



Evidence of Significant Effects of Stunning and Chilling Methods on PSE Incidences

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ABSTRACT : The current study was conducted to investigate the optimum stunning voltage and chilling regime with emphasis on reduction in pale, soft and exudative (PSE) pork. The experiments were conducted at seven Korean major pig abattoirs using a total of 91,082 industrial population. Frequencies of PSE meat was found to be significantly ($p < 0.05$) increased as stunning voltage was elevated from 220-240 (13.14%), 250-280 (29.32%) to 430 volts (36.74%). Chilling methods after slaughter, either with cold water showing or rapid chilling reduced PSE meat by 22% compared to a classic chiller-based slow chilling regime. The current study also revealed that chiller temperature during the first 90 minutes had a significant ($p < 0.001$) effect on PSE incidences. Pigs chilled between -5 to 7°C resulted in the lowest PSE meat (17.8%), followed by higher than 7°C (21.3%) and lower than -5°C (37.5%). The current data implies that low voltage stunning method (eg., 220-240 volts), followed by rapid chilling regime, maintaining chiller temperature between approximately -5 to 7°C could reduce PSE incidences. (**Key Words :** Pigs, PSE, Stunning Method, Chilling Method, Chiller Temperature)

INTRODUCTION

The most important single defect of pork meat is pale, soft and exudative (PSE) meat, which is generally caused by loss of water-holding capacity (WHC) of muscle fiber leading to soft and pale texture (Offer et al., 1989; Bertram et al., 2004). Lack of oxygen soon after slaughtering initiates anaerobic glycolysis in the muscles which brings down the muscular pH during the chilling process. Decline in the rate and extent of pH and the carcass temperature together directly influence WHC through protein denaturation and myofibrillar shrinkage (Warner et al., 1997; Hwang et al., 2003; Rosenvold and Andersen, 2003).

Early studies (Mitchell and Heffron, 1982) identified that pigs resulted in PSE meat had three-fold faster postmortem glycolytic rate than those for normal pork, regardless of genetic background. There are contradictory

reports on significant factors associated with the incidence of PSE meat, but it is quite apparent that the prime source of PSE incidence includes pre-slaughter stress particularly stunning methods (Tarrant, 1989; Grandin, 1994; Eilert, 1997) and chilling conditions (Park et al., 2003). From the animal welfare's point of view, the international regulation (Council Directive 93/119/CEE, 1993) demands a complete anesthetic state of animals prior to bleeding process. To keep up to the international regulation for animals welfare electronic and CO₂ stunning methods has been employed by pig industry (Casteels et al., 1995; Channon et al., 2000; Channon et al., 2002).

It has been documented that the rate of chilling for pig carcass has significant effects on the incidence of pH related-PSE meat (Offer, 1991; Van Laack and Smulders, 1996). For the purpose of reducing PSE meat, majority of Korean pig industry has employed a slow chilling system, while various chilling systems including classic slow chilling, enforced blast chilling and spray chilling systems (Channon, 2001). A fast chilling method (eg., -20°C tunnel system) can reduce PSE incidences (Channon, 2001), but its effect was found to be variable among different research groups (Maribo et al., 1998). The current study was therefore, conducted to evaluate the effects stunning and

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Table 1. Treatments and total number of animals for three consecutive experiments

	Stunning voltage	Chilling condition	No. of animal
Experiment 1	220-240 (1.24-1.26 Amps, 2.5 s)	Conventional chiller (0-4°C, 0.4-0.5 m/s)	89,989
	250-280 (1.24-1.26 Amps, 2.5 s)		
	430 (5 Amps for 3 s)		
Experiment 2	230 (1.24-.26 Amps, 2.5 s)	Conventional chiller Rapid chilling ¹ Cold water spray ²	94,333
Experiment 3	230 (1.24-1.26 Amps, 2.5 s)	4~ -20°C	1,093

¹ -20°C chiller (air speed: 0.5 m/s) for 80 minutes and replaced at the conventional chiller.

² Spray water (lower than -10°C) for 90 minutes and replaced at the conventional chiller.

