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Abstract

The purpose of this study was to determine the specific effects of extending the interval between dwell time and the duration of scalding on pork quality attributes. Sixty-four Duroc × Yorkshire pigs were randomly assigned to a 2 × 2 factorial treatment arrangement. Treatments included extending the dwell duration from 5 to 10 min and extending the scald duration from 5 to 8 min. All carcasses entered the cooler 50 min after exsanguination. At exsanguination, blood was collected for three 1-min intervals and then for a final 2-min period. Temperature and pH of the LM and semimembranosus muscle (SM) were measured at 45 min, and at 2, 4, 6, and 24 h postmortem (PM). Hunter L*, a*, and b* values were determined on the LM, SM, and biceps femoris (BF). Purge loss was measured on the SM, BF, and the sirloin end of the loin. Drip loss was measured in duplicate from LM chops after 1 and 5 d of storage. Warner-Bratzler shear force (WBS) measurements were determined on LM chops aged 1, 3, 5, and 7 d PM. Over 99% of the collected blood was obtained during the first 3 min after sticking. Carcasses scalded for 8 min had greater ($P < 0.05$) semi-membranosus 2 h temperature (28.8°C) than carcasses scalded 5 min (27.3°C). An 8-min scald process resulted in longissimus dorsi chops with lower hue angle and greater WBS values than the 5-min scald process. Increasing dwell time from 5 to 10 min resulted in biceps femoris chops with greater hue angle and loin chops with greater WBS values at 3 d PM. Harvest processes did not significantly affect subjective quality scores, Hunter L* values, purge or drip loss. Lengthening the duration of dwell and scalding may result in a more rapid PM pH decline. Reducing the duration of scalding may lead to increased time for manual removal of hair. Because of differences in facilities, it is recommended that individual facilities monitor dwell and scald durations to determine how to best minimize time of entry into the cooler.

Keywords

evisceration, exsanguination, pork quality, scalding

Disciplines

Agriculture | Animal Sciences | Meat Science

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Influence of harvest processes on pork loin and ham quality¹

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ABSTRACT: The purpose of this study was to determine the specific effects of extending the interval between dwell time and the duration of scalding on pork quality attributes. Sixty-four Duroc × Yorkshire pigs were randomly assigned to a 2 × 2 factorial treatment arrangement. Treatments included extending the dwell duration from 5 to 10 min and extending the scald duration from 5 to 8 min. All carcasses entered the cooler 50 min after exsanguination. At exsanguination, blood was collected for three 1-min intervals and then for a final 2-min period. Temperature and pH of the LM and semimembranosus muscle (SM) were measured at 45 min, and at 2, 4, 6, and 24 h postmortem (PM). Hunter L*, a*, and b* values were determined on the LM, SM, and biceps femoris (BF). Purge loss was measured on the SM, BF, and the sirloin end of the loin. Drip loss was measured in duplicate from LM chops after 1 and 5 d of storage. Warner-Bratzler shear force (WBS) measurements were determined on LM chops

aged 1, 3, 5, and 7 d PM. Over 99% of the collected blood was obtained during the first 3 min after sticking. Carcasses scalded for 8 min had greater ($P < 0.05$) semimembranosus 2 h temperature (28.8°C) than carcasses scalded 5 min (27.3°C). An 8-min scald process resulted in longissimus dorsi chops with lower hue angle and greater WBS values than the 5-min scald process. Increasing dwell time from 5 to 10 min resulted in biceps femoris chops with greater hue angle and loin chops with greater WBS values at 3 d PM. Harvest processes did not significantly affect subjective quality scores, Hunter L* values, purge or drip loss. Lengthening the duration of dwell and scalding may result in a more rapid PM pH decline. Reducing the duration of scalding may lead to increased time for manual removal of hair. Because of differences in facilities, it is recommended that individual facilities monitor dwell and scald durations to determine how to best minimize time of entry into the cooler.

