factsheet

Pork Information Gateway

Critical Points Affecting Fresh Pork Quality within the Packing Plant

Authors
Eric P. Berg, University of Missouri

Reviewer
Scott J. Eilert, Excel Corporation

Originally published as a National Pork Board/ American Meat Science Association Fact Sheet.

Introduction

Postmortem metabolism of porcine muscle is more rapid than beef or lamb (Marsh et al. 1972). Metabolism of intramuscular glycogen plays the primary role in the conversion of muscle to meat and the expression of different quality attributes of fresh pork. The two most common quality concerns with fresh pork are pale, soft, and exudative (PSE) and dark, firm, and dry (DFD) lean, with PSE being much more economically important than DFD. Both are a result of postmortem glycogen metabolism. The level and extent of postmortem pH decline is glycogen dependent as anaerobic conversion of glycogen to lactic acid results in the achievement of an acceptable (or unacceptable) meat pH. The PSE condition occurs when intramuscular lactic acid (localized lactidosis) accumulates very rapidly (<1h) while the carcass temperature is still high. The initiation of glycolysis could be attributed to many things: 1) genetic predisposition (porcine stress syndrome); 2) elevated metabolism or if a pig is prone to a high "excitability" (Grandin, 1994); 3) pre-slaughter stress; and/or 4) combinations of all of these. Activation of the glycolytic system just prior to exsanguination leads to the production of heat which will elevate the pig's body temperature. Pearson (1987) wrote that the ultimate condition of pork muscle is influenced by skeletal muscle pH drop as a function of time, in vivo temperature patterns, carcass chilling rate, and the conditions at the onset of rigor mortis. The rate of postmortem pH decline is approximately three times faster in carcasses that ultimately produce PSE meat, regardless of presence or absence of the stress gene (Mitchell and Heffron, 1982). This rapid pH drop while the carcass temperature is above 37°C leads to denaturation of myofibrillar proteins that bind water (Penny, 1969).

Grandin (1994) reported that ultimate pork quality was a responsibility given 50% to the producer and 50% to the packer. The producer is responsible for selection of swine genotypes that possess acceptable pork quality traits and must provide environmental conditions to optimize composition (growth) and quality of the final food product. The producer must guarantee proper selection, care, and handling to the point of delivery to the packing plant. The packer accepts the responsibility of optimizing pre- and post-slaughter conditions to ensure optimal meat quality. The purpose of this review is to identify the critical points affecting fresh pork quality at the slaughter and processing plant with a brief discussion regarding pig handling at the production site. This review will provide scientific documentation regarding conditions which can be controlled within the packing plant in an effort to optimize fresh pork quality.

Production Site

Acceptable pork quality is the responsibility of both the packer and producer (Grandin, 1994) therefore, a brief discussion regarding conditions at the production site is in order. Appropriate genetic selection is but one attribute that can be controlled by the swine producer. Adequate care and treatment must be a standard production practice. Good management includes development of an efficient and economic feed ration, proper record keeping (sire and dam summaries), and appropriate housing conditions. Grandin (1989) suggested methods for "environmental enrichment" of feeder pigs for growth in a less stressful environment. Pigs that are accustomed to people and sounds are less likely to produce quality problems associated with pre-slaughter handling. Hogs become more accustomed to sudden noises if they have been raised in an environment where a radio has been playing or have had frequent encounters with people (such as opening and closing pen gates; walking in pens). Excitable pigs (Grandin 1998a) and pigs that have had little human contact or poor "environmental enrichment" will experience more stress during loading and transport. Hunter et al. (1997) found that the rearing, finishing, and loading environment will significantly affect the stress encountered by transport and lairage. Pigs which are easy to move are less likely to be treated harshly during transport and lairage.

