PSE (pale, soft, exudative) Pork : The Causes and Solutions* - Review -

Y. B. Lee[1] and Y. I. Choi[2]
College of Agricultural and Environmental Sciences, University of California, Davis, CA 95616-8521, USA

ABSTRACT : Intensive selection for muscle development and against fat deposition in pigs during the last 50 years has contributed to the increased incidence of porcine stress syndrome (PSS) and pale soft exudative pork (PSE). Genetics, nutrition and management, preslaughter animal handling, stunning, dehairing and carcass chilling influence the incidence and magnitude of the PSE condition. The normal incidence of PSE has been reported to range from 10 to 30%, but in some isolated instances is up to 60%. The elimination of halothane-positive pigs in breeding programs has reduced PSS and PSE. Further improvements in meat quality by terminal sire evaluation and selection can be achieved within halothane-negative populations because around 20% of the variation in meat color and water binding capacity seems to be genetically related. Pre-slaughter handling on the farm, during transit to the packing plant and at the packing plant can greatly influence the meat quality, contributing 10 to 25% of the variation. An effective stunning method, skinning instead of scalding/dehairing and rapid post-slaughter chilling further reduce the incidence of PSE pork. In addition to proper care and handling a carcass-merit based marketing system, that reflected the value differential between desirable and undesirable meat quality in the pricing system for pigs, would provide a great incentive to change pork production systems in order to improve meat quality, thus improving the image and usefulness of pork as food.
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Key Words : PSE, PSS, Pre-Slaughter Handling, Post-Slaughter Chilling, Meat Quality

INTRODUCTION

Of most importance to more than 60% of consumers standing in front of the meat counter is how the product looks. Customers buy pork on visual appearance and will not buy a pale and wet product (Young, 1996). An important quality defect in pigmeat is termed pale, soft and exudative (PSE). The PSE condition is characterized by muscle that is pale in color, has a soft texture, and is exudative or watery. PSE pork quickly became recognized as undesirable not only because of its unattractive visual appearance but also because of shrinkage due to drip, lowered processing yields, increased cooking losses, and reduced juiciness.

There is now clear evidence (Ollivier et al., 1991) that intensive selection for muscle development and against fat deposition in pigs during the last 50 years has contributed to the increased incidence of PSS (porcine stress syndrome) and PSE pork. Genetics, production systems, environment, and handling of both the live animal and its carcass before and after slaughter can influence the incidence and magnitude of the PSE condition. The normal rate of incidence was reported to range from 10% to 30% but in some isolated cases is up to 60% (Kauffman et al., 1992; McKeith et al., 1994; Santos et al., 1994; Valenzuela et al., 1995). This paper reviews the causes of PSE and means to minimize the occurrence of this defect in pork quality.

[1] Address reprint request to Y. B. Lee.

[2] Dept. of Animal Science, College of Agriculture, Chungbuk National University, Korea.

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GENETICS

Porcine stress syndrome (PSS) and the associated deleterious PSE carcass traits have plagued the swine industry for many years. When a stress response is triggered, there is a marked increase in aerobic and anaerobic metabolism, rates of production by the animal of heat, CO_2 and lactic acid are high, and there is contracture of skeletal muscle. The syndrome is also triggered following exposure of animals to volatile halogenated anesthetics, such as halothane (Hall et al., 1980). PSS is an inherited syndrome, transmitted by a single autosomal recessive gene. This gene has been variously called the stress gene, halothane or hal gene, and PSS gene (Hall et al., 1980). Halothane-positive pigs are homozygous recessive (nn) for a mutation of the ryanodine receptor (RYR) gene responsible for malignant hyperthermia or stress syndrome in pigs (Fujii et al., 1991; MacLennan and Phillips, 1992). It is well documented that in its homozygous mutant form (nn), the stress gene can have devastating effects. If physical stress does not cause death, it is almost (>80%) sure to cause PSE meat under even the best handling and processing conditions. Recently, a molecular genetic test for halothane gene which enables the identification of carrier as well as homozygous recessive pigs has been developed to be used to selectively remove the PSS gene from breeding stocks (McLaren and Schultz, 1992).