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INTRODUCTION

A harvest facility is responsible for maintaining the level of pork quality provided by the producer. Variations in pH (Homer and Matthews, 1998) and ultimate pork quality can occur from plant to plant (Hambrecht et al., 2003). Within a plant, procedures used at key locations such as stunning (Channon et al., 2002), bleeding, hair

removal (Maribo et al., 1998; Troeger and Woltersdorf, 1986), and chilling (McFarlane and Unruh, 1996; Milligan et al., 1998) are expected to influence the quality of meat produced.

There are several processes on the slaughter floor that can influence the rate of heat removal. These include exsanguination, hair removal, and evisceration. Sosnicki et al. (1998) suggested a minimum of 5 min be given for adequate bleeding. Shortening the duration of the blood collection process would allow the carcasses to enter the scald tank, and ultimately the cooler, at an earlier time postmortem (PM). Scalding periods of up to 9 min may be needed for adequate hair removal (van der Wal et al., 1993). However, carcass temperature may increase during extended scalding (Honkavaara, 1989; van der Wal et al., 1993). Reducing the duration of scalding allows for earlier evisceration and entry into the cooler, which may minimize protein denaturation due to prolonged exposure to high muscle temperatures. Removal of viscera also expedites carcass chilling. A delay in the time to evisceration has been shown to increase drip loss

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(Eldridge et al., 1993) and produce paler meat (Eldridge et al., 1993; D'Souza et al., 1998). The objective of the present study was to determine the extent to which duration of blood collection and scalding affect pH decline, temperature decline, and meat quality.

MATERIALS AND METHODS

Animals

Sixty-four halothane-negative Duroc × Yorkshire gilts (n = 32) and barrows (n = 32) each weighing approximately 113 kg were harvested using humane practices at the Iowa State University Meat Laboratory, Ames. All pigs originated from the same farm and were held in lairage without feed overnight. Four harvest groups (16 pigs per group) over a 4-wk period were used. The interval between sticking and scalding (dwell time of 5 or 10 min) and duration of scalding (5 or 8 min) were assigned to barrow and gilt carcasses in a 2 × 2 factorial treatment arrangement. Each of the resulting four treatments contained 16 pigs with an equal number of barrows and gilts in each.

Harvest Conditions

Pigs were immobilized using a head-only electric hog stunner (Model ES, Best and Donovan, Cincinnati, OH) at 300 V for 3-4 s and hung vertically before exsanguination. Blood was collected each minute for the first 3 min of exsanguination and for a final 2-min period. Total blood volume was determined over the 5-min bleed time. Total blood weight was determined as the sum of all four collection periods. Values reported are based on a percentage of the total volume of blood collected and as a percentage of the live weight.

All carcasses were held in a scald/dehairing tank (Oscar Baumann GmbH Co. type BM 20, Pioneer Food Equipment, Penns Grove, NJ) at 61°C. Depress S silicone anti-foam (DuBois Chemicals, Sharonville, OH) was added to the water to aid in foam reduction and hair removal. The hair was mainly removed by rotating paddles, which ran on a 5-min cycle. To prevent excessive physical damage to the carcass, a passive treatment without paddle rotation was used for the last 3 min of scalding for carcasses in the 8-min scald treatments. After removal from the scald tank, carcasses were scraped with a knife and singed to remove any remaining hair. Following singeing, carcasses were showered with cold water and eviscerated. The time at the initiation of evisceration (time to evisceration) was recorded for each carcass. To ensure PM chilling did not mask the treatment effects, all carcasses entered the cooler at 50 min PM.

PM Temperature and pH

Core temperature of the LM at the last rib on the right side of the carcass was measured with a digital

thermometer immediately after each carcass was taken out of the scald tank (Electro-therm IT670A thermometer, Cooper Instrument Corp., Middlefield, CT). Core temperature and pH of the LM (at the last rib) and the semimembranosus muscle (SM) on the right side of the carcass were measured at 45 min and at 2, 4, and 6 h PM. Temperature and pH were measured in the LM, SM, and the biceps femoris (BF) at 24 h PM on the left side of the carcass. Temperature measurements at 45 min and at 2, 4, 6, and 24 h PM were taken with a Thermocouple Thermometer Dual J-T-E-K Model No. 600-1040 (Barnant Company, Barrington, IL). pH was measured with a glass penetration pH electrode (pH-Star, SFK Technology, Inc., Kolding, Denmark). The pH probe was calibrated using 2 buffers (pH 4.0 and pH 7.0) at the temperature of the muscle at each time period and was checked after measurement on each carcass.