Pre-transport handling at the production site

Pigs react to a stress with an inborn fear response. High levels of fear may result in a physiological stress response that may adversely affect welfare, productivity, and ultimately meat quality (Hemsworth, 1993). Transport is stressful for pigs (Mickwitz, 1982; van Putten, 1982; McGlone et al., 1993; Lambooij and van Putten, 1993; Martoccia, et al. 1995), therefore, care should be taken to minimize handling stress prior to transport. Kilgour and Dalton (1984) suggest holding market pigs together in an unfamiliar pen the night before transport and moving them early in the morning. Pigs will load more easily into a trailer if they are provided secure footing and the trailer is level with the loading plane. Market weight pigs are more difficult to drive on concrete slabs, plastic, or metal floors because of unstable footing (Warris et al., 1983; Grandin, 1994). Pigs will load more easily through a dual ramp and chute design constructed to facilitate side by side loading. A distressed pig will try to maintain contact with its pen-mate if not physically, then at least visually (van Putten, 1982). The outer sides of the loading ramp should be solid with an inner middle partition panel that is "see-through" (such as a wire panel). The see-through middle panel will promote the pigs' following behavior while the solid outer sides restrict the view of distractions outside of the chute (Grandin, 1998b; Grandin, 1998c). Because sight restriction lowers stress levels, a solid portable (hand-held) panel is a very effective means of driving market hogs. Electric prods should be avoided and used only in cases of emergency (Grandin, 1989; Guise and Penny, 1989a; Kilgour and Dalton, 1984). These same guidelines are effective for unloading pigs upon arrival at the packing plant.

Pigs have a tendency to move from dimly to brightly lit areas. A spotlight directed into a ramp or trailer will facilitate entry as long as it illuminates the interior of the ramp or trailer and does not shine directly in the pigs eyes (Grandin, 1989). Nanni Costa et al (1996) reported that use of a loading ramp that has a minimal slope had no negative consequences on muscle quality. Tarrant (1989) recommends these options for loading of pigs (listed in order of importance): 1) a loading platform that is level with the truck deck; 2) a hydraulic tailgate lift on the truck; 3) a fixed, permanent loading ramp with an incline slope £ 20° (pigs have an aversion to downward slopes); 4) a portable loading ramp with an incline of £ 27°.

Transport

Martoccia et al. (1995) concluded that pig transport was the most influential pre-slaughter factor because it affects both meat quantity and quality. Grandin (1998d) provides several recommendations to reduce transport stress in market swine. Trailers should be maintained and kept in good repair. Trucks and trailers should be cleaned after each load to prevent slipping and skin blemishes (carcass bruising). Overcrowding will result in increased body temperature (Guise and Warris, 1989), death loss, and PSE carcasses.

Studies of transportation stress are difficult to analyze because of the cumulative contribution of each component associated with transport (Stephens and Perry, 1990). Changes in velocity, vibration, handling by unfamiliar persons, mixing with unfamiliar hogs, and establishment of a new social group all contribute to the total stress of transport. The factor (or combination of factors) contributing the highest amount of total stress may not be readily evaluated. In general, transportation conditions will affect post-mortem meat quality by provoking stress or animal fatigue (Lambooij and van Putten, 1993).

Stocking density, weather, and temperature during transport

The person transporting pigs will most often determine the stocking density of the truck or trailer. The number of pigs per load is largely a function influenced by economics. Market pigs will experience heat stress, fatigue, lower meat quality, and a higher mortality if too little space is allowed. Too much space is not cost effective and the extra space provides more room for injury as pigs can be thrown about during sudden stops and cornering (Tarrant, 1989). The effect of stocking density on ultimate meat quality is greatly influenced by breed and ambient temperature. Tarrant (1989) provides a review of different stocking densities used for road transport of pigs to slaughter. The average, minimum recommended space allowance of 0.35 m^2/100kg pig was derived from the review of 10 transport studies. The space allowance per pig must be increased by 10% in hot weather and when the route to slaughter is through areas of heavy traffic or urban areas where ventilation may be reduced as a result of slowed or stopped transport velocity.

Trucks or trailers should be lined with wet sand or shavings to keep pigs cool when temperatures exceed 15°C (60°F). When temperatures are above 27°C (80°F) pigs should be sprinkled with water prior to loading. Never bed pigs with straw during hot weather. High temperature and humidity are extremely dangerous for pigs because of their inefficient means of heat respiration. In fact, Williams (1985; as cited by Tarrant, 1993) found that pig transport death rate plotted against temperature began a steep rise when temperatures exceeded 18°C and became almost vertical above 25°C.

Grandin (1998d) recommends pigs be scheduled for delivery to the packing plant at night or early morning when the Livestock Weather Safety Index is in the Danger and Emergency zone. If this is not possible, trucks should be kept moving to facilitate air flow. During hot weather, pigs should be unloaded as soon as they reach the plant. In cold weather at temperatures below 15°C (60°F), trucks and trailers should be bedded with straw or deep, dry shavings to keep pigs warm. Aluminum transport trailers should have approximately half the air flow holes closed with plywood if temperatures fall below minus 12°C (10°F). Eilert (1997) stated that from a physiologic standpoint, if a hog gets excessively cold on a truck, this will not affect pork quality. However, if the pig experiences cold to the degree of frost bite or wind chill burn, the respective pork carcass will require more time on the kill floor for extra trimming (at an elevated temperature) which is detrimental to pork quality. Grandin (1994) advises that it is very important to take weather into account when testing new methods for reducing PSE and (or) bloodsplash at the packing plant. The incidence of PSE carcasses may easily double during the first four hot days of spring.