In a recent survey by the University of Minnesota and Universal Pig Genes, Inc. (Christian, 1995), barrows and gilts were classified by the stress genotype using the halothane DNA probe test. Of the 3,261 pigs examined, seven (0.2%) were mutant pigs (nn), 391 (12%) were mutant-carrier pigs (Nn) and 2,863 (87.8%)

were normal (NN). Pommier et al. (1992) reported a similar occurrence, 14.9%, of Nn pigs. Since the incidence of PSE meat due to Nn pigs is approximately 30%, the economic contribution of the halothane gene to the PSE problem is only about 4.5% (i.e., 14.9% x 30.0%). If the frequency of the mutant gene in the population were greater, however, the economic loss would be greater due to death in transit or PSE carcasses.

Despite the incidence of PSE meat, Nn pigs exhibit 15 g/d more lean tissue growth, 0.9% greater carcass yield and 1.5% higher lean content in the carcass, compared with normal pigs (McLaren and Schultz, 1992). This raises the question: is it more profitable to produce all heterozygous pigs or all normal pigs? Christian (1995) argued against the production of Nn pigs by quoting the survey data. Differences between NN and Nn groups were essentially zero for growth rate and backfat thickness, but the Nn group had a 0.4% higher dressing percentage and a 1.9 cm^2 advantage in loin eye area which contributed to their slight advantage in the rate of lean gain. The Nn pigs, however, produced paler and less tender meat that had less intramuscular fat and a greater drip loss.

Table 1. Pork loins failing minimum muscle quality standards

Criteria	Stress genotype	
	Normal (NN) 2,863 pigs, %	Carrier (Nn) 391 pigs, %
Very pale color	4.2	15.9
Very dark color	10.6	7.7
Devoid marbling	1.3	4.6
Firmness (soft)	10.4	27.9
Drip loss (exudative)	2.9	6.9
Overall rating	22.5	36.8

As shown in table 1, a higher percentage (36.8%) of loin from Nn animals were extremely pale, were devoid of marbling, were excessively soft and produced excessive exudate. Whereas 22.5% of the loins from animals of normal genotype were considered unacceptable, the frequency was nearly twice as high among carriers. Hence, because the gene offers only a minimal increase in lean percentage while increasing significantly PSE frequency, it is clearly evident that the gene should be eliminated from the pig population.

Heritability estimates within populations not containing the halothane gene suggest that meat quality can be improved by selection. Trials at the Dutch Research Institute for Animal Production indicated that around 20% (10-30% range) of the variations in meat pH and color and water binding capacity of halothane negative pigs seemed to be genetically related and thus selection to avoid PSE-prone stock and to avoid DFD (dark, firm, dry) lines appeared to be practicable (Vries et al., 1994).

Another quality concern that has recently been brought to the attention of the pork industry relates to the low ultimate pH associated with the Hampshire effect. The ultimate pH is lower than the norm; however, pH decline is normal. The Rendement Napole (RN) gene has been identified as the gene responsible for the higher muscle glycolytic potential and lower ultimate pH in hogs from Hampshire ancestry (Monin et al., 1987). In addition, water holding capacity and cooking yield was lower for meat from hogs expressing the RN gene (Enfalt et al., 1994), which may need to be excluded from terminal sires.

The Terminal Sire Line National Genetic Evaluation Program (NGEP) sponsored by National Pork Producers Council of USA was designed to conduct a comprehensive study to provide unbiased results of genetic evaluation comparing seedstock populations for crossbreeding use. The extensive program provides unbiased and highly accurate sire line information for over 40 traits, genetic heritabilities and correlations among these traits, effects of the halothane gene on these traits, and how to use the results to select seedstock. Meat quality traits included color score, marbling score, firmness score, Minolta reflectance and Hunter score, ultimate pH, protein solubility, drip loss, water holding capacity, dry-matter content, total lipid content, cholesterol content, cooking loss, cooked moisture content, instron tenderness, juiciness sensory score, tenderness sensory score, chewiness sensory score, and flavor sensory score.

