ผลของอุณหภูมิการแช่เย็นขั้นปฐมภูมิต่อการสูญเสียน้ำหนักของซากสุกร และคุณภาพของเนื้อสันนอก
EFFECT OF PRIMARY CHILLING TEMPERATURE ON WEIGHT LOSS OF PORCINE CARCASS AND QUALITY OF SIRLOIN MEAT

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บทคัดย่อ

งานวิจัยนี้มีวัตถุประสงค์เพื่อศึกษาผลของการแช่เย็นขั้นปฐมภูมิที่ภายใต้ความชื้นสูงต่อการ
สูญเสียน้ำหนักและคุณภาพของเนื้อสันนอก โดยการลดอุณหภูมิซากสุกรในห้องแช่เย็นขั้นปฐมภูมิ
(-5°C, -10°C and -20°C) จนกระทั่งซากสุกรมีอุณหภูมิ 35°C จากนั้นลดอุณหภูมิซากสุกรต่อ
(การแช่เย็นขั้นทุติยภูมิ) ที่อุณหภูมิ 0°C เป็นเวลา 22 ชั่วโมง ผลพบว่าอุณหภูมิในการแช่เย็น
ขั้นปฐมภูมิมีผลต่อค่าพีเอชของซากสุกรอย่างไม่มีนัยสำคัญ (P>0.05) โดยซากสุกรมีค่าพีเอชลดลง
จนมีค่าเท่ากับ 6.40-6.87 และ 5.90-6.20 ภายหลังการตาย 45 นาที และ 24 ชั่วโมง ตามลำดับ
ซากสุกรที่ผ่านการแช่เย็นขั้นปฐมภูมิที่อุณหภูมิ -20°C มีค่าการสูญเสียน้ำหนักน้อยที่สุดเท่ากับ
1.57±0.17% ซึ่งอาจเป็นผลจากการเกิดน้ำแข็งเคลือบผิวซากสุกรในระหว่างการแช่เย็น ภายหลัง
การแช่เย็นต่อข้ามคืน ซากสุกรจะถูกตัดแต่ง และนำส่วนเนื้อสันในมาแช่เย็นก่อนนำมาวิเคราะห์คุณภาพ
ผลพบว่าอุณหภูมิการแช่เย็นขั้นปฐมภูมิมีผลต่อค่าแรงเฉือนแต่ไม่มีผลต่อค่าการสูญเสียของเหลว
ของเนื้อสันในดิบอย่างมีนัยสำคัญทางสถิติ (P>0.05) โดยเนื้อสันในดิบที่ผ่านการแช่เย็น
ขั้นปฐมภูมิที่อุณหภูมิ -20°C มีค่าแรงเฉือนต่ำที่สุดคือเท่ากับ 2.17±0.96 kg/cm2 อย่างไรก็ตาม
เนื้อสันในปรุงสุกที่ได้จากการใช้อุณหภูมิการแช่เย็นขั้นปฐมภูมิที่ต่างกันมีค่าการสูญเสียภายหลังการปรุงสุก
และคุณภาพด้านเนื้อสัมผัสแตกต่างกันอย่างไม่มีนัยสำคัญ (P>0.05) ผลการวิจัยบ่งชี้ว่าการแช่เย็น
ขั้นปฐมภูมิที่อุณหภูมิต่ำสามารถลดการสูญเสียน้ำหนักได้โดยไม่ส่งผลต่อคุณภาพด้านเนื้อสัมผัสของ
เนื้อสันนอก