Sample Collection

At 24 h PM, samples from the LM, SM, and BF were excised from the left side of the carcass. Before fabrication, backfat thickness at the last rib was measured on the left side of each carcass. Two 2.54-cm-thick LM chops were removed approximately 2.54 cm anterior to the ileum pocket. These samples were used for color, drip loss, and subjective analysis. The remaining posterior end of the boneless loin (sirloin end, approximately 1.2 kg) was used for purge analysis. From a point immediately anterior to the previously mentioned LM chops, four 2.54-cm-thick chops were removed for Warner-Bratzler shear force (WBS) analysis. A 2.54-cm-thick cut chop from the SM was removed from the posterior end of the muscle and used for color analysis. The remainder of the SM (approximately 1.4 kg) was used for purge analysis. A 2.54-cm cut was removed from the center portion of the BF for color analysis, and the remainder (approximately 1.2 kg) was used for purge analysis.

Color and Subjective Quality Analysis

Hunter L*, a*, and b* values were determined at 1 d PM on 2.54-cm-thick chops from the LM, SM, and BF. Samples were allowed to bloom for a minimum of 1 h at 4°C and were analyzed on a calibrated Hunter lab Labscan colorimeter (Hunter Associated Laboratories Inc., Reston, VA). A CIE D – 65 10° standard observer and a 1.27-cm viewing port were used to obtain 4 color measurements on each of 2 LM chops. All 8 color measurements were used to determine an average color score for the LM on each carcass. Four BF and 5 SM measurements were taken on one chop from each muscle to determine an average color value. Using a* and b* values, saturation and hue angle were calculated on all 3 muscles. Saturation was calculated as $[(a^{*2}) + (b^{*2})]^{1/2}$, and hue angle was calculated in degrees as $[\tan^{-1}(b^*/a^*)]$ (Little, 1975).

Subjective color, firmness, wetness, and marbling scores were assigned for each LM chop 24 h PM by an

experienced panel ($n = 3$). Chops had an average of 60-min bloom time prior to evaluation. Both the National Pork Board (NPB; 1 = pale, 6 = dark) and Japanese (JCS; 1 = pale, 6 = dark) color standards were used to determine an average color score for each loin. Firmness and wetness were evaluated on a 3-point scale (Berg, 2000; 1 = soft and wet, 3 = firm and dry). Marbling values were based on NPB standards (Berg, 2000).

Water-Holding Capacity

Drip loss was measured in duplicate using 2.54-cm-thick LM chops. At 24 h PM, chops were placed in a plastic bag under atmospheric conditions at 4°C. Immediately before being placed in bags, chops were towel-dried and the initial weight of the chops was recorded. After 1 d of storage, samples were removed from their individual bags and were towel-dried and weighed. The chops were then placed in new bags and stored for an additional 4 d. Following 5 d of storage, chops were again towel-dried and weighed. Drip loss after 1 and 5 d of storage was calculated as a difference between final and initial weight expressed as a percentage of the initial weight.

Purge loss was measured on the sirloin, SM, and BF after 7 d of storage at 1°C in a vacuum bag. Before storage, samples were towel-dried to remove excess surface moisture, weighed to determine initial weight, and vacuum packaged. After storage, samples were removed from their packaging, towel-dried, and weighed. Purge loss was calculated as a percentage of the final weight from each location compared with the initial weight.