In Korea, the study of PSE incidence by molecular genetic test has not been fully investigated. According to Park et al. (1997), the PSS gene frequency based on the PCR-RFLP (Polymerase Chain Reaction-Restriction Fragment Length Polymorphism) test results from 695 Korean pigs was 0.106 in Large Yorkshires, 0.274 in Landraces and 0.021 in Durocs. These frequency estimates are similar to those made in other countries for Large Yorkshires and Durocs, but are higher for Landraces. Data on PSE incidence for five different swine breeds (included 1 hybrid) raised in Korea are shown in table 2 (Park, 1980).

Table 2. Incidence of PSE pork for different swine breeds*

Item \ Breed	L	H	L·H	D	B	Total
(Female)						
Survey No	426	24	169	13	389	1,021
Incidence No	163	12	62	4	117	358
Incidence %	38.3	50.0	36.7	30.8	30.1	35.1
(Male)						
Survey No	695	24	226	6	298	1,249
Incidence No	215	17	80	2	64	378
Incidence %	30.9	70.8	35.4	33.3	21.5	30.3
Incidence (by breed)	33.7	60.4	35.9	31.6	26.3	

* L=Landrace, H=Hampshire, L·H=Landrace × Hampshire, D=Duroc, B=Berkshire.

Regardless of breed, females showed a higher PSE incidence than males (35.1% vs 30.3%). Among breeds, Hampshire showed the highest incidence (60.4%) and the Berkshire showed the lowest (26.3%). The hybrid (Landrace × Hampshire) showed a slightly higher incidence (35.9%) compared to that in Landrace (33.7%) or Duroc (31.6%).

Further evidence on the effect of sex on PSE incidence is shown in table 3 (Park et al., 1985). The higher incidence in females (32.3% vs 25.3%) appeared to result from the differences between sexes in fat deposition. In addition, Choi et al. (1998) reported that barrows showed a higher PSE incidence than gilts (34.6% vs 29.7%).

Table 3. Incidence of PSE pork by sex

Sex	Survey	Incidence	
	No.	No.	%
Male	2,595	657	25.3
Female	2,628	850	32.3

NUTRITION AND MANAGEMENT

As lean meat quality is mainly affected by genetic factors, the effects of feeding have been considered to be minor. Nevertheless, recent observations seem to indicate some influence of nutritional factors on the postmortem characteristics of muscle tissue and meat quality. Henry et al. (1992) observed that a dietary deficiency in tryptophan, associated with a decreased synthesis of serotonin in the hypothalamus, increased muscle pH compared to a control tryptophan-adequate diet. This effect was only observed in females. On the other hand, Adeola and Ball (1992) reported that a dietary overload of tryptophan in growing-finishing pigs was associated with a reduced stress response and exerted a positive effect in reducing the severity of PSE pork. Anon (1991) also reported that increasing levels of tryptophan in diets resulted in a reduction in aggressive behavior. Supplementation with an extra 0.5% tryptophan for 5 days prior to slaughter led to reduced incidence of PSE from 9 to 6%. More recent results (Henry and Seve, 1993) showed that ultimate pH in loin and ham was slightly but significantly lower at the optimum level of tryptophan (0.17%) than at a level either higher or lower than the requirement. Undoubtedly, further research is necessary to elucidate the possible relationship between nutritional factors and meat quality.

Another nutritional factor, which is implicated in meat quality, is vitamin E. Dietary supplementation of vitamin E (1000 mg/kg diet) for 46 days significantly reduced excess release of Ca^{++} and prevented formation of PSE carcasses. The improved pork quality was attributed to the ability of vitamin E to stabilize membrane integrity (Buckley et al., 1995).