คำสำคัญ: อุณหภูมิการแช่เย็นขั้นปฐมภูมิ การสูญเสียน้ำหนัก แรงเฉือน พีเอช ซากสุกร

Abstract

This research aimed at investigating effect of primary chilling temperatures under high humidity on weight loss and sirloin meat quality. Three primary chilling temperatures (-5°C, -10°C and -20°C) were applied to porcine carcasses until their temperatures reached 35°C. Subsequently, the carcasses were conventionally chilled (secondary chilling) at 0°C for 22 h. The results showed that primary chilling temperature did not show significant effect on pH of carcasses (P>0.05). The pH of carcasses decreased to 6.40-6.87 and 5.90-6.20 after 45 min and 24 h post mortem, respectively. The lowest weight loss of 1.57$\pm$0.17% was found in sample undergone primary chilled at -20°C. This might be due to the ice glazing as a protecting agent during carcass chilling. After overnight chilling, carcasses were cut and sirloin meat was chilled before determining its qualities. Primary chilling temperature significantly affected shear force (P≤0.05) but not drip loss of the raw meat (P>0.05). Raw meat experienced primary chilled at -20°C had the significantly lowest shear force of 2.17+0.96 kg/cm2. However, there was no significant difference in cooking loss and texture quality of meat after cooking (P>0.05). The study indicates that lowering primary chilling temperature could improve weight loss of sirloin meat without significant effect on its texture quality.

Keywords: Primary Chilling Temperature, Weight Loss, Shear Force, pH, Porcine Carcass

Introduction

Pork is an excellent source of protein and other nutrients such as niacin. After hygienic slaughter and evisceration, porcine carcasses are subjected to 2-step chilling, i.e., primary chilling and secondary or overnight chilling in order to retard microbial growth and other deterioration processes. Abused temperature may result in either pale-soft and exudative (PSE) meat and/or muscle shrinkage. High carcass temperature accelerates post-mortem metabolism resulting in rapid decline of pH in meat. This phenomenon causes extensive protein denaturation and meat becomes lighter and loss its water holding capacity. According to Chadwick and Kempster [1], PSE carcass was classified when pH in the longissimus muscle was less than 6.0 after 45 min post mortem. The best approach to prevent PSE case is chilling meat immediately after exsanguination. However, high cooling rate at an early stage of post mortem (primary chilling) causes meat susceptible to shortening. This condition is severe when meat with pH more than 6.2 is cooled to a temperature less than 10°C [2]. Wal van der, et al. [3] found negative effect as indicated by increase of shear force when ultra-rapid chilling was applied. Unlike the previous report, Drumm, et al. [4] concluded that rapid reduction in deep round temperature of beef decreased substantial shrinkage in term of weight loss at the first 6 h post mortem. Due to

those controversial findings, this study was undertaken to investigate the effects of low primary chilling temperature on carcass weight loss and sirloin quality of porcine. The findings would be useful to the development of the guideline on porcine handling practice.

Objectives

The effects of low primary chilling temperature on carcass weight loss and sirloin quality of porcine were investigated.

Methods

1. Materials and Experimental Design

A total of 6 crossbred pig [(Large white x Landrace) x Duroc] carcasses (75-82 kg) was randomly selected as the sample for each treatment. Their initial temperatures were $39.0\pm0.2^{\circ}$C. Slaughtering process (e.g., electrical stunning, slaughtering, bleeding, scalding, dehairing, head removing, eviscerating, splitting with two sides remaining joined by the back, and carcass chilling) as well as meat cutting and meat storage were performed at the meat plant located in the central region of Thailand. The post mortem period prior to carcass chilling step was controlled to be within 35-40 min.

Figure 1 shows schematic diagram of the experiment. After splitting, the *M. longissimus dorsi* (sirloin) of each carcass was inserted with a TR-52i temperature recorder (T & D Corporation, Japan) in order to recording temperature change throughout chilling process. The carcasses were subsequently sprayed with 300 mL of cold water ($11.2\pm0.5^{\circ}$C), and immediately blast-chilled at -5°C, -10°C, or -20°C until the core temperature of *M. longissimus dorsi* reached 35°C. Subsequently, the carcasses were placed in the conventional chiller (0°C) and held for 22 h. After chilling, the sirloin meat carcasses were cut into 5.39 ± 0.72 x 6.40 ± 0.58 x 20.10 ± 1.52 cm^3, and vacuum packed in polyvinylidene chloride (PVDC) bag. The sirloin was chilled at 0°C for 6 h before measurement of meat qualities such as drip loss, color, cooking loss, and texture analysis.