Table 2. Number of animal and least square mean (standard error) of carcass characteristics of pigs judged as normal, light PSE and severe PSE in longissimus muscle

	Normal	Light PSE	Severe PSE
Number of animal	74,341	2,803	12,845
Hot carcass weight (kg)	75.22 ^a ±0.03	77.69 ^b ±0.15	78.14 ^a ±0.07
Backfat thickness (mm)	16.59 ^b ±0.02	17.95 ^a ±0.10	18.04 ^a ±0.05
Meat color ¹	3.51 ^a ±0.00	3.19 ^b ±0.01	2.44 ^c ±0.01
Texture ²	1.14 ^c ±0.00	2.00 ^b ±0.00	2.67 ^a ±0.00
Marbling ³	2.08 ^a ±0.01	1.59 ^b ±0.02	1.35 ^c ±0.01
Surface moisture ⁴	1.02 ^c ±0.00	2.00 ^b ±0.00	2.70 ^a ±0.01
Muscle separation ⁵	1.03 ^c ±0.00	1.13 ^b ±0.01	1.41 ^a ±0.01

^{a-c} Means bearing different letters in the same row significantly differ ($p < 0.05$).

¹ Meat color: 1 = Pale, 6 = Dark.

² Texture: 1 = Firm, 3 = Soft.

³ Marbling: 1 = Low marble, 5 = High marble.

⁴ Surface moisture: 1 = Low exudative, 3 = High exudative.

⁵ Muscle separation: 1 = Low rate, 3 = High rate.

chilling methods on the incidence of PSE meat.

MATERIALS AND METHODS

Animal, experimental design and treatment

A total of 91,082 pigs were sampled from seven major pig abattoirs of Korea, which used a similar processing system, between 2003 to December, 2004 for three experiments with emphasis on the frequency of PSE incidences: i.e. effects of 1) stunning voltage under a conventional chiller condition (0-4°C, air speed: 0.4-0.5 m/s), 2) chilling method after a 230 volts stunning, and 3) early postmortem chiller temperatures (4 ~ -20°C, air speed: 0.4-0.5 m/s) after 230 volts stunning (Table 1). Pigs were transferred by the ordinary commercial trucking system with minimum stress, and each experimental animals were randomly selected at the time of arrival. The low voltage stunning methods (eg., lower than 280 volts) were applied by the mixture of head to head and head to breast technique (1.24-1.26 Amps for 2.5 seconds). The high voltage stunning method by head to head technique was applied for approximately 5 Amps for 3 seconds. Carcasses for the rapid chilling methods were placed at a -20°C chiller with air speed of 0.5 m/s for 80 minutes and re-placed at a conventional chiller 0-4°C with air speed of 0.4-0.5m/s until the following day. The cold water spray method was

composed of spraying carcasses with cold water (lower than -10°C) at a 10°C cooling room, equipped by blast pan, for 90 minutes and replacing the carcasses at a conventional chiller (0-4°C, air speed: 0.4-0.5 m/s) until the following day. To generate a wide range of carcass temperature for the third experiment under the various chiller temperature, 1,093 pigs were placed in either the conventional chilling regime, or the rapid chilling regime for 24 h. It is worth to note that chiller temperature and carcass temperature under a certain chilling condition could vary between chillers and carcasses practically due to working and carcass conditions.

Meat quality determination

Frequency of PSE incidence on hot carcass was determined by meat graders from the Korean Animal Products Grading Service according to the method described by (Department of Agriculture and Forestry, 2004). Carcasses were segregated into three classes: severe PSE (Meat color No. 1 or 2+Texture No. 3+Surface moisture No. 3), moderate PSE (Meat color No. 3+Texture No. 2, or Surface moisture No. 2), and normal (for other carcass characteristics). Temperature of longissimus muscle at the 9th/10th ribs was recorded from immediately after placing carcass for chilling process at a 5-minute interval until the following day by inserting temperature data logger (TR-50, T&D Co. Japan). The following day after slaughter,

Table 3. Effect of stunning and chilling methods on the rate of PSE incidence

	Normal	PSE			No. of animal
		Light	Severe	Total	
Stunning voltage ¹					
220-240 V	86.86	2.51	10.63	13.14	67,638
250-280 V	70.68	4.76	24.56	29.32	19,556
430 V	63.26	6.19	30.55	36.74	2,795
Chilling method ²					
Conventional chilling	62.49	4.85	32.66	37.51	16,696
Rapid chilling	85.78	2.48	11.74	14.22	68,866
Cold water spray chilling	84.64	6.28	9.08	15.36	8,771

¹ χ^2 Value = 3,541.97 ($p < 0.0001$), ² χ^2 Value = 5,520.031 ($p < 0.0001$).

the same meat grader cut 4th/5th ribs, and determined backfat thickness, meat color, texture, marbling, surface moisture and degree of muscle separation.