Many of the excitable animals are hybrids that have been reared in confinement (Grandin, 1993). In confinement buildings, producers must provide hogs with more environmental stimulation. Producers who walked in the fattening pens every day produced calmer pigs that were easier to drive. This resulted in less stress during handling at the slaughter plant. To have the maximum calming effect, the producer must walk inside every fattening pen every day (Grandin, 1989; Pedersen et al., 1993). Playing a radio in the building can help pigs to become accustomed to strange noises. Observations have also indicated that raising finishing pigs on plastic or metal floors produces animals that are hard to drive because they do not know how to walk on concrete. Plastic or metal floors work well for young pigs, but during the final finishing phase, confinement hogs should be raised on a concrete surface.

In addition to nutrition or management factors, market weight and fat thickness may also influence the incidence of PSE. As shown in table 4 (Park et al., 1985), the average PSE incidence for 1,726 pigs was 31.2%, and pigs with market weights in the range of 86-105 kg showed a lower PSE incidence than lighter or heavier pigs. In particular, the incidence was lowest in pigs of 86-95 kg market weight (23.3%), and was greatest in those over 106 kg (72.3%). This result is similar to those of Choi et al. (1998), shown in table 5, in which pigs of over 110 kg market weight showed the greatest incidence.

Table 4. Incidence of PSE pork by market weight

Item	Market weight (kg)					Total
	65~75	76~85	86~95	96~105	>106	
Survey No	54	54	829	457	177	1,726
Incidence No	20	20	193	118	128	538
Incidence %	37.0	37.0	23.3	25.8	72.3	31.2

Table 5. Incidence of PSE pork by market weight

Market weight (kg)	PSE Incidence (%)
90~100	25.0
100~110	31.6
110~120	42.1
Over 120	45.5

Park et al. (1985) also investigated the effects on PSE incidence in Korea of sex and backfat thickness; the results are shown in table 6. Overall, females showed a 7.7% higher PSE than males, and carcasses of females with over 2.1 cm backfat thickness showed a higher PSE compared to those with less backfat. However, backfat thickness was not related to PSE incidence in males.

Table 6. Incidence of PSE pork by backfat thickness

Backfat thickness (cm)	Female			Male		
	Survey	PSE		Survey	PSE	
	No.	No.	%	No.	No.	%
2.0>	34	14	41.2	56	23	41.1
2.1~3.0	110	55	50.0	29	11	37.9
3.0<	58	27	46.6	18	7	38.9
Total	202	96	47.5	103	41	39.8

PRESLAUGHTER HANDLING AND TRANSPORTATION

No stress factor causes a wider range of effects than does the environmental temperature. According to Forrest et al. (1968), high environmental temperatures or large fluctuations in temperature result in a high incidence of PSE pork which occurs mainly during the holding period prior to slaughter. When temperatures become higher than those to which pigs are accustomed, muscle temperature is likely to rise because the pig is unable to dissipate heat rapidly enough. High body temperatures will speed up the respiration rate and metabolic reactions, increasing the likelihood of PSE (Galloway et al., 1973).

The study of PSE incidence in Korea by month during a year is shown in table 7 (Park et al., 1985). The incidence was lowest in January (22.0%) and February (30.1%), months with low environmental temperatures. As environmental temperatures increased, so too did PSE incidence. It was higher in July and August and greatest in September (48.7%).

Nishio (1976) in Japan surveyed variation in PSE incidence with season of year. The incidences in spring, summer, fall and winter were 34.2%, 46.0%, 41.3% and 26.4%, respectively, a result similar to that found in Korea.