Air velocity, temperature and relative humidity in both blast and conventional chiller were measured by using anemometer (DA-41, DIGICON, Taiwan), thermo recorder (TR-52i, T&D Corporation, Japan) & kistock temperature and humidity datalogger (KH 110, KIMO Instruments Co., Ltd., France), respectively. The conditions of each chilling treatment were shown in Table 1.
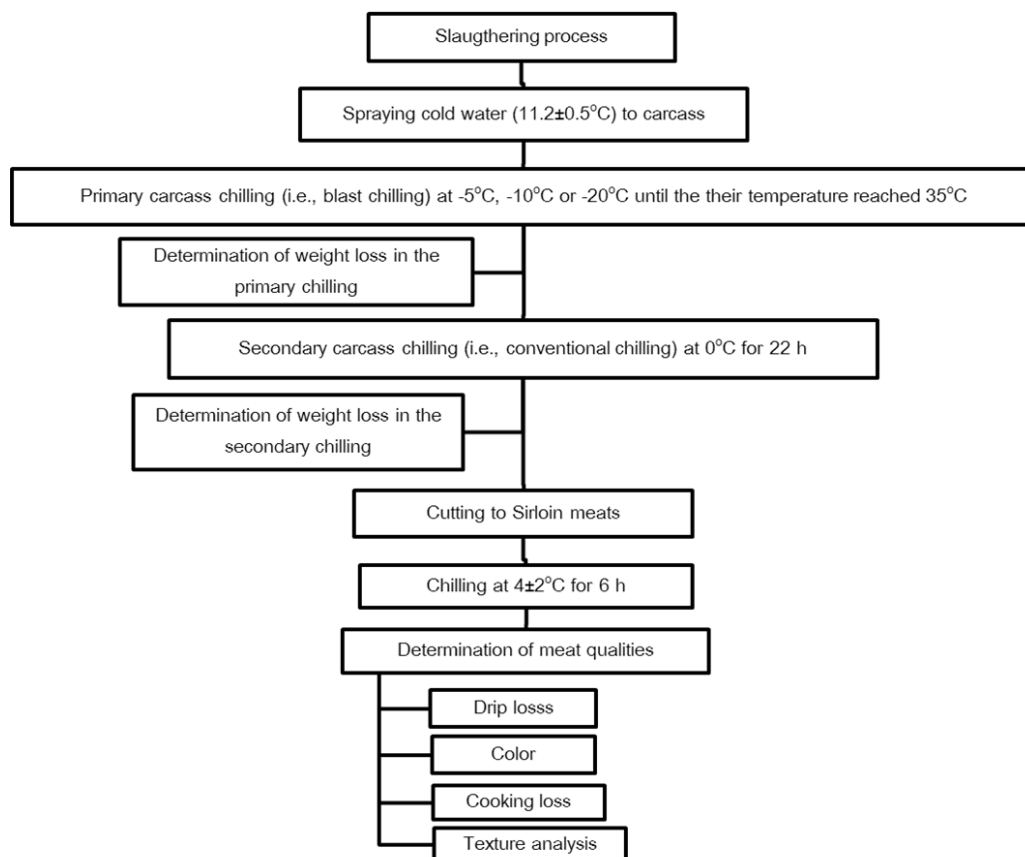
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┌─────────────────────────────────────┐
│         Slaugthering process         │
└─────────────────────────────────────┘
┌─────────────────────────────────────┐
│ Spraying cold water (11.2±0.5°C) to carcass │
└─────────────────────────────────────┘
┌──────────────────────────────────────────────────────────────┐
│ Primary carcass chilling (i.e., blast chilling) at -5°C, -10°C or -20°C until the their temperature reached 35°C │
└──────────────────────────────────────────────────────────────┘
┌───────────────────────────────┐
│ Determination of weight loss in the │
│        primary chilling        │
└───────────────────────────────┘
┌──────────────────────────────────────────────────────┐
│ Secondary carcass chilling (i.e., conventional chilling) at 0°C for 22 h │
└──────────────────────────────────────────────────────┘
┌───────────────────────────────┐
│ Determination of weight loss in the │
│       secondary chilling       │
└───────────────────────────────┘
┌─────────────────────────────────────┐
│         Cutting to Sirloin meats     │
└─────────────────────────────────────┘
┌─────────────────────────────────────┐
│        Chilling at 4±2°C for 6 h     │
└─────────────────────────────────────┘
┌─────────────────────────────────────┐
│    Determination of meat qualities   │
└─────────────────────────────────────┘
        ┌──────────────────┐
        │    Drip losss    │
        └──────────────────┘
        ┌──────────────────┐
        │      Color       │
        └──────────────────┘
        ┌──────────────────┐
        │   Cooking loss   │
        └──────────────────┘
        ┌──────────────────┐
        │ Texture analysis │
        └──────────────────┘
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Figure 1. Schematic Diagram of the Experiment.