Length of Transit

Transit duration has a variable affect on pork quality. Martoccia et al. (1995) found that pigs transported 650 km had a significantly higher pH45 (45 min postmortem pH), pHult (ultimate pH), and a darker, redder meat than pigs transported 180km. These authors are quick to conclude that, although these differences were significant, they were well within the range considered normal. Warris et al. (1990) found transportation times of 1-4h had no significant affect on pHult. A large amount of the stress of transport occurs at loading and unloading. Bradshaw et al. (1996) reported that concentrations of the stress hormones cortisol and beta-endorphin were substantially elevated immediately after loading. Shorter transport time may be more detrimental than longer ones if the driving, stocking density, and ventilation are adequate (Tarrant, 1989). Stephens and Perry (1990) suggest that pigs may acclimate to the stress of transport. The authors found the largest increase in heart rate occurred immediately on starting the engine (to generate vibration and noise) and then gradually declined as the test progressed. Grandin (1994) observed that pigs hauled very short distances for under 30 minutes are often more stubborn and difficult to drive at the plant than pigs experiencing a longer transit time and short duration stress may lead to a higher incidence of PSE. Pigs transported a longer distance may be more likely to develop DFD meat as a result of long duration stress and depletion of intramuscular glycogen stores.

Death loss due to transport was lowest for short transit duration (10-25min) while the greatest death occurred during 45-80 minutes of transport (Honkavaara, 1989a) suggesting that stress sensitive pigs die in a relatively short period of time (<45min) as a result of transport. Honkavaara (1989a) found maximum mortality occurred in warm weather (14-24°C) while the least mortality occurred in cool weather (around 8°C).

Lairage

Martoccia et al. (1995) concluded that transport distance itself did not seem to determine severe levels of stress in pigs and found that transport stress may be offset by the amount of time pigs spend in lairage before stunning. It is generally accepted that time spent in lairage allows a stressed animal time to recover from loading, transport, and unloading stressors. Pigs should be rested (transport recovery period) 2-4 hours before entering the stunning chute (Grandin, 1994). Once unloaded into lairage, pigs will rapidly begin establishing a dominance hierarchy. Messe and Ewbank (1973) found that the average aggression rate was 2 incidents per pig per hour in groups of familiar pigs. Pigs in unfamiliar groups have higher frequency, higher intensity, more spontaneous, and less resource-related aggression. The average aggression rate can be as much as 12 incidents per pig per hour. Baxter (1985) reported that 10 groups of 6 previously unacquainted pigs gave an average of 138 aggressive interactions per group in the first hour after introduction (23 aggressive interactions per pig per hour). Pigs slaughtered during the initial hours of lairage, during this period of aggressive behavior, experience both physical and physiological stress (Grandin, 1997) which will result in increased metabolic activity, reduced intramuscular pH (Enfalt et al., 1993), and elevated body temperature. On average, the hierarchy is established within 2 hours and pigs begin to rest. Grandin (1994) suggests that after 4h in lairage pigs begin to "wake up" and return to the aggressive behavior that may ultimately affect meat quality. Honkavaara (1989b) concluded that the high occurrence of PSE carcasses in his study may have been largely due to the stressful treatment of pigs being woken up and driven to the stunner after being held in lairage overnight. De Smet et al. (1996) found a lairage time of 2-6 h, compared with immediate slaughter, improved meat quality resulting in a lower percentage drip loss, lower Hunter L-values, and higher pH45.