Table 7. Incidence of PSE pork by months

Month	Survey	Incidence	
	No.	No.	%
1	482	106	22.0
2	586	176	30.1
3	404	131	32.4
4	1,128	447	39.6
5	844	229	35.4
6	1,088	446	41.1
7	977	413	42.3
8	1,538	680	44.2
9	1,278	622	48.7
10	1,097	402	36.6
11	779	260	33.4
12	732	243	33.2
Total	10,933	4,225	38.6

The stress placed on an animal prior to slaughter directly influences meat quality. Various handling practices can be used to reduce this stress or to alter the metabolism of the animal prior to slaughter.

The most important reasons for withdrawing feed from pigs before transport are to lower the mortality rate during transport (Williams, 1985) and to reduce problems at the abbatoir associated with spillage of gut contents and waste disposal. It was found that withdrawal of feed before pigs were loaded for transport reduced the incidence of PSE pork and increased the final pH of meat (Eikelenboom et al., 1991). There was less PSE meat after a fasting period of 24 h before transportation and the ultimate pH in loin and ham was higher than in the non-fasted group. On the other hand, losses of carcass yield due to fasting will occur when the total time from feeding the last meal to slaughter goes over 18 h. The present recommendation in Denmark and in the Netherlands (Nielsen, 1982; Eikelenboom, 1988) is to give pigs their last feed in the afternoon or evening before collection the following morning.

The effects of feeding before transportation and holding period on the PSE incidence in Korea are shown in table 8 (National Livestock Research Institute, 1997). Feeding before transportation increased the incidence of PSE pork regardless of holding period and, particularly, the PSE incidence was higher when pigs fed before transportation were directly slaughtered without a holding period (13.1%). The incidence was not high, however, when pigs fed before transportation were slaughtered after 4h or 24h holding periods (4.0% or 2.5%).

Driving pigs from the fattening pen to the truck and making them mount the loading ramp and enter the truck are stressful operations (Van Putten, 1982). The structural design of fattening pens, doors, races and collecting pens are important for moving pigs easily with minimum stress. Pigs also move more easily from dark to light, providing the light is not intense enough to blind them, in which case they baulk. The lamp must illuminate the floor and not shine into the eyes of the approaching animals. Small wooden boards instead of electric prods are recommended to drive animals.

Table 8. Incidence of PSE pork by feeding and holding period

Feeding before transportation	Holding period(hrs)	Incidence(%)
No feeding	0	7.8
	4	2.9
	24	1.9
Feeding	0	13.1
	4	4.0
	24	2.5

Mixing animals during collection, transport and lairage caused a great stress to the animals, resulting in lower pH, higher weight loss and higher fighting damage than non-mixed groups. Incidence of both PSE and DFD was higher in a mixed group (19.1% PSE, 7.0% DFD) than in a non-mixed group (13.0% and 4.0%, respectively) studied by Karlsson and Lundstroem (1992). If animals from different social groups have to be mixed, this should take place at loading time; pigs fight less on a moving truck (MLC, 1986).

Loading facilities are often very poor on pig farms. The maximum recommended angle for a permanent pig ramp is 20° and if space permits, a 15° angle is better. Livestock move more easily up and down stair-step ramps than cleated ramps. Stair-steps with a 7 cm rise and a 20 cm tread width work well with pigs (Grandin, 1988). On wooden ramps, the cleats should have a 20 cm space between them. A loading ramp should be wide enough to allow two or three pigs to climb it together. A very good loading system is the hydraulic tailgate lift capable of holding groups of 8-10 pigs. A tailgate lift is particularly useful on multideck trucks. It reduces considerably the amount of stress at loading.

The duration of transport can also have an influence on meat quality. A number of studies prove that immediate slaughter after a short transportation time (< 1 h) leads to more carcasses showing PSE conditions than after a longer time of transport (Fortin, 1989). The reason may be that a longer transportation time leads to a calming phase, which normalizes metabolic disturbances caused by loading. When the transit time is long, it is necessary to implement practices to minimize death loss.