Statistical analysis

Differences in carcass characteristics between severe PSE, light PSE and normal meats and effect of early postmortem temperature on PSE incidence were examined by Duncan function of ANOVA procedure (SAS, 2001) against residual error terms. Frequency of PSE incidence as a function of various stunning and chilling methods, and early postmortem chiller temperatures were evaluated by Chi-Square procedure (SAS, 2001).

RESULTS AND DISCUSSION

Carcass characteristics and PSE incidence

Table 2 shows a pooled dataset of carcass characteristics for normal, light PSE or severe PSE pigs in longissimus muscle resulted from three experiments. The results were in fact confounded by various factors including stunning methods and chilling regimes, but the data were tabulated to provide an overview of carcass characteristics between different meats. At the first glance, the results were rather expected because pigs showing PSE meat had greatly ($p < 0.05$) higher hot carcass weight and backfat thickness. Previous studies similarly reported that faster growing pigs tended to result in PSE meat under an identical feeding condition (eg., Webb et al., 1982; Candek-Potokar et al., 1998). In the current dataset, normal pigs had approximately 2 kg lighter carcass weight and 1.5 mm thinner backfat (75.2 kg and 16.6 mm) than pigs for light (77.7 kg and 18 mm) and severe (78.1 kg and 18 mm) PSE meats. On the other hand, it was of interest that normal longissimus muscle showed a significantly ($p < 0.05$) higher marbling score (2.1 points) than PSE ones (1.6 and 1.4 points for slight and severe, respectively). From the energy partitioning point of view, it is reasonable to expect the negative relationship between intramuscular and subcutaneous fat depositions (Beattie et al., 1999; Wood et al., 2004). On the other hand, one might presume that a high level of intramuscular fat could insulate heat transit and

retard chilling rate, consequently increasing PSE incidence. However, the current data indicated that intramuscular content had a limited effect on PSE incidence compared to the backfat thickness and carcass weight. Indeed, our previous study (Hwang et al., 2004) showed that pigs for high marbling scores in longissimus muscle showed a higher stress resistance and less PSE incidence despite the data was confounded by breed effect.

Effect of stunning and chilling methods on PSE incidence

The prime source of pH-related PSE meat is the rate of postmortem glycolytic rate, regardless of genetic background (Christine Fischer and Hamm, 1980; Mitchell and Heffron, 1982; Monin and Sellier, 1985) and that was significantly associated with stunning method (Tarrant, 1989; Grandin, 1994; Eilert, 1997). Application of electrical current to animals induces rigorous muscle contractions, and results in the accumulation of lactic acid in muscle tissue (Carballo et al., 1988; Devine et al., 2003). As a consequence under a physical body temperature, muscle fibers are prone to get denatured (Pearson and Young, 1989). Bovine and ovine data showed that high voltage stimulation resulted in a faster rate of pH decline (Hwang et al., 2003). Although we are unaware of accessible data, if any, for pig, the current results similarly demonstrated that a higher voltage linearly resulted in a significantly higher frequency of PSE meat (13, 29, 37% for 220-240, 250-280 and 430 volts, respectively, Table 3). An early industrial data (Grandin, 1994) showed that a constant current of 1.25 amps reduced PSE incidence. In addition, the same study recommended 300 voltage stunning for heavier pigs (approximately 110 kg) and a lower voltage stunning for more a lighter pigs in order to reduce PSE meat. The current study did not determine postmortem glycolytic rate, but the result implied that the high voltage stunning hastened decline in pH after slaughter as proposed by Taylor and Martoccia (1995). However, it could be a subject of further debate for the relative impact of stunning voltages, which were applied for only 3 seconds in the current study, on PSE incidence.

As previously discussed, postmortem glycolytic rate

Table 4. Effect of average chiller temperature for 90 minutes after being placed at a chiller and carcass temperature at 90 minutes

Chiller temperature	Normal	PSE			No. of animal	Carcass temperature (°C)
		Slight	Severe	Total		
<-5°C	68.32	7.73	23.94	31.67	543	16.27 ^c ±0.21
-5~7°C	82.21	1.64	16.16	17.80	489	17.17 ^b ±0.09
7°C≤	78.69	0.00	21.31	21.31	61	20.68 ^a ±0.00

χ^2 Value = 38.2996 (p<0.0001).