Warris (1987) provides an excellent review of the effect of time and conditions of transport and lairage on pig meat quality and contends that under modern conditions, holding pigs in lairage may have negligible or no influence on meat quality. Prolonged holding may lead to a reduction in meat quality if pigs have not been subjected to stressful handling prior to or during transport or if they are of a breed particularly resistant to stress. Warris et al. (1996) found longer lairage time reduced the incidence of PSE meat but increased the prevalence of DFD meat. Longer lairage produced progressively more skin blemishes as a result of fighting among unfamiliar pigs and an overnight lairage reduced carcass yield and backfat thickness. Warris (1987) summarizes Elliot and Patton (1968) who concluded that if pigs were not stressed on arrival at the plant, resting in lairage would not improve meat quality. However, if pigs experienced stressful transport, then a lairage of at least 2h was suggested for groups of mixed animals. Warris et al. (1996) found no evidence that leaner, more stress-susceptible pigs reacted differently to length of time in lairage than fatter, more stress-resistant animals.

Water sprays

Schutte et al. (1996) found that showering pigs with water after transport possesses three distinct advantages: 1) it cools the pigs, reducing the strain on the cardiovascular system; 2) calms the pigs, reducing aggressive behavior in lairage; and 3) cleans the pigs, reducing contamination in the slaughter line. Pigs in lairage should have ad libitum availability of drinking water and (ideally) cool showers during hot periods of the year (Grandin, 1994; Weeding et al., 1993). These precautions will lower muscle temperature prior to exsanguination allowing body temperature to be more close to "normal" during early postmortem metabolism conversion of muscle to meat (Klont and Lambooy, 1995). Offer (1991) found that a reduction in body temperature of 2°C prior to exsanguination would reduce the initial rate of denaturation of myosin by 37% resulting in a corresponding reduction in drip loss. An intermittent shower regime may provide the greatest cooling effect through evaporative cooling on the pigs skin surface (Weeding et al., 1993). Pigs have no sweat glands in their skin and use water and wallowing as a means of keeping cool in hot climates (Kilgore and Dalton, 1984; Lambooij and van Putten, 1993). Weeding et al. (1993) observed that pigs sprayed with water during lairage exhibited less stereotypic stressful behavior. Water sprayed pigs were involved with rooting about the pen floor, chewing and licking pen walls, and walking about the pen. These results would suggest that water sprayed pigs experience better welfare which should facilitate greater ease of handling upon entrance into the stunning chute.

Honkavaara (1989b) suggested that optimum lairage temperature, humidity, and time were 15-18°C, 59-65%, and 3-5h, respectively. These levels resulted in lower muscle lactate levels and decreased occurrence of PSE meat.

Feed Restriction

It is generally accepted that a period of fasting before slaughter will reduce the amount of total carbohydrate available for postmortem conversion of glycogen to lactic acid (De Smet et al., 1996). From an animal welfare standpoint, it may appear that the stress of transport combined with the stress of feed restriction may produce deleterious affect on the well being of pigs being transported to market. This is not the case. Becker et al. (1989) reported that the combination of feed restriction and transport stress did not present an additive demand on the pigs biological systems. In fact, Stephens and Perry (1990) found that a pig's aversion to transport was increased if they had eaten a large meal before transport and Tarrant (1993) reported that death losses are greater when pigs are fed on the day of transport. Eilert (1997) suggested that producers factor in approximate transit time and holding time at the plant to determine length of feed withdrawal. Jones et al. (1985) reported overnight fasting at the plant resulted in increased ultimate meat pH, meat color intensity, and water holding capacity. Eikelenboom et al. (1991) found that hogs held off feed (but not water) for a minimum of 12h before slaughter exhibit fewer PSE carcasses. Murray et al. (1989) reported that a 24 or 48h fast significantly reduced the frequency of PSE in stress susceptible (porcine stress syndrome) pigs. The advantage of feed restriction is not unanimous in the literature. De Smet et al. (1996) found overnight feed withdrawal to have no effect on meat quality for all PSE related traits. Becker et al. (1989) found no relationship between pigs fasted up to 72h and ultimate pork quality but did note that meat tenderness was enhanced by transport and fasting.

Feed restriction of market pigs has a more practical application even if one discounts the effect on pork quality. Eilert (1997) suggests that a 16-24h feed withdrawal period is consistently advantageous to the packer because of the greater ease of carcass evisceration, reduced waste handling at the plant, and reduced incidence of broken viscera on the slaughter floor.