Warner-Bratzler Shear Force

Loin chops (2.54 cm thick) were stored in a vacuum bag at 1°C for 3, 5, or 7 d PM. After aging, chops were frozen in a -20°C freezer for 5 wk. The chops were then held at 4°C for 24 h and subsequently broiled in an electric broiler (Model 685; General Electric, Chicago Heights, IL) to an internal endpoint temperature of 71°C. After broiling, the chops were cooled overnight to 1°C before measurement. The chops were allowed to equilibrate at room temperature before coring. Four 1.27-cm-diameter cores were removed from each chop parallel to the muscle fibers. The WBS measurements were obtained using a TA.TX2 Texture Analyzer (Texture Technologies Corp., Scarsdale, NY). The tests were performed using a Warner-Bratzler Probe and Guillotine Set (number TA-7B, USDA). The probe was lowered 30 mm from the point of resistance; the penetration speed was 3.3 mm/s. All data were collected using Texture Expert software Version 1.22 (Stable Micro Systems, Ltd., Surrey, UK).

Statistical Analysis

All data were analyzed using SAS Version 8.2 (Cary, NC), and significance is reported at the $P < 0.05$ level. For response variables on a continuous scale, a full mixed

model with a $4 \times 2 \times 2 \times 2$ completely randomized design was used. The factors were date of slaughter (4), scald time (2), dwell time (2), and sex of the animal (2). When date of slaughter did not affect the results, a reduced $2 \times 2 \times 2$ randomized complete block design (block = date of slaughter) was utilized. Temperature and pH of the BF used the full model, but fat thickness, Hunter color, saturation, hue angle values, and purge loss were analyzed with the reduced model. The SM pH was analyzed repeatedly over PM time; thus, a repeated measures full mixed model was used. The whole plots were date of slaughter, scald time, dwell time, sex of animal, and their interactions in a completely randomized design. For the remaining repeated measures (temperature/pH of the LM, temperature of the SM, and WBS), the previously mentioned reduced model with a split plot in time was more appropriate. The whole plots were scald time, dwell time, sex of animal, and their interactions in a randomized complete block design (block = slaughter date). Over the analysis of all continuous data, higher order interactions (e.g., date \times scald \times dwell \times sex) for response variables were dropped when there was no evidence of a lack of fit for the reduced model. These variables were tested with a lack of fit F -test.

For the response variables (NPB color, JCS, firmness, wetness, and marbling) that were discrete, tests for independence between treatments and response were conducted using Fisher's exact test. Because of the size of the contingency tables, the exact statistic (and P -value) was estimated with a Monte Carlo method (Agresti et al., 1979) based on 100,000 samples.

RESULTS AND DISCUSSION

There were no treatment differences for live weight, dressing percentage, hot carcass weight, and the interval between stunning and sticking (data not shown). The average live weight and dressing percentage among all groups were 113.68 kg and 77.38%, respectively. The average interval between stunning and sticking was 47.7 s.

Barrows had more ($P < 0.01$) fat at the last rib than gilts (2.45 vs. 2.19 cm, respectively). In the present study, barrows had greater ($P < 0.05$) L^* values in the SM (52.5 vs. 51.1) compared with gilts, but this was the only quality characteristic significantly influenced by gender. Adipose has a lower thermal conductivity than muscle (van der Wal et al., 1993), and because of this, variation in backfat thickness may result in greater PM muscle temperatures.

In a preliminary study, we observed that market weight (~115 kg) pigs could be adequately bled within 5 min of sticking. For this reason, blood was not collected after 5 min for carcasses in the 10-min dwell treatment groups. The total collected blood, on average, accounted for 3.55% of live weight and 4.59% of HCW. These amounts are slightly lower than the 4.1 and 5.3% of the live and carcass weights, respectively, reported by Warriss and Wotton (1981) in lighter weight pigs (63 kg

Table 1. Least squares means for percentage of blood, based on the amount collected and the live weight of the animal, during the first 5 min after sticking ($n = 61$)

Time after sticking, min	% of blood collected	SEM	% of blood based on live wt	SEM
0–1	90.77	0.56	3.22	0.04
1–2	7.33	0.43	0.26	0.02
2–3	1.33	0.15	0.05	0.005
3–5	0.57	0.08	0.02	0.003
Total	100		3.55	0.05

live weight). As shown in Table 1, 90.77% of the collected blood was obtained during the first minute after sticking and more than 99.4% was obtained during the first 3 min. These results are similar to those reported by Warriss and Wotton (1981) in which, on average, approximately 99.6% of the blood was collected in 2.5 min.