2. Determination of Weight Loss During Chilling

The carcasses were weighed and transported to the primary chilling room. Weight loss in primary chilling was determined after the carcass temperature was at 35°C and reweighed. Then secondary chilling was continued until 24 h of post mortem after which carcass weight was determined and calculated as weight loss in secondary chilling.

3. pH and Color Determination

At 45 min and 24 h of postmortem, pH of *M. longissimus dorsi* was measured by using a SevenGoTM portable pH meter (Mettler-Toledo, Inc., Switzerland). Color of five different locations on each sample was measured using a colorimeter (ColorQuest XE, HunterLab, USA) in terms of L*, correlating lightness (0-100).

Table 1. Conditions of Each Chilling Treatment.

	Treatment		
	-5°C	**-10°C**	**-20°C**
Primary Carcass Chilling			
Air Temperature (°C)	−8.6±5.3	−13.6±3.2	−20.3±2.4
Relative Humidity (%)	95.0±1.4	91.4±0.9	88.5±0.7
Air Velocity (m/s)	2.8±0.0	3.1±0.3	3.2±0.6
Chilling Time (min)	41	38	33
Secondary Carcass Chilling			
Air Temperature (°C)	−0.1±1.8	−0.5±1.5	−1.4±1.5
Relative Humidity (%)	88.8±8.6	91.6±1.1	85.8±9.4
Air Velocity (m/s)	0.5±0.0	0.3±0.1	0.3±0.1
Chilling Time (min)	22	22	22

4. Drip Loss and Shear Force Determination

The sirloin meat of each treatment was weighed before and after overnight storage at $4\pm2\,°C$. The difference in weight (g) was divided by the initial weight of the sample (g) and expressed as drip loss. Shear force of the raw sample was determined by Texture analyzer (TA.XA plus, Stable micro system, UK) equipped with 5 kg of load cell. The sample was cut through by the Warner–Bratzler blade which moved down with pre-test speed of 3.0 mm/s and test speed of 2.0 mm/s.

5. Cooking Loss and Texture Analysis

Cooking loss (%) was assessed by reweighing the sirloin samples after boiling until the core temperature reached $79\,°C$ for 1 min in PVDC bags and subsequent cooling. The texture profile analysis (TPA) of cooked samples was evaluated by Texture analyzer equipped with 5 kg of load cell. A cylindrical probe (P36R) was used with pre-test speed, test speed and post-test speed of 3.0, 1.0 and 3.0 mm/s, respectively.

The sample $(1.5 \times 1.5 \times 1.5 \text{ cm}^3)$ was pressed at 75% strain. TPA parameters were reported in terms of hardness, springiness, cohesiveness, chewiness and gumminess.

6. Statistical Analysis

Each treatment was performed in two replicates. Results were presented mean values ± standard deviation which were then evaluated by analysis of variance (ANOVA) together with Duncan's new multiple range tests at 95% confidence interval.