Stunning: Movement of pigs to stunning

Grandin (1994) maintains that selection for lean, heavy muscled hogs has inadvertently resulted in increased problems with extremely excitable hogs that "are almost impossible to handle in a calm, gentle manner." As pig excitability has increased, problems with single file stunning chutes have worsened. It is natural behavior for cattle to move well through single-file chutes because cattle instinctively move from pasture to pasture via narrow, single-file cow paths. Pigs, however, do not possess the instinct to walk in single file (Grandin, 1994). Increased occurrence of highly excitable pigs is associated with both meat quality and animal welfare problems. Heavy muscled, excitable pigs will constantly balk in the restraining chute making it necessary for plant personnel to apply increasingly stressful handling practices in an effort to maintain constant delivery of pigs to the stunner at rates of (or above) 1,000 pigs per hour. Rough handling of pigs in the stunning chute during the last few minutes before exsanguination will increase the occurrence of PSE meat even in pigs resistant to the stress gene (Tarrant, 1989). Use of two stunning systems which operate at 500 pigs per hour will greatly reduce problems associated with meat quality and animal welfare. Appropriate design of restraining chutes (a side-by-side loading chute as described in Pre-transport handling at the production site) will assist proper delivery of pigs to the stunner.

Rendering the animal insensible

Under the Humane Methods of Slaughter Act of 1978, all animals slaughtered under federal inspection must be rendered insensible prior to exsanguination. Electrical stunning is the most common method of stunning slaughter pigs in the United States. With electric stunning, sufficient amperage must pass through the pigs brain to induce an epileptic seizure resulting in instantaneous, painless, unconsciousness of the pig. Meat packers should use amperage, voltage, and frequency settings that will reliably induce insensibility. When electric stunning is done correctly, the animal will feel nothing. Insufficient amperage or poor current contact may paralyze the pig, however, the animal will not be insensible and will experience the feeling of a large electric shock and heart attack symptoms (Grandin, 1998e). To insure proper, humane stunning of pigs and to avoid potential meat quality problems, Grandin (1994) recommends use of a constant amperage power supply where the amperage is a constant 1.25 amps and the voltage varies with pig resistance. A minimum of 300 volts should be used for larger pigs and slightly lower voltages for lighter hogs. Grandin (1994) notes that packing plants should never reduce stunning amperage (for example, 0.5 amps) in an attempt to reduce blood splash because low amperages (or frequencies over 200 Hz) fail to induce instantaneous unconsciousness (Hoenderken, 1983).

Stunning and meat quality

A review of the effect of stunning on carcass and meat quality is provided by Gregory (1987). Carcass and meat quality defects influenced by stunning include bone fractures, blood splash, bruising, inadequate bleeding, and PSE meat. Stunning pigs with high voltages may result in broken shoulder blades if the animal is not supported off the floor. Hemorrhage associated with broken bones will require trimming, resulting in more time on the kill floor (at an elevated temperature) which is detrimental to pork quality. Shattered scapulas can be avoided either by elevating the animal from the floor prior to stunning (via a restraining conveyor) or by reducing the length of time current is applied to the animal (2 seconds at 320 volts; Braathen and Johansen, 1984). High stunning currents administered to restrained pigs have also resulted in fractured thoracic vertebra and pelvis (Gregory, 1987).

Blood splash (ecchymosis) occurs when the physiological stress of stunning induces capillary rupture resulting in the appearance of small spots or large clots of blood in the lean tissue. High voltage stunning in a restraining conveyor and captive bolt stunning lead to intense muscular contraction and a high incidence of blood splash (Burson et al., 1983; Larsen, 1983). A study by van der Wal (1978) reported that stimuli from the adrenal medulla continued after captive bolt stunning, increasing blood catecholamine concentrations and violent muscle contractions. These actions increase lactate concentrations in the blood, cause capillary hemorrhage (blood splash), and (or) carcass bruising. Gregory (1987) summarized that high voltage head to back stunning (240V at 50Hz) gave a reduction in the severity of blood splash compared to low voltage, high frequency (97V at 1700Hz) or low voltage, low frequency (80-125V at 50Hz) head only stunning. Larsen (1982) found less blood splash in carcasses from pigs stunned at 700V compared to those stunned at 300V. In these studies, the higher voltage could have been sufficient to induce cardiac arrest, stopping the heart altogether, eliminating the means (pump) to force blood through the ruptured blood vessels, thus generating a lower occurrence of blood splash.

The operator of the stunning equipment must be attentive and well trained. The operator should keep the contacts clean and watch for worn cords and switches. The operator should avoid sliding the stunning wand over the animal during stun. Grandin (1994) refers to this as "double stunning" because it causes the pig to contract more than once. Double stunning can also occur if the electricity is turned on before the applicator is pressed firmly against the pig.