Sosnicki et al. (1998) suggested a minimum of 5 min should be given for adequate bleeding of the carcass. In our personal communications with commercial facilities, we found bleed times varied from 2 to 10 min. Reducing the amount of blood collected can have negative consequences for slaughter companies. Blood accounts for 60% of the total protein available from meat animal by-products, and recovered proteins can be used in sausage and other processed meat formulations (Ockerman and Hansen, 2000). The average value of blood is \$1.66 per pig (Gralapp-Gonzalez and Goodwin, 2002). With the data from the present study, 99.43% (\$1.65) of that value can be achieved during the first 3 min after initiation of bleeding. In addition, meat quality may be improved by decreasing the time from exsanguination to entering the cooler (D'Souza et al., 1998; Eldridge et al., 1993), and a reduction in the dwell time would allow carcasses to enter the cooler at an earlier time point. If an improvement in quality can be achieved through a reduction in dwell times, more product would be eligible for premium and export markets.

Eldridge et al. (1993) found delaying the time to evisceration by 8 min resulted in significantly more drip loss and lighter colored lean. Similarly, (D'Souza et al., 1998) reported that carcasses with a delayed time to evisceration had significantly greater L^* values. In the present study, removal of the viscera occurred, on average, 8 min later for carcasses with 10-min dwell duration and 8-min scald duration compared to carcasses with 5-min dwell and 5-min scald duration (Table 2). The difference in the timing of evisceration was expected to lead to differences in carcass temperature while on the slaughter floor. However, no significant differences in 45-min temperature were detected ($P > 0.05$; Table 2). Previous studies have reported that the time spent from stunning to splitting had only a minor effect on carcass temperature (Honkavaara, 1989).

Time to evisceration was added to the statistical model to determine if the duration between stunning and evis-

ceration affected any of the meat quality measurements. None of the loin and ham measurements of temperature, pH, color, or WHC were affected by time to evisceration ($P > 0.05$). Previous studies (Eldridge et al., 1993; D'Souza et al., 1998) have found that increasing the amount of time from stunning to evisceration (up to 20 min) negatively affects pork quality. Neither study reported at what time the carcasses were allowed to enter the cooler. The effects of time to evisceration on meat quality might have been due to an earlier or later entry into the cooler. If a constant time for carcass entry into the cooler is not set, it is difficult to discern which is more important, time to evisceration or time into the cooler. In the present study, entry time into the cooler was constant across all carcasses and, under these controlled conditions, time to evisceration played a limited role in determining meat quality.

Dwell \times scald interactions were found to significantly affect temperature of the SM at 2 h ($P < 0.05$), temperature of the BF at 24 h ($P < 0.01$), and WBS at d 7 ($P < 0.05$; data not shown). These are the only measurements of temperature, pH, and the PM quality measures in the loin and ham that were affected by treatment interactions. Therefore, the remaining results will be discussed as the treatment effects within the dwell and scald duration.

There were no differences among dwell or scald times on pH of the LM at any time PM (Table 3). There was a trend for longer scald duration to produce lower LM pH values early PM ($P = 0.073$ at 45 min). The impact of scalding on pH values in the LM decreased over time ($P = 0.10$ at 2 h, $P = 0.14$ at 4 h, $P = 0.30$ at 6 h, and $P = 0.29$ at 24 h). Honkavaara (1989) found that lengthening the scald time from 6 to 6.5 min caused an increase in the rate of glycogen breakdown from 1.1 to 4.1 $\mu\text{mol}/(100 \text{ g} \times \text{min})$. When comparing scalding to skinning of carcasses, Troeger and Woltersdorf (1986) reported that scalding accelerated biochemical reactions in the muscle because of thermal and mechanical influences on the carcass. Accelerated biochemical reactions may lead to a more rapid pH decline. The rate of pH decline early PM can influence protein denaturation and the water-holding properties of meat (Penny, 1969).

