		Weight range	Source
Adequate	Deficient	Adequate	Deficient	(kg)	
18.5/0.96	13.l/0.64	l.5	2.5	to 103	Essen-Gustavsson et al, 1994
17.6/0.81	11.9/0.48	1.4	3.5	25 - 98	Castell et al, 1994
25.0	10.0	3.4	9.4	30 - 90	Goerl et al, 1995
16.0/0.82	12.0/0.55	5.5	11.2	10 - 100	Kerr et al, 1995
20.5/1.05	16.6/0.70	1.2	2.4	39 - 90	Blanchard et al, 1998
14.0/0.56	10.0/0.40	3.8	5.7	80 - 110	Cisneros et al, 1996

tion the influence of feeding regime and growth rate on eating quality.

There is concern that the low levels of IMF in some of the genetically lean lines of pigs result in reduced palatability of pork. In the short term, the easiest method to increase IMF levels is via nutrition and a number of studies have shown substantial increases in intramuscular fat from feeding protein-deficient diets to pigs (Table 4). However, most of these trials were carried out during both the growing and finishing phases of production. The protein-deficient diets also produced substantial increase in carcass fat levels and reductions in feed efficiencies and would be uneconomic in most situations. The impact of short-term feeding of protein-deficient diets on IMF levels is less well established. Cisneros et al. (1996) produced a 2 percentage units increase in IMF from feeding a protein-deficient diet for approximately 5 weeks prior to slaughter (Table 4). In a follow up study, Cisneros et al. (1998) investigated the interaction between the level of protein deficiency and time of feeding of protein deficient diets on longissimus IMF. The results of this study suggested that a minimum feeding period of 5 weeks was required to elicit a consistent response in IMF and that there was an optimum level of protein deficiency to produce the maximum response. Feeding protein levels above or below this optimum resulted in a reduction in the level of IMF within the muscle. In the study of Cisneros et al. (1998), pigs on the lowest level of protein (0.4%) had reduced growth rates relative to the other treatments and this is the probable explanation for the relatively modest response in IMF for this treatment.

Data from the lean growth modeling project being carried out by the National Pork Producers Council has also shown a positive effect of feeding amino acid deficient diets on intramuscular fat but also the low-protein diets produced a deleterious impact on drip loss and tenderness.

4. Feed Withdrawal Prior to Slaughter

Denying pigs access to feed for a period of time prior to slaughter has a number of potential advantages. The stomach is relatively empty at slaughter and consequently the incidence of stomach punctures during the evisceration process and, therefore, the potential for carcass contamination by gut contents should be reduced. In addition, it may be possible to lower the glycogen content of muscles at slaughter and increase ultimate pH (Warriss and Brown, 1983), which may improve pork quality attributes.

The impact of feed withdrawal prior to slaughter has been investigated in a series of studies carried out at the University of Illinois which have used pigs with high and low glycolytic potential resulting from the presence of the Rendement Napole gene (LeRoy et al., 1990; Lundstrom et al., 1996). Pigs that carry the dominant allele of this gene (RN-RN- or RN-rn+) have elevated muscle glycogen levels and might be expected to respond differently to feed withdrawal compared to animals that are homozygous recessive at this locus (rn+rn+) and have normal, lower muscle glycogen levels. In the first of these studies (Bidner, 1998; unpublished data), pigs with high (RN-rn+) and low (rn+rn+) glycolytic potential were held off feed for 12, 36 and 60 hours before slaughter. The results from this study are presented in Table 5. Withdrawing feed for 36 or 60 hours resulted in an increase in muscle ultimate pH and improvements in muscle color for animals with low (rn+rn+) but not with high (RN-rn+) glycolytic potential. There was a numerical improvement in purge and drip loss for pigs with low glycolytic potential on the 36 and 60 hour treatments but this was not statistically significant (Table 5). Apparently, feed deprivation in animals with high glycolytic potential did not reduce muscle glycogen to a level low enough to impact muscle ultimate pH.

In a further study (Bidner, 1998; unpublished data), pigs with high and low glycolytic potential were held off-feed for period of 12 or 36 hours prior to slaughter. The longer period of feed withdrawal produced no change in muscle pH or any of the quality attributes for pigs with low or high glycolytic potential which is in contrast to the results of the previous study (Table 5). In the first study, pigs were mixed with other animals at the start of the feed withdrawal period, whereas they were not mixed with other pigs in the second study. This suggests that some form of additional stressor(s) is required to reduce muscle glycogen levels and improve meat quality. These two studies suggest that genotype and animal handling factors interact to determine the response in pork quality to feed withdrawal.