Reducing the amount of time between stunning and sticking minimizes the period when increased blood pressure provides more force for blood to leak through ruptured blood vessels (Burson et al. 1983). Many U.S. slaughter plants apply a horizontal stick before the pig is shackled as a means of reducing the stun to stick interval. This will improve meat quality by reducing bruising and prevent struggling after stunning (Eilert, 1997). Grandin (1994) recommends bleeding pigs within 10 seconds after stunning (Burson et al, 1983 advise 10 to 20 s) to minimize blood splash. Exsanguination as soon as possible after stunning is an important practice of humane slaughter, reducing the possibility an animal will regain consciousness during the initial stages of slaughter (Grandin, 1994). Wotton and Gregory (1986) found that after severing the brachiocephalic trunk and anterior vena cava, it took (on average) 18 seconds to induce a loss of brain function in 55kg (avg. weight) pigs. Hoenderken (1983) reported that an experienced sticker could induce an isoelectric elecrocorticogram in 12-20 seconds. A pig that is stuck incorrectly may take 55 to 60 seconds to lose responsiveness (Wotton and Gregory, 1986).

Postmortem Temperature and pH

Classic work by Penny (1969) reported that postmortem rate of pH decline of PSE meat is approximately three times faster than normal, producing an intramuscular pH below six before the carcass temperature has time to cool below 37°C. The combination of low pH and high temperature results in muscle protein denaturation which leads to the reduced water holding capacity associated with PSE meat. The net electrical charge of myosin becomes minimal as the pH of meat nears the isoelectric point (pI) of myosin (pI=5.4) resulting in a low water binding capacity (Wismer-Pedersen, 1987). Lean tissue possessing a low water holding capacity is detrimental to the meat processing industry as approximately 75% of all pork meat is sold in the processed form (Cannon et al., 1995). Eilert (1997) suggested that an ideal plant would have the carcasses off of the slaughter floor within 20-25 min. The plant should do everything possible to reduce the length of time from stunning to chilling.

Offer (1991) generated a model for the formation of PSE meat reporting that the normal rate of pH fall in pork carcasses is about 0.01 pH units/min, corresponding to a rigor time of about 150 min (assuming a linear pH decline). A marginal case of PSE (corresponding to a pH at 45 min £ 6; Penny, 1969) would have a rate of pH decline of 0.02 units/min and an extreme case (achieving rigor in 15min postmortem) would have a rate of decline of 0.1 pH units per min. Prerigor muscle is metabolically active generating heat from the conversion of glycogen to lactic acid and the hydrolysis of creatine phosphate and ATP (Essen-Gustavsson, 1993; Swatland, 1993). Prolonged contractile activity results in localized accumulation of heat, CO_2, and lactic acid which results in a higher than normal body temperature. At a very high rate of pH decline (> 0.067 pH units/min) the muscle temperature initially rises before falling as a consequence of this metabolic activity. Offer (1991) proposed that metabolic heat was proportional to the pH fall at a rate of 2°C/pH unit and found that more rapid chilling always decreased the amount of myosin denatured at rigor. Protein denaturation in a carcass with a relatively moderate pH decline and a prolonged period of temperature abuse may be greater than in a carcass experiencing more severe conditions (elevated temperature and rapid pH decline) for a shorter period duration. Offer (1991) reported that increasing the length of time to reach carcass half-cooling from 100-700min produced an 18 fold increase in the fraction of denatured myosin when the rate of pH decline occurred at the normal rate of 0.01 pH units/min while a rate of pH decline of 0.02 units/min (representing a marginal case of PSE) would increase the fraction of denatured myosin 7 fold. At a rate of pH fall of 0.1 units/min (severe PSE), this same extreme temperature abuse would only increase the fraction of denatured myosin a factor of 1.7. It is apparent that more rapid chilling has greater benefits for carcasses experiencing slower and intermediate pH declines.

Temperature and pH of a pork carcass may vary from the right to left side. According to van der Wal et al. (1995), initial temperature of the right biceps femoris and semimembranosus muscles were significantly higher than their counterparts on the left side yet longissimus lumborum and subcutaneous temperature remained equal. The pH of the right semimembranosus was also found to be significantly lower within the right ham. These differences in temperature and pH were maintained till at least 45min postmortem. The authors discovered that the right and left differences in temperature and pH were a consequence of shackling the carcass on the right hind leg immediately following stunning. Care should be exercised in the design of pork quality experiments to include side randomization or to randomize right and left leg shackling.

