Management Practices and Meat Quality

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Introduction

The title of this paper includes two extremely important but also very broad and often poorly defined areas. One dictionary definition of management would be the organization and control of the way something (especially a business) operates and obviously could encompass every aspect of pork production from on the farm through to the point of consumption of the product. Pork quality also encompasses many different components including compositional, nutritional, technological, toxicological, sensorial, and hygienic aspects. Obviously, to consider all of these broad areas is outside the scope of this paper. Consequently, this review will focus on a very narrow but critically important aspect of quality, namely pork color and water-holding capacity, and on a limited number of management factors associated with the on-farm production of the pigs and their transportation to the packing plant that are potentially associated with variation in this quality component.

Animal Stress and Pork Color and Water-holding Capacity

It has long been known that pork color and water-holding capacity are greatly influenced by the stress that the pig experiences in the period leading up to harvest. Acute stress pre-harvest can increase the incidence of Pale Soft Exudative (PSE) pork and the closer to the point of harvest that the stress occurs the larger the impact. Thus, most recommendations for minimizing the incidence of PSE include approaches to minimizing the stress on the animal caused by transportation and handling practices. On the other hand, longer-term, chronic stress can result in Dark Firm Dry (DFD) pigmeat. Pigs experience many potential stressors from the time of leaving the farm to the point of harvest and, with the exception of animal handling, few of these have been studied extensively, particularly under typical US commercial conditions. We have been involved in a program of research to investigate the impact of a number of these stressors on the response of harvest weight pigs largely in an attempt to understand their impact on the incidence of losses of pigs during transport, however, the results of this research also has potential implications for pork color and water holding capacity.

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Transport Stressors and Losses

Although losses during transport to the plant are relatively low (generally averaging 1% or less), they do represent a significant economic loss to the industry as well as being a major welfare concern. Transport losses consist of animals that die during the journey and those that arrive at the plant unable to walk normally if at all (non-ambulatory). A proportion of the non-ambulatory animals are injured (non-ambulatory, injured or NAI), however, in our experience a large proportion (commonly referred to as non-ambulatory, non-injured or NANI) exhibit symptoms of an extreme stress response, characterized by open-mouthed breathing (dyspnea), skin discoloration (cyanosis), muscle tremors, abnormal vocalization, and/or unresponsiveness to stimulation to move. Metabolic changes in such animals include elevated body temperature and changes in blood acid-base balance characterized by an acidosis involving increased blood lactate and reduced bicarbonate and pH. Such changes are observed in all pigs during transportation but appear to be extreme in NANI animals (Ivers *et al.*, 2002).

Obviously, the potential link between the NANI condition and PSE pork is that both result from an acute stress response that results in an increased rate of muscle metabolism. Consequently, lactate and hydrogen ions rapidly accumulate in the muscle thereby reducing muscle and blood pH.

Additionally, it is possible that NANI pigs could result from chronic as well as acute stress. Chronic stress depletes muscle glycogen stores and may result in physical exhaustion and fatigue. In support of this, Carr *et al.* (2005) reported that the vast majority of fatigued pigs evaluated had high loin muscle ultimate pH (> 5.90) suggesting that muscle glycogen stores were depleted prior to harvest. However, the relationship between muscle glycogen stores and the incidence of NANI pigs has not been established and warrants additional research.

Factors Affecting the Pig s Response to Pre-harvest Stress and Transport Losses

We have been involved in an extensive series of studies to characterize the response of harvest weight pigs to a variety of stressors commonly experienced by the animal during transportation and to identify potential intervention strategies. Changes in blood acid-base parameters, physical indicators of stress, rectal temperatures and/or actual transport losses (dead, NAI, and NANI) have been the parameters used to characterize the pigs responses in studies carried out under both commercial conditions and also in controlled research studies using a standardized handling model. A brief summary of this research is presented here.

Animal factors evaluated have included the genotype, sex, and weight of the pigs. Pre-transport factors investigated have included handling intensity, distance moved from the pen to the truck during loading, and fasting of pigs prior to loading. Major transportation factors included mixing of pigs from different farm groups on the trailer, and trailer floor space.