Results

Figure 2 shows that temperature profile for each sample was based on two successive periods: a period of primary chilling and a period of secondary or overnight chilling. Primary chilling which ended up when the core temperature of samples reached $35\,°C$ took very short periods of 33, 38 and 41 min for chilling temperature of −20, −10 and −5 °C, respectively. Ice glazing was only observed on the surface of the carcasses exposed to chilling temperature of −20 °C (Figure 3).
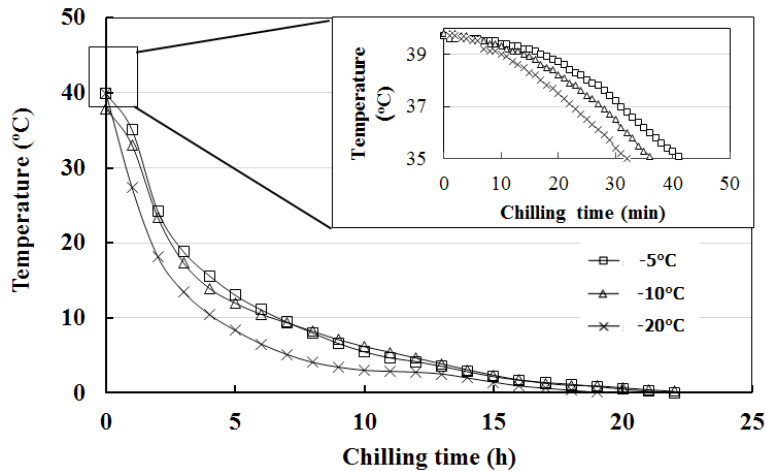
Figure 2. Temperature reduction of the *M. longissimus dorsi* (sirloin) during the primary and secondary carcass chilling when primary chilling temperatures at $-5°C$, $-10°C$, and $-20°C$ were applied.

Figure 3. Ice glazing of the carcass surface when primary chilling temperature at $-20°C$ was applied.

Figure 4 demonstrates weight loss of the samples during chilling process. The sample undergone primary chilling temperature of $-5°C$ and $-10°C$ had significantly higher weight loss after primary chilling and secondary chilling process than that undergone primary chilling temperature of $-20°C$. Table 2 shows that pH of carcasses after 45 min (pH 45 min) and 24 h (pH 24 h) post mortem did not significantly differ among primary chilling temperature treatments $(P>0.05)$. The pH 45 min and pH 24 h of all samples were 6.40-6.87 and 5.90-6.20, respectively whilst the core temperatures were approximately 35 and 4°C at 33-41 min and 24 h post mortem, respectively.
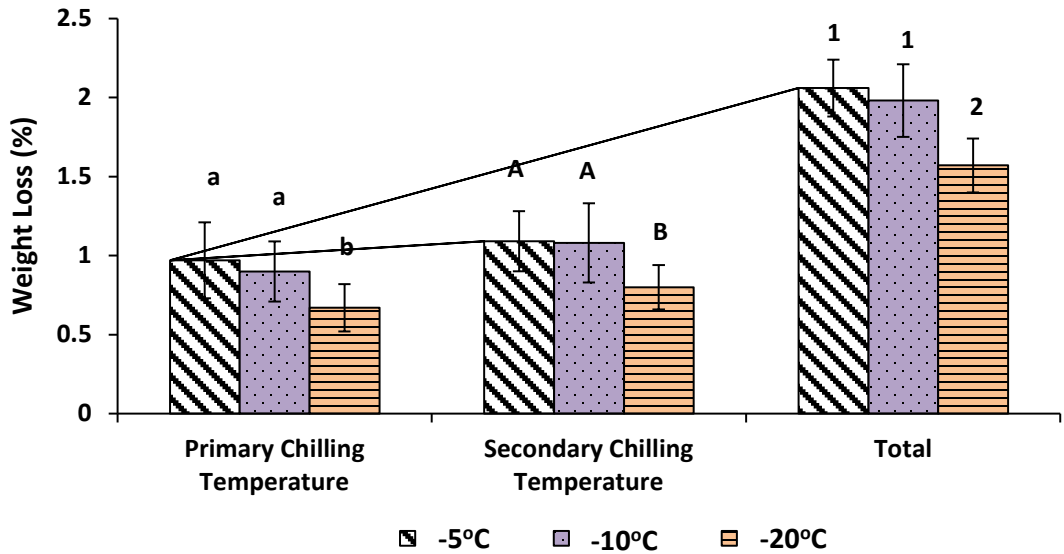
Figure 4. Weight loss of the *M. longissimus dorsi* (sirloin) during the primary and secondary carcass chilling when primary chilling temperatures at $-5\,^{\circ}$C, $-10\,^{\circ}$C, and $-20\,^{\circ}$C were applied. Different superscript letters indicate statistically significant ($P \leq 0.05$).