Scalding of Carcasses

Tarrant (1993) concluded that factors affecting carcass temperature or delay chilling (such as ante-mortem handling, air temperature on the slaughter floor, and carcass scalding) require specific attention. In their study on the affect of scalding on subcutaneous and deep ham temperatures, van der Wal et al (1993) found that scalding carcasses at 60°C for at least 5.5-7.5 minutes gave satisfactory dehairing results with the exception of carcasses of pigs slaughtered in autumn (during hard hair season). The latter required 9min scalding to be dehaired sufficiently. Van der Wal (1993) reported that heat was absorbed superficially during scalding and can be removed quickly when scalding and scorching have finished. The group discovered that even an extremely long scalding time of 19 minutes only increased ham muscle temperature (5cm below the skin in the biceps femoris) approximately 1°C. The authors concluded that scalding pork carcasses for 9 minutes will not affect pork quality however, even a small increase of muscle temperature means that no heat was removed from the tissue over the time this increase was maintained.

Monin et al. (1995) tested differences in fresh pork quality as a result of pigs dehaired by scalding or singeing. During the process of singeing, the pigs body is passed through a series of gas burners before they are scraped and brushed (polished) in the usual way. The authors found no difference in 30min post-mortem temperature or pH between the two dehairing methods. The singed carcasses showed slightly higher ultimate pH (20h PM) in the semimembranosus and aductor and lower reflectance and higher water holding capacity in the biceps femoris. Monin et al. (1995) concluded that meat quality was slightly better in singed carcasses but differences in meat quality between the dehairing methods was insignificant.

Eilert (1997) suggested that skinning of pork carcasses will improve meat quality in the sense that it will shorten the time prior to evisceration. Rapid emptying of the peritoneal cavity results in elimination of the visceral heat and more rapid carcass temperature decline and removal of the skin will result in more rapid transmittance of heat from the interior musculature. Troeger (1987) found the average temperature of skinned versus scalded carcasses was approximately 1°C cooler in the loin and ham at 30min postmortem. At 1h postmortem, the average pH of the biceps femoris of skinned carcasses was 6.23 and scalded carcasses 5.90, however, no difference was observed for ultimate pH. Skinned carcasses had a lower cooler shrink loss (1.8% versus 2.6%) compared to scalded carcasses. No differences were observed for 24h light intensity of the longissimus lumborum, however after 4 days of vacuum packaging, the loins from skinned carcasses were significantly darker.

Carcass Chilling

Grandin (1994) believes that handling practices account for 10 to 15 % of the variation in PSE meat and chilling practices account for 20 to 40%. Blast chilling of carcasses with forced air at temperatures well below freezing has been used as a means of rapidly reducing intramuscular temperature to reduce the occurrence of PSE meat. Eilert (1997) stated that more rapid chilling procedures will not prevent PSE because, in severe cases of PSE, the damage has already occurred before the carcasses enter the cooler. As stated in the previous section, more rapid chilling has greater benefits for improving quality in carcasses experiencing slow and intermediate pH declines.

Rapid chilling of pork muscle may generate a toughening effect through muscle shortening (cold shortening). Jones et al. (1993) found no significant differences in mean Warner-Bratzler shear force values for blast chilled versus conventional chilled carcasses. However, blast chill treatments did increase the variability in shear values. The standard errors for shear values of blast chilled carcasses were 2-3 times greater than those of carcasses spray chilled at conventional chilling rates.

Jones et al. (1991) submerged pork sides in liquid nitrogen at 40min postmortem as an extreme method of removing carcass heat. Carcass sides were completely submerged for 1-3min. The group found no significant treatment differences in meat color, protein solubility, or sarcomere length. Warner-Bratzler shear force was significantly increased in chops obtained from sides chilled by liquid nitrogen for one minute but surprisingly, no significant difference was noted between conventional chill and 3min submersion in liquid nitrogen. A second study revealed that liquid nitrogen chilling had no effect on meat color, drip loss, protein solubility, sarcomere length, or shear value. Jones et al (1993) noted that blast chilling can induce cold shortening of the muscles if temperatures fall below 10°C when the muscle pH is above 6.0. Cold shortening may be more of problem when heavy muscled, lean carcasses are blast chilled. Less external fat will allow a more rapid release of carcass heat and a greater susceptibility to muscle cold shortening. McFarlane and Unruh (1996) reported blast chilled pork carcasses (1hr at -25°C and then chilled 23hr at 1°C) tended to have a higher 24h pH than carcasses chilled in the conventional manner (24h at 1°C). Increasing the chilling rate also reduced the combined percentage of purge and cooking loss without negatively affecting Warner-Bratzler shear force (WBS). The blast chilling process did not induce cold toughening and (or) decrease tenderness even though the carcasses used in this study were very lean possessing minimal external fat (10^{th} rib fat depth=1.34 cm).