^{a, b, c} Means having different letters in the same column are significantly different (p<0.05).

itself significantly influences the WHC-related PSE meat. However, magnitude of its effect is greatly prevaricated by muscle temperature (Hwang et al., 2004) as muscle temperature *in situ* at a certain pH has a direct linkage to protein denaturation (Offer, 1991; Van Laack and Smulders, 1996). Furthermore, muscle temperature in part governs enzyme activities involved in the rate of glycolysis (Pearson and Young, 1989; Maria et al., 2005, 2006). Ninety pig abattoirs out of 99 in Korea has employed the slow chilling system, while various chilling systems including the enforced blast and spray chilling systems are also available and these systems have effectively evidenced the reduction of PSE incidence (Maribo et al., 1998; Channon, 2001). On the basis of the current study (Table 3), the prevalently used by Korean pig industry (eg, slow chilling system) resulted in the highest frequency of PSE incidence in that 6,344 pigs out of 16,696 (approximately 38%) showed PSE-like meats in longissimus muscle. On the other hand, when pigs received the water shower of colder than -10°C water for approximately 90 minutes soon after halving demonstrated a significant improvement of meat quality (ie, approximately 15% PSE). Similarly, pigs underwent the -20°C chiller for 80 minutes exhibited a great reduction of PSE meat (ie, approximately 14%). Although a recent study employed slightly lighter pigs (Savell et al., 2005), the results also evidenced effectiveness of the cold water spraying technique to reduce PSE meat. The current study did not determine quantity of protein denaturation between the treatments, but it was presumed that accelerated decline in muscle temperature at a constant pH decline retarded heat shortening, and consequently reduced protein denaturation and myofibrillar shrinkage (Warner et al., 1997; Rosenfold and Andersen, 2003).

Effect of early postmortem chiller and carcass temperature on PSE incidence

Visual attraction of meat and meat products is the most important quality traits determining consumers' preference (Rosenfold and Andersen, 2003). Besides fiber type, meat color is a reflection of meat surface and that is greatly influenced by WHC. Muscle pH and temperature interact continuously during rigor development, and they impact on both physical shortening and protein denaturation (Tomberg, 1996). Previous studies identified that rigor development at temperature higher than 35°C with pH lower than 6.0 and

lower than 12°C with pH higher than 6.0 resulted in heat and cold shortening, respectively (Nuss and Wolfe, 1980; Devine et al., 2002) and rigor development at an intermediate temperature resulted in the least muscle shortening without protein denaturation (Hwang and Thompson, 2001).

Current study did not compare metabolic rate between the carcasses placed at various chilling temperatures, but the results revealed that average chiller temperature between 5 to -7°C for 90 minutes resulted in the lowest rate of PSE incidence (17.8%), followed by higher than 7°C (21.3%) and lower than -5°C (37.5%) (Table 4). The result implied that rapid chilling rate is not invariably best practice to reduce PSE incidence, despite one may expect a fast reduction in muscle temperature for the carcasses. Indeed, muscle temperature at 90 minutes for the carcasses placed at a chiller between 5 to -7°C at 90 minutes was significantly (p<0.05) lower than that for others.

However, it was speculated that chilling efficiency was lower for the carcasses placed at the fast chilling regimes, because ice cover on the carcass surface was frequently observed. It is well documented that PSE meat has a direct association with the loss of WHC of muscle fiber, consequently resulting in soft and pale texture (Offer et al., 1989; Bertran et al., 2004). Furthermore, cold shortening at the outer layer of the carcass likely elevated "squeeze-out" phenomenon, consequently increasing PSE incidence, as reported by previous studies (James et al., 1983; Hwang et al., 2004). The current data indicated that chiller temperature has a significant effect on PSE incidence and further suggested that an intermediate chilling condition (eg., 5 to -7°C for 90 minutes after being placed at chiller) was the best practice.

IMPLICATION

At the wake of increasing consumers' demand for high quality pork, the use of appropriate stunning and chilling regime become significant and that has been documented in part. However, the importance is frequently ignored by industrial and even academic personals. The current study, which identifies the optimum stunning voltage and chilling regime, demonstrated that a low voltage stunning method (eg., 220-240), followed by rapid chilling regime,

maintaining chiller temperature between approximately -5 to 7°C could reduce PSE incidence.

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