Industry reports suggest that heavier pigs may be more likely to develop the NANI condition. However, in a study comparing pigs of 104 and 128 kg, we found no effect of live weight on either blood acid-base status or rectal temperature in animals handled either gently with livestock paddles or aggressively with electric goads (Hamilton *et al.*, 2004). Thus, it appears that live weight per se, across the range currently used by many in the US industry, does not increase the pig s response to handling stress. In addition, a number of studies have shown no effect of live weight across this range on the incidence of PSE or DFD (Cisneros *et al.*, 1996). It has been suggested that heavier pigs may experience more stress during the transportation process than lighter pigs because, for example, they may be more likely to become jammed in the aisles during loading, and may be more likely to be crowded on the trailer if a fixed number of pigs are loaded onto the trailer.

Two management factors that can have a major impact on the stress level experienced by the pig during transport and, consequently, on the incidence of transport losses are the intensity of handling that pigs experience during loading and unloading and the floor space that they have on the trailer. Several studies have shown that aggressive handling of animals, including the use of electric goads, produces changes in blood acid-base status, physical indicators of stress, and rectal temperature (Bertol *et al.*, 2002; Hamilton *et al.*, 2004) identical to those observed in NANI pigs (Ivers *et al.*, 2002) and, also, results in an increased incidence of both NANI animals (Benjamin *et al.*, 2001), and PSE pork (D Souza *et al.*, 1998).

Additionally, transport floor space has a major impact on the incidence of dead and non-ambulatory pigs. For example, Ritter *et al.* (2006a) recently compared the effects of two different trailer floor spaces (0.39 vs. 0.48 m^2/pig), that represent the range currently being used in the U.S. industry, and showed that total losses (dead and non-ambulatory) on arrival at the plant were more than halved at the higher floor space (0.88 vs. 0.36 ± 0.16%; $P < 0.05$). In a follow-up study, Ritter *et al.* (2006b) compared six different transport floor spaces ranging from 0.40 to 0.52 m^2/pig and showed that total losses on arrival at the plant were minimized above a trailer floor space 0.46 m^2/pig. Further research is required to more precisely define the minimum trailer floor space that results in minimum transport losses under typical US commercial production conditions. Interestingly, results from a recently completed study suggest that the effects of transport floor space on losses at the plant may depend upon season and the location of the pigs on the trailer. For example, Ritter *et al.* (2006c) showed that reduced floor space on the trailer (0.39 vs.either 0.46 or 0.54 m^2/pig) resulted in increased total transport losses in the summer but not in the winter. In addition, this study also showed a higher incidence of transport losses on the top than the bottom deck of the trailer for loads transported in the winter, whereas the reverse was the case for loads transported in the summer. The reason for these interactions of season with floor space and trailer deck is not clear but may well relate to the micro environment experienced by pigs in different locations on the trailer under different weather conditions. Our knowledge of the conditions experienced by pigs on the trailer during transportation is extremely limited and further research into this critical area is very much needed.

We have investigated a number of potential interventions to reduce the impact of the stress experienced by the animal during transport. Hamilton *et al.* (2003) showed that feeding magnesium sulfate (3.2 g/day of magnesium) for 5 days resulted in lower blood lactate relative to controls after an aggressive handling model, however, there was no effect of the magnesium treatment on blood pH. In another study, administration of sodium bicarbonate via the water supply (at a concentration of 2.5%) for 2 days increased blood pH at all stages from the farm through to the point of harvest in pigs subjected to a simulated commercial handling and transportation procedure (Yu *et al.*, unpublished data). Water delivery of compounds that potentially could minimize the impact of stress on the pig has not been widely researched but may offer the most rapid and easily applicable approach for use under commercial conditions.

Link between Transportation and Pork Color and Water-holding Capacity

Obviously, the extent to which transportation factors will influence pork color and water-holding capacity will be determined by what happen to the pigs between unloading at the plant and the time of harvest. We have long been aware of the potential for transportation stress to increase the incidence of PSE and, consequently, most plants rest pigs after arrival for a period of at least two hours prior to harvest. There has been limited research carried out to determine the optimum period of rest after transportation to minimize the incidence of PSE. Our studies involving aggressive handling of animals, which produced blood acid-base levels and rectal temperatures similar to those observed in NANI pigs, showed that the majority of pigs had returned to baseline levels by 2 hours after the end of the aggressive handling procedure. Thus, most pigs will recover fully, even after exhibiting an extreme stress response, if given sufficient time. However, some may not fully recover even after a relatively lengthy period of time after the stressor has been removed. Interestingly, we have shown that the majority of pigs (72%) that became NANI at the farm on the truck after loading were classed as normal on arrival at the plant after a journey time of around 3 hours. However, some pigs did not recover and were still classed as NANIs on arrival at the plant. This suggests that the time required for pigs to fully recover from the stress of transportation may well vary among animals and that, for some animals, the effects of transportation may well carry over to the time of harvest and influence the incidence of PSE. This is an area that warrants further investigation.