Van der Wal et al. (1995) tested 3 different chilling regimes. A moderate conventional chilling regime (0-4°C; air velocity 0.5m/s) served as a control and two forced chilling regimes; moderate rapid chilling (-5°C) for 2h or ultra rapid chilling (-30°C) for 30min with a downward air velocity of 1, 2, or 4 m/s. After forced chilling, the carcasses were delivered to the cooler for equalization chilling (0-4°C, 0.5 m/s) until 24h postmortem. The authors found a significant effect of forced chilling on muscle temperature compared to control carcass halves. The internal muscle temperatures after prolonged (120min) moderate (-5°C) chilling were lower compared to ultra rapid (30min) chilling (-30°C). An increase in air velocity resulted in a reduction of longissimus lumborum and semimembranosus temperature but not biceps femoris (believed to be due to increased external fat covering this muscle). Ultra rapid chilling generated less carcass shrink compared to conventional and moderate forced chilling, however, meat quality parameters (with the acceptation of variables related to tenderness) were not affected by chilling regime. Taylor et al. (1995) found no difference in quality associated with different cooling rates. Jones et al. (1993) reported that carcasses blast chilled for 3h (-20 or -40°C with an air velocity of 5m/s) had longissimus thoracis muscles that were darker, had a higher protein solubility, less drip loss, shorter sarcomere lengths, and higher Warner-Bratzler shear force values compared to conventional chilling (1°C, air velocity of 1m/s and forty, 60s spray chill cycles set at 15min intervals). Furthermore, muscle color was darker in the longissimus thoracis and semimembranosus muscles of carcasses blast chilled for 3h at -40°C compared to the conventional spray-chill treatment. The authors note that these color differences would be “on the borderline of detection” using subjective visual appraisal. In another study, Jeremiah et al. (1992) reported that carcass sides blast chilled for 1h (-20 or -40°C) were more tender and rated higher in overall palatability than sides blast-chilled for 2 or 3h. The authors were quick to clarify that the magnitude of these differences had limited practical significance as the palatability differences between short and extreme (-40°C for 3h) blast-chill times were inconsequential.

Accelerated carcass chilling will most often have little or no significant effect on final lactic acid concentrations in the muscle, however, it will reduce the rate of lactic acid formation (Wismer-Pedersen, 1987).

Rapid chilling of pork carcasses will most always reduce carcass cooler shrink, however, the effects on pork quality parameters are limited and conflicting in the literature.

Conclusions

The term welfare is relevant only when an animal is alive but death during handling and transport is usually preceded by a period of poor welfare (Broom, 1993). Improving the welfare of market pigs will generate less stress on the pig and give less stress to the individuals handling these pigs. Handling of pigs greatly improved when the United States entered the Japanese export trade. Grandin (1993) declares that when slaughter plant managers watched a Japanese grader reject up to 40% of their pork loins due to PSE a strong economic incentive was created to improve handling. Simple changes in handling procedures such as showering and resting pigs enabled 10% more pork to be exported to Japan (Grandin, 1993). Preslaughter treatments are much easier to control than the postmortem biochemical reactions triggered by stressful handling (Honkavaara, 1989c). Attention to the critical points outlined in this review is necessary to produce a high quality food product and make pork the meat of choice in the next millennium.

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Information developed for the Pork Information Gateway, a project of the U.S. Pork Center of Excellence supported fully by USDA/Agricultural Research Service, USDA/Cooperative State Research, Education, and Extension Service, Pork Checkoff, NPPC, state pork associations from Iowa, Kentucky, Missouri, Mississippi, Tennessee, Pennsylvania, and Utah, and the Extension Services from several cooperating Land-Grant Institutions including Iowa State University, North Carolina State University, University of Minnesota, University of Illinois, University of Missouri, University of Nebraska, Purdue University, The Ohio State University, South Dakota State University, Kansas State University, Michigan State University, University of Wisconsin, Texas A & M University, Virginia Tech University, University of Tennessee, North Dakota State University, University of Georgia, University of Arkansas, and Colorado State University.