Schafer et al. (2002) reported that a model that includes 2 h loin pH and 1 min loin temperature explained 85% of the variation in drip loss. Even though scald time did not significantly influence LM pH in the present study, a trend for carcasses to have a lower pH in the LM early PM was found for carcasses with 8-min scald times compared to those with 5-min times. Therefore, increasing the time the carcass spends in the scald tank has the potential to decrease loin quality.

Although not significant ($P = 0.067$), the longer scald duration tended to increase immediate postscald temperature by 0.19°C. This measurement was taken 3 min later for carcasses in the 8-min scald treatment group compared with those in the 5-min scald treatment group because temperature was measured immediately after scalding, not at a fixed time PM. Therefore, heat removal

Table 2. Least squares means of the time taken from stunning to opening of the carcass (time to evisceration)¹

Treatment combination	n	Time to evisceration	SEM	LM temperature, ² °C	SEM	LM ² pH	SEM
10-min dwell							
8-min scald	16	31:59	0:23	35.5	0.4	6.17	0.07
5-min scald	16	27:49	0:17	36.0	0.4	6.30	0.06
5-min dwell							
8-min scald	16	25:56	0:12	36.1	0.4	6.21	0.06
5-min scald	16	23:59	0:21	35.7	0.3	6.29	0.05

¹The time is reported in minutes for each treatment group with the corresponding temperature (°C) and pH of the longissimus dorsi at 45 min postmortem (measured at the last rib on the right side of the carcass).

²No significant differences were found at the $P < 0.05$ level.

within the muscle was delayed by the longer scald times. A delay in the heat removal from the carcass may influence overall meat quality (van der Wal et al., 1993), and it is possible to produce pale, soft, and exudative lean because of high carcass temperatures for extended periods (Wisner-Pedersen and Briskey, 1961). van der Wal et al. (1993) reported a 2.8°C increase in ham temperature measured between the skin and subcutaneous fat for 5.5 to 7.5 min at 60°C, and Honkavaara (1989) reported an increase of 1.2 ± 1.4 °C in carcass temperature during scalding. A stronger relationship exists between the length of scalding and subcutaneous temperatures than for muscle temperature (van der Wal et al., 1993). Therefore, it can be concluded that heat is absorbed superficially and can be removed quickly.

Dwell time did not influence pH of the SM at any time or the pH of the BF at 24 h PM (Table 3). A longer duration of scalding resulted in greater pH values at 24 h in both the SM and BF ($P < 0.05$). At 2 h, a 5-min

dwell time resulted in a greater ($P < 0.05$) temperature in the SM than did the 10-min dwell time. Carcasses scalded for 8 min had a significantly ($P < 0.05$) greater temperature in the ham at 2 h than those scalded for 5 min. These differences were not evident at 45 min or at times later than 2 h PM. Temperature of the LM, however, was not affected by scald or dwell duration at any time PM (Table 3).

Hunter L* values were not affected by the length of scalding or the dwell time in any of the three muscles (Table 4). In the LM (Table 4), a longer scald time produced a redder (higher a*) and more yellow (higher b*) lean ($P < 0.05$) than shorter scald times. Hue angle, therefore, was significantly greater for carcasses in the 5-min scald treatment, but saturation was unaffected by scald treatments. No dwell treatment differences in the LM were observed for any color measurements. However, carcasses with a 5-min dwell duration had greater b* and saturation values ($P < 0.05$) in the SM (Table 4)

Table 3. Least squares means for temperature and pH in the LM immediately after scalding and at 45 min, 2, 4, 6, and 24 h postmortem, in the semimembranosus (SM) at 45 min, 2, 4, 6, and 24 h postmortem, and in the biceps femoris (BF) at 24 h postmortem