Table 2. Quality of carcass, raw meat and cooked meat affected by primary chilling temperatures.

	Treatment		
	-5°C	**-10°C**	**-20°C**
Carcass			
pH$_{45}$^{NS}	6.87±0.29	6.81±0.39	6.40±0.29
pH$_{24}$^{NS}	6.2±0.2	6.1±0.3	5.9±0.1
Weight loss	2.06±0.18^a	1.98±0.23^a	1.57±0.17^b
Raw Meat			
Drip Loss^{NS} (%)	4.35±3.47	4.13±1.88	4.12±2.33
L*	48.05±3.95^b	52.61±2.94^a	53.61±2.05^a
Shear force (kg/cm^2)	2.50±1.08^a	2.52±1.17^a	2.17±0.96^b
Cooked Meat			
Cooking Loss ^{NS} (%)	30.34±5.00	29.66±3.46	29.11±5.40
Texture			
Hardness^{NS} (kg/cm^2)	25.09±5.00	25.56±4.56	23.31±5.03
Springiness^{NS} (s)	0.47±0.14	0.52±0.09	0.49±0.09
Cohesiveness^{NS}	0.50±0.08	0.49±0.07	0.49±0.09
Gumminess ^{NS} (kg/cm^2)	12.53±3.64	12.71±3.21	11.33±3.68
Chewiness ^{NS} (kg s/cm^2)	5.91±2.51	6.57±2.00	5.63±2.27

Means with difference letters (a,b,…) in the same row were significantly different ($P \leq 0.05$)

^{NS}Means in the same row were insignificantly different ($P > 0.05$)

Raw meat cut had drip loss within the range of 4.12–4.35% when primary chilling temperature of –5 to –20°C was applied (Table 2). Statistical analysis indicated that there was no significant difference (P>0.05) in drip loss among temperature treatments. Similar results were observed when the raw samples were cooked. The cooked meat had cooking loss ranging from 29.11±5.40% to 30.34±5.00%. Lightness (L*) of the raw meat was slightly increased when primary chilling temperature decreased. L* of raw meat primary chilled at –10°C (52.61±2.94) was higher than that of –5°C (48.05±3.95)

and no significant difference was found in L* between –10 and –20°C (53.61±2.05) (Figure 5). Shear force of the raw samples primary chilled at –20°C was significantly lower than that of the samples at –5°C and –10°C (P≤0.05) (Table 2). Contrastingly, texture profile analysis results of cooked meat showed that temperature treatments had insignificant effects on texture qualities with the values of 23.31–25.56 kg/cm^{2}, 0.47–0.52 s, 0.49–0.50, 11.33–12.71 kg/cm^{2} and 5.63–6.57 kg s/cm^{2} for hardness, springiness, cohesiveness, gumminess and chewiness, respectively.