Loading density during transport has an effect on death loss, as well as the incidence of injury and PSE meat. It is important to allow enough room in the truck for each individual pig, particularly in hot humid weather, to reduce stress-related poor quality pork. The Meat and Livestock Commission in the United Kingdom has recommended a space allowance of 0.4-0.5 m^2 per pig during transport (Guise and Warriss, 1989). In Germany, 0.5 m^2 per 110 kg porker, which allows pigs to lie down, is recommended. The optimum loading densities for different types of truck recommended in Korea are shown in table 9 (National Livestock Research Institute, 1997).

Table 9. Optimum loading density during transportion by truck

Type of truck		Loading room size	Loading density (head)* (Pig of 100 kg
Ton	Type	(m^2)	live weight)
5~4.5	Extra long	13.1	37
	Long	11.2	32
	Short	9.8	27
4~3.5	Extra long	10.9	31
	Long	9.4	26
2.5	-	8.4	24
1	-	5.0	14

* Optimum loading density (0.35 m^2/100 kg).

Grandin (1994) recommended a 2-4 h resting period after arrival for hogs prior to slaughter to help reduce the incidence of PSE meat. Honkavaara (1989) conducted a study to evaluate environmental conditions for holding pigs prior to slaughter and concluded that optimum ranges for temperature, humidity, and holding periods are 15-18°C, 59-65% RH and 3-5 h, respectively. The optimum holding conditions resulted in a higher ultimate pH (5.9-6.4) and a lower incidence of PSE pork.

Transportation time or holding period prior to slaughter could be determined by several factors such as distance from farm to packing plant or time needed for slaughter etc. However, optimum transportation time and holding period in Korea were recommended as 1-2 h and 6 h, respectively. A study by Choi et al. (1998) showed that PSE incidence increased with increasing transportation time (table 10).

Table 10. Incidence of PSE pork by transportation time

Transportation time	PSE incidence(%)
less than 30 min	29.5
30~60 min	32.5
over 60 min	40.0

Holding pigs in a stockyard prior to slaughter provides an opportunity for rest, and recovery from stress. When the holding period was not too short, stress resistant pigs did not produce abnormal meat, but stress susceptible pigs need a longer holding period so that they may not produce PSE pork.

Results of a study in Korea of variation in PSE incidence with length of holding period, summarized in table 11 (Park, 1980), provides guidance on the appropriate duration of these periods. Pigs held 11-15 h prior to slaughter showed the lowest PSE (16.8%), but pigs held for a shorter or longer time showed higher PSE (20.9% or 19.1%, respectively).

The practice of spraying pigs with cold water is fairly common. Showering has been recommended for several reasons: 1) to cool and clean the pigs after transport, 2) to reduce aggression and to quieten the animals, 3) to facilitate electrical stunning by lowering skin impedance, and 4) to reduce bacterial contamination of the water in the scalding tank. Accelerated cooling of excess body heat and reduced physical activity (quietening) contribute to the reduced incidence of PSE pork.

Table 11. Incidence of PSE pork by holding period

Holding period (hrs)	Survey No.	Incidence No.	Incidence %
7 ~ 10	67	14	20.9
11 ~ 15	179	30	16.8
16 ~ 20	282	54	19.1
21 ~ 24	81	21	25.9

Moving pigs forward to the stunning point and the stunning process itself may be the two most important sources of stress when slaughtering pigs (Troeger and Woltersdorf, 1989). Rough handling at the plant causes pigs to overheat and increases PSE. The last 15 minutes in the stunning race is very critical, and pork quality can be ruined even in the last five minutes. Handlers need to be trained to move pigs quietly in small groups; the use of electric prods should be discouraged.

IMMOBILIZATION

Stunning must be conducted humanely and must ensure that optimal muscle quality is attained. Common stunning techniques are electrical, captive bolt and carbon dioxide. All methods cause some stress to the animal but there is variation between them in the magnitude of the effect (Carr, 1985).