Nutrition and Pork Color and Water-holding Capacity

Pettigrew and Esnaola (2001) produced an extensive and broadly-based review of the literature in relation to swine nutrition and pork quality. This included nutritional approaches to manipulate post-mortem muscle metabolism and/or limit its impact to improve pork color and water-holding capacity, including the feeding of compounds such as quercetin, sodium oxalate, vitamin C, magnesium, tryptophan, creatine, and electrolytes (e.g., sodium bicarbonate). A number of other compounds have been investigated that potentially could improve muscle color and/or water-holding capacity including betaine, trimethylamine oxide, various chromium compounds, and vitamin D_3. In general, the responses observed in pork quality to the administration of all of the compounds listed above have been extremely variable and inconsistent.

One of the most promising approaches to improve pork color and water-holding capacity would be to reduce muscle glycogen content at harvest. This would lower the amount of energy available for post-mortem glycolysis and should limit the extent of pH decline and increase the ultimate pH in the muscle. The most practical approach to achieve this is by fasting the animals prior to harvest. In addition, changes in dietary energy substrates offer potential to impact muscle glycogen levels at harvest.

Fasting of pigs prior to harvest has a number of potential benefits including reducing deaths in transport, reducing gut fill and the incidence of punctured intestines during evisceration, and improving pork color and water-holding capacity. This later effect is generally considered to result from a reduction in muscle glycogen content at harvest, however, feed withdrawal also results in a reduction in body temperature (Bertol *et al.*, 2005), which would also be potentially favorable for pork quality. Although there has been a considerable volume of research carried out in this area, the results have generally been very variable and inconclusive and it is still difficult to give precise recommendations on the optimum time of feed withdrawal to improve pork quality. For example, Bidner *et al.* (1999a) showed an increase in muscle ultimate pH following 36 hours of feed withdrawal. However, in a follow-up study carried out using the same genotypes of pig and under similar conditions (Bidner *et al.*, 1999b), 36 hours of fasting had no effect on muscle ultimate pH. The only obvious difference between these two studies was that the pigs were mixed with those from other groups in the first study whereas they were unmixed in the second. This suggests that the conditions pigs are exposed to during the period of feed withdrawal will influence responses in muscle glycogen levels and pork quality. This variable response in pork quality to time of fasting is most likely the result of a number of factors including the following:

- Muscle glycogen levels prior to the imposition of fasting which, in part at least, are genetically determined.
- The handling of the pigs during the fasting period, including during transportation, and particularly the levels of stress and exercise that the animals are exposed to.
- The period of recovery prior to harvest.
- The time during the day of start of fasting. Pigs exhibit a characteristic diurnal pattern of feeding behavior and feed intake (Hyun *et al.*, 1997). The time during the day when the period of fasting starts will determine how much feed they have consumed in the period leading up to feed removal.

The complex nature of responses in muscle glycogen levels and pork quality to periods of fasting prior to harvest is illustrated in the study of Leheska *et al.* (2003) that showed that in pigs subjected to short journey times (0.5 hours), fasting for 48 hours improved pork color and water-holding capacity whereas fasting had little effect on pork quality in pigs transported for longer times (2.5 or 8 hours). In addition, these authors showed that 48 hours of fasting lowered muscle glycolytic potential and increased ultimate muscle pH in a genetic line with high initial pork quality but not in a genetic line with low initial pork quality.

Approaches to reduce muscle glycogen levels by manipulation of the energy content of the diet have included feeding diets low in digestible carbohydrate and/or high in fat for periods of around 3 to 5 weeks prior to harvest (Rosenvold *et al.*, 2001; 2003). This approach has been successful in reducing muscle glycogen levels (e.g., Rosenvold *et al.*, 2003) and in reducing muscle ultimate pH (e.g., Rosenvold *et al.*, 2001). However, responses in pork quality have been variable and inconsistent and the low carbohydrate diets have generally resulted in substantial reductions in the growth performance of the pigs and/or are likely to increase production costs.

In a recent study carried out at the University of Illinois (Bertol *et al.*, 2004), feeding diets containing 10% supplemented fat for 4 weeks prior to harvest substantially reduced muscle glycogen levels, without negatively affecting growth rates. Although further research is needed in this area, it is possible that the use of high fat diets in late finishing could be part of a strategy to improve pork color and water-holding capacity without negatively affecting growth performance or costs of production.

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