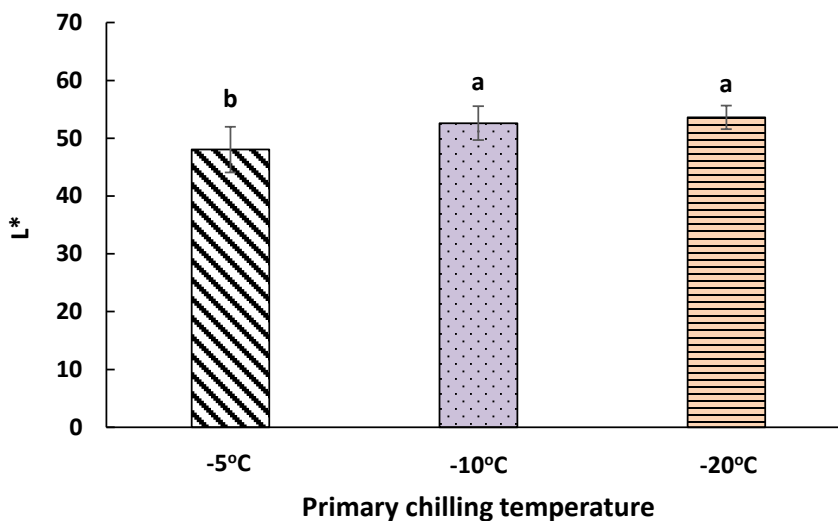**Figure 5.** L* values of the *M. longissimus dorsi* (sirloin) after carcass chilling when primary chilling temperatures at –5°C, –10°C, and –20°C were applied. Different superscript letters indicate statistically significant (P≤0.05).

Conclusions and Discussion

The effects of primary chilling temperature on qualities of carcass, raw meat cut and cooked meat cut were studied. Temperature profiles of the carcass suggested that higher primary chilling temperature resulted

in longer chilling period. Ice glazing on the sample surface was observed when chilling temperature of –20°C was applied. This consequence was according to high humid (88.5–95.0%) in chilling room together with low chilling temperature.

At the end of primary chilling period, surface temperature of the sample chilled at -20°C reached 0°C, the freezing point of water, thus making water turned into ice. Ice formation on the pig carcasses' skin was occasionally detected by the previous studies. Wal van der [3] reported that there was ice glazing on carcass surface when primary rapid chilling (-30°C, 30 min) at high air velocities (4 m/s) was used. Nevertheless, there was no mention of ice formation in the study of Tomović, et al. [5] when the primary rapid chilling (-31°C, 180 min) at 5 m/s of air velocity was applied. Different results might be due to the difference of relative humidity in the chilling room. Unfortunately, both studies did not reveal the relative humidity within the primary chilling room. Unlike the sample chilled at -20°C, the samples chilled at -10 and -5°C presented lower chilling rate and their surface temperatures were at 9 and 13°C, respectively. Hence water did not change its phase.

Weight loss of the carcasses was significantly lower when lower primary chilling temperature was applied ($P \leq 0.05$). The carcasses experienced primary chilling temperature at -20°C had minimum weight loss of $1.57 \pm 0.7\%$ while those at -5°C and -10°C presented weight loss of $2.06 \pm 0.18\%$ and $1.98 \pm 0.23\%$, respectively (Figure 4). This was expected since the experiment was undertaken under high humidity (85.8-95.0%) and carcasses were water-sprayed during initial period of chilling. It was found that less water evaporated from carcasses as surface temperature decreased, especially, at surface temperature of 0°C. At that temperature, water turned into ice and thus preventing moisture loss from the carcass surface (Figure 3). The results are in agreement with other previous studies which reported that rapid primary chilling of carcasses (e.g., -30°C for 0.5-3 h) resulted in significant weight loss (1.3-1.4%) comparing with conventional chilling (approximately 2.0%) [3, 5]. Wal van der et al. [3] concluded that decrease of chillng temperature resulted in a relative high amount of water condensed on carcass surface. Thus making weight loss decreased.

Primary chilling temperatures had no significant effect on both pH 45 min and pH 24 h (Table 2). In the literature, pH 45 min of less than 5.7-6.0 were typically used as an index for identification of PSE pork meat [1, 6]. Normal pork meat was identified when pH 24 h is ranged 5.5-5.8 [6] or 5.8-6.2 [7]. On the other hand, Saleem and Majeed [2] demonstrated that meat became susceptible to shortening when meat with pH 45 min of more than 6.2 is cooled to a temperature less than 10°C. According to this information, it is obvious that neither PSE meat nor cold shortening occur in our study. It was noticed that the carcass experienced primary chilling temperature at -20°C presented the lowest pH. This was due to ice glazing on the carcass surface. Though the protective layer of ice prevented moisture migration, it limited heat transfer from the carcass resulting in heat accumulation inside. This phenomenon accelerated

anaerobic metabolism, therefore, lactic acid increased.