Electrical stunning is currently the most widely used technique in the U.S. High voltage electrical stunning (more than 240 volts) has been preferred because the animal is rendered insensible quickly and remains insensible during bleeding. To be effective, a minimum current of 1.25 amps through the brain of the pigs is necessary, and to guarantee this in all pigs the average current during stunning needs to be higher. Troeger and Woltersdorf (1990) recommended the use of 250 V with the necessary amperage to achieve complete stunning in a short period of time. The minimum current of 1.25 amps will effectively stun and cause a cardiac arrest if it is applied using head-to-back electrodes. The electrode positions and electrical setting must be verified by measures of electrical activity in the brain. The use of head-to-back electrodes to stun and cause cardiac arrest appeared to be more efficient and to give better meat quality with a lower incidence of PSE when compared with the head-on electrode method (Fehrenberg et al., 1991).

Carbon dioxide immobilization has been criticized because some researchers feel that the animal is exposed to stressful conditions before loss of consciousness (Tarrant, 1993). However, a new stunning system in Denmark appeared to greatly reduce excitement during handling because groups of five pigs were moved into the CO_2 chamber at one time. Troeger and Woltersdorf (1991) observed a lower incidence and a lower intensity of excitement in halothane positive pigs when CO_2 concentrations were equal to or greater than 80% compared to concentration of 60%.

The incidences of PSE pork by several immobilization methods are shown in table 12 (National Livestock Research Institute, 1997). Conventional stunning showed the highest incidence (43.0%), followed by electrical stunning (18.5% at 300V and 15.1% at 700 V) and CO_2 gas immobilization (4.0%). Although CO_2 gas immobilization shows the lowest PSE incidence, the electrical method is widely used in Korea because of easy operation. However, this immobilization method should be followed as quickly as possible by rapid bleeding. Unless bleeding is accomplished within a few seconds of immobilization, meat may exhibit blood spots that cannot be removed.

Table 12. Incidence of PSE pork by immobilization method

Immobilization		Incidence(%)
Electrical stunning	300V	18.5
	700V	15.1
CO_2 gas		4.0
Conventional stunning		43.0

The bleeding position of pig carcasses after electrical stunning affects meat quality (William and Lorencz, 1994). Bleeding in the lying position improved pH and electrical conductivity in the loin and ham; PSE incidence was reduced from 62% in carcasses bled in the suspended position to 25% in carcasses bled in the lying position.

DEHAIRING

Scalding and dehairing has been the most common technique used by the major U.S. packers to remove hog hair. A disadvantage to using this process is an increase in quality problems arising from an acceleration at high carcass temperature of postmortem anaerobic glycolysis (Carr, 1985). The resultant low ultimate pH (Troeger and Woltersdorf, 1987; Honkavaara, 1989), as well as a rapid decline in pH at high body temperature leads to protein denaturation and produces the characteristic PSE condition. Troeger and Woltersdorf (1987) suggested that muscle from a skinned carcass has improved muscle color and water holding capacity. Recently, some export-minded U.S. packers adopted a skinning method to reduce PSE pork. Furthermore, skinning reduces the processing time; thus carcasses are moved to the chiller faster than with the conventional scalding method, which further improves meat quality.

The incidence of PSE pork by scalding temperature in Korea is shown in table 13 (Park, 1980). Scalding temperature at 66°C resulted in the lowest PSE incidence (21.4%). As scalding temperature increased from 66 to 70°C, the PSE incidence also increased from 21.4% to 47.7%. A scalding temperature lower than 66°C resulted in a higher PSE incidence because of a longer scalding time.