In addition, prolonged periods of feed withdrawal may be associated with loss of carcass weight and a reduced return for animals that are paid for on a carcass weight basis. British research has shown that carcass weights start to decline after about 9 to 18 hours of feed withdrawal and Warriss and Brown

(1983) predicted that between 18 and 48 hours of feed withdrawal the rate of loss was to equivalent to 0.11 % of carcass weight per hour. However, studies at the University of Illinois have suggested little impact of feed withdrawal times of up to 60 hours on carcass weight. The British research was based on entire males rather than castrates and used much lighter slaughter weights than in the Illinois studies, two factors that may explain the differences in response in carcass weight observed. Dressing percentage (i.e. carcass weight expressed as a percentage of slaughter live weight) is actually increased by feed withdrawal prior to slaughter as a result of losses of gut fill and offal weight, particularly a reduction in liver weight. This is illustrated by the results from the first study from the University of Illinois described above where dressing percentage was increased from 68.9 to 74.2 % for pigs held off feed for 12 and 60 hours, respectively.

An interesting finding with implications for feed withdrawal prior to slaughter has emerged from recent research carried out at the University of Illinois that investigated eating behavior in growing-finishing pigs (Hyun et al., 1997). This study showed that in uncrowded situations, pigs consumed relatively little feed during the night time between 6.00 pm and 6.00 am. This suggests that if pigs are despatched for slaughter early in the morning then the majority will not have fed for approximately 12 hours. If, however, pigs are crowded or the environmental temperature is high then feeding is likely to continue during the night time for most animals.

Another important factor that should be taken into account when considering feed withdrawal times is the impact on the shedding of bacteria by the animal. For example, there is evidence of an increase in the shedding of salmonella with increasing time of feed withdrawal prior to slaughter (R. E. Isaacson, 1999, personal communication), which obviously could have a negative impact on food safety. Further research is required in this area.

5. Other Compounds

A number of other dietary components have been reported to improve meat quality. Two recent studies have highlighted the potential to improve meat quality through inclusion of specific compounds in the diet immediately prior to slaughter that modify post-mortem glycolysis. A study carried out in Australia has shown a large effect on pork quality of dietary magnesium supplementation for 5 days prior to slaughter (D'Souza et al, 1998) in terms of reduced drip loss, improved color and a lower incidence of the PSE condition for treated animals compared to controls (Table 6). Magnesium reduces plasma cortisol and catecholamine concentrations and may act to reduce the animal's glycolytic response to pre-slaughter stress. In a follow-up study, these researchers showed that cheaper magnesium sources (magnesium chloride and sulphate) were as effective in reducing drip loss and magnesium aspartate (D'Souza et al., 1999).

Kremer et al. (1998) showed that feeding sodium oxalate to pigs for 4 hours immediately pre-slaughter slowed the post-mortem decline in pH and decreased water loss from the muscle during a 12-day storage period. Sodium oxalate inhibits the action of the enzyme pyruvate kinase and, consequently, reduces the rate of post-mortem glycolysis.

There has also been interest in the administration of oral electrolytes in the last few days prior to slaughter to alter the acid-base balance of the animal. In particular, the use of oral sodium bicarbonate, an alkaline salt, has been evaluated as a technique to reduce the incidence of PSE. One study (Ahn et al., 1992) has shown a delayed post-mortem pH decline in pigs given sodium bicarbonate orally immediately prior to slaughter. However, this study and that of Boles et al. (1994) failed to show any positive benefit of sodium bicarbonate treatment on pork color or drip loss.

Other reports have suggested that feeding high levels of L-carnitine (up to 300 mg/kg) and niacin (150 mg/kg) may positively impact meat quality (cited by Mordenti and Marchetti, 1996), although further research is required to confirm these findings. Also, recent data support the use of creatine monohydrate to enhance growth rate and to reduce drip loss as well as to improve juiciness and tenderness of the final product (E. P. Berg, 1998, personal communication). This work also needs further confirmation.

Conclusions

Research relating to potential links between nutrient supply and pig meat quality have been reviewed and a number of opportunities for nutrition to impact pork quality, both positively and negatively, have been identified. Generally speaking, most of the approaches to improving quality will increase production costs and ways of capturing any added value for the producer are needed before widespread adoption of these techniques by the industry.

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