Drip loss of raw meat was not affected by primary chilling temperature (Table 2). In another word, low chilling temperature did not affect water holding capacity of the raw meat. However, sample color in term of lightness was slightly different. The sample undergone lower primarily chilled temperature tended to demonstrate higher lightness values due to the fact that the samples had lower pH. As the pH decreased, proteins in the myofibers were denatured and lose some water in cells which made meat color slightly pale with a washed-out appearance. The decrease of shear force was also noticed due to the collapse of sarcomeres [8]. Many researches reported that rapid chilling at $-20°C$ to $-40°C$ with an air velocity of 3-5 m/s resulted in a higher ultimate pH (pH 24 h = 5.47-5.77), lower drip loss (1.5-3.9%) and darker meat color (L* = 45.74-57.32), comparing to conventional chilling [3, 5, 8]. Furthermore, there was no significantly difference of the ultimate pH, drip loss, and lightness (L*) color of meat between primary chilling temperatures of $-5°C$ and $-30°C$ [3]. Rapid primary chilling may increase the risk of cold shortening because it resulted in shorter sarcomeric segments in muscle and lower meat tenderness, comparing to conventional chilling [3, 9]. It seems that drip loss in our research is in line with these previous studies whilst our results of color and shear force were in the opposite way. This might be because the color of meat surface is not only affected by the pH, but also amount of marbling and connective tissue, size of muscle fibers, denaturation of sarcoplasmic protein as well as the amount of state of myoglobin [10]. On the other hand, it was observed that shear force of the raw meat showed negative correlation with weight loss. This can be explained by the definition of shrinkage, the per cent loss of mass, expressed by Drumm and McKenna [4]. The higher weight loss, the more sample shrinkage and thus the higher shear force.

It was noticed that the influence of minimum weight loss extended to quality of cooked meat. Cooked meat exposed to primary chilling temperature at $-20°C$ had slightly cooking loss ($29.11\pm5.40\%$). However, magnitude of the effect was not significant ($P>0.05$) (Table 2). It was in agreement with the results of Juárez, et al. [11] and Li, et al. [12]. On the other hand, Tomović, et al. [5] demonstrated that rapid chilling ($-30°C$, 3h) improved the cooking loss (38.1%), comparing to conventional chilling (42.5%). It was mentioned that the cooking loss depended on the meat pH. The higher pH 24 h value, the lower cooking loss [5, 13]. Texture analysis results indicated that all TPA values were not affected by primary chilling temperatures ($P>0.05$) (Table 2). However, the low value of hardness (23.31 ± 5.03 kg/cm^2), gumminess (11.33 ± 3.68 kg/cm^2), and chewiness (5.69 ± 2.27 kg.s/cm^2) were detected when the low primary chilling temperature at $-20°C$ was applied. This result was similar to the results of shear force demonstrated in Table 2, which

confirmed that there was no risk of cold shortening occurring in our study.

In summary, primary chilling temperature had no significant effect on pH of carcass, drip loss of raw meat, cooking loss and texture quality of cooked meat ($P>0.05$). The low primary chilling temperature did not induce PSE meat due to pH 45 min of carcasses from all temperature treatments were higher than 6.2 and their core temperature were approximately 35°C. The samples, primary chilled at -20°C, had the significantly lowest weight loss and shear force ($P\leq0.05$) which implied that showering the carcasses at initial stage of chilling together with high humidity environment could prevent carcass shrinkage as indicated by weight loss. These insights of physicochemical changes as affected by chilling process can inform the future developement of guideline to optimize chilling process of porcine production. However, further studies conducted in other aspects such as porcine carcass (species and fat content) as well as chilling room (air velocity and relative humidity) are required to confirm the best product quality.

Acknowledgements

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