Table 13. Incidence of PSE pork by scalding temperature

Temp. (℃)	Survey No.	Incidence No.	Incidence %
63	53	16	30.2
64	78	22	28.2
65	50	11	22.0
66	117	25	21.4
67	324	80	24.7
68	209	51	24.4
69	276	90	32.6
70	44	21	47.7
71	44	18	40.9
Total	1,195	334	27.9

POST-SLAUGHTER CHILLING

The incidence of PSE pork at various chilling temperatures of carcasses in Korea is shown in table 14 (Park, 1980). Chilling carcasses at 0~2℃ resulted in less PSE pork (16.6%) than athigher chilling temperatures; at 6~12°C there was 37.4% PSE. This result indicates that to reduce PSE incidence carcasses should be chilled rapidly after slaughter at a low temperature.

Rapid chilling immediately after slaughter is a procedure used in the pork industry to improve pork quality characteristics. This procedure slows the rate of postmortem glycolysis, resulting in higher ultimate muscle pH and reduced incidence of PSE pork (Carr, 1985). Crenwelge et al. (1984) reported improved pork color and firmness and decreased muscle separation when carcasses were rapidly chilled (3 h at -34°C, then 21 h at 2°C). Kauffman et al. (1992) also reported a lower incidence of PSE in those plants that used sub-zero temperatures. However, increased toughness is associated with ultra-rapid chilling systems employing -30°C or lower (James et al., 1983). Consequently, rapid chilling at -20°C for 2-3 h followed by conventional chilling was recommended to reduce pale color without affecting tenderness (Tarrant, 1989).

Table 14. Incidence of PSE pork by chilling temperature

Temperature (℃)	Survey No.	Incidence No.	Incidence %
0	509	87	17.1
1	476	80	16.8
2	115	16	13.9
Total	1,100	183	16.6
6	55	22	33.8
7	70	29	41.4
8	89	39	43.8
9	160	71	44.4
10	60	21	35.0
11	207	45	21.7
12	214	74	34.6
Total	805	301	37.4

CONCLUSION

A number of factors are related to pork quality, including genetics, nutrition, time of year (temperature and humidity levels and fluctuations), handling procedures on the farm and during transit to the packing plant, care of the pigs after arrival at the packing plant, method of stunning, method of dehairing, and method and time of chilling after slaughter. Depending on how many of these factors are present, the frequency of PSE can be widely variable. Kauffman et al. (1992) reported that the incidence of PSE pork was more than five-fold greater in some plants than in others (6 to 33%), and DFD pork existed with a range of 4 to 18%. Another interesting observation in the survey (Kauffman et al., 1992) was that over one-half of the hams possessed reddish pink color but were soft and floppy and presumably exudative (RSE pork). This raises the concern about using color as the only indicator of water-holding capacity. This normal color accompanied by a soft, floppy and exudative condition is likely to be an intermediate condition of the PSE problem. Overall, the survey indicated that at least one-quarter of all the pork was clearly undesirable (16% PSE and 10% DFD), and only 16% was identified as RFN (reddish pink, firm and dry) or IDEAL. The implication of all this is that the pork industry has a pork quality problem.

Some European countries, such as the Netherlands, have significantly reduced PSS through the elimination of halothane-positive boars in breeding programs. Denmark's pork packers have developed model procedures to minimize stress prior to slaughter. Also, they were pioneers in developing rapid chilling procedures after slaughter. These are some examples of how to minimize or eliminate variations in quality. Therefore, good guidelines should be established and used to ensure acceptable production, management and welfare procedures at all times, including breeding, feeding, handling, shipping and transporting. Pork packers should evaluate all the procedures for pre-slaughter handling, slaughtering and post-slaughter chilling that will minimize unacceptable quality.

If possible, procedures should be put in place to electronically identify and evaluate every individual pig slaughtered. The information collected should be related to producers to inform them of quality variations so that appropriate steps can be taken to improve their production system. Working towards marketing all pigs on a comprehensive carcass merit basis would be extremely beneficial to improve the image of pork. The price paid for market pigs should reflect not only differentials for lean and fat carcasses but also value differentials between desirable and undesirable meat quality.

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