Muscle	Time	Temperature, °C				SEM	pH				SEM
		5-min dwell	10-min dwell	5-min scald	8-min scald		5-min dwell	10-min dwell	5-min scald	8-min scald	
LM ¹	Scalding	39.9	39.9	39.8	40.00	0.07	—	—	—	—	—
	45 min	35.9	35.88	35.8	35.8	0.26	6.25	6.23	6.30	6.19	0.04
	2 h	26.4	27.0	26.4	27.0	0.33	5.88	5.88	5.95	5.82	0.06
	4 h	15.2	15.6	15.2	15.6	0.35	5.78	5.74	5.82	5.71	0.05
	6 h	10.4	10.9	10.7	10.6	0.46	5.70	5.69	5.72	5.67	0.03
	24 h	2.2	2.0	2.1	2.1	0.05	5.57	5.56	5.55	5.58	0.02
SM	45 min	36.2	36.4	36.3	36.3	0.25	6.29	6.23	6.28	6.24	0.07
	2 h	28.8 ^a	27.3 ^b	27.3 ^d	28.9 ^c	0.50	5.88	5.86	5.90	5.83	0.07
	4 h	21.4	21.6	21.5	21.6	0.38	5.64	5.65	5.65	5.64	0.05
	6 h	16.6	17.0	16.5	17.0	0.52	5.55	5.56	5.54	5.57	0.03
	24 h	2.8	2.8	2.9	2.7	0.08	5.59	5.60	5.56 ^d	5.62 ^c	0.02
BF	24 h	2.9	2.9	3.00	2.9	0.05	5.62	5.62	5.58 ^d	5.66 ^c	0.02

^{a,b}For dwell comparisons within a row, means without a common superscript letter differ ($P < 0.05$).

^{c,d}For scald comparisons within a row, means without a common superscript letter differ ($P < 0.05$).

¹No significant differences for LM were found at the $P < 0.05$ level.

Table 4. Least squares means of Hunter color, saturation, and hue angle values for the LM, semimembranosus (SM), and biceps femoris (BF)

Muscle	Item	L*	a*	b*	Saturation	Hue angle
LM	Dwell ¹ – 5 min	56.96	3.03	15.72	16.03	79.22
	Dwell ¹ – 10 min	56.21	3.30	15.33	15.72	78.50
	Scald – 5 min	56.06	2.70 ^d	15.25 ^d	15.04	80.07 ^c
	Scald – 8 min	57.10	3.64 ^c	15.80 ^c	16.25	77.61 ^d
	SEM	0.649	0.191	0.185	0.286	0.397
SM	Dwell – 5 min	52.13	6.72	16.29 ^a	17.66 ^a	67.70
	Dwell – 10 min	51.52	6.20	15.52 ^b	16.74 ^b	68.65
	Scald ² – 5 min	52.29	6.38	16.14	17.39	68.60
	Scald ² – 8 min	51.36	6.54	15.67	17.01	67.26
	SEM	0.443	0.234	0.192	0.285	0.460
BF	Dwell – 5 min	53.03	8.04 ^a	17.12 ^a	18.94 ^a	64.89 ^b
	Dwell – 10 min	52.53	7.12 ^b	15.98 ^b	17.53 ^b	66.25 ^a
	Scald – 5 min	53.28	7.36	16.69	18.27	66.64 ^c
	Scald – 8 min	52.28	7.80	16.41	18.20	64.73 ^d
	SEM	0.645	0.164	0.231	0.295	0.439

^{a,b}For dwell comparisons within a column, means without a common superscript letter differ ($P < 0.05$).

^{c,d}For scald comparisons within a column, means without a common superscript letter differ ($P < 0.05$).

¹For dwell comparisons within a column for the LM, no significant differences were detected ($P < 0.05$).

²For scald comparisons within a column for the SM, no significant differences were detected ($P < 0.05$).

than those in the 10-min treatment. Saturation values, a*, and b* in the BF were significantly ($P < 0.05$) greater for carcasses within the 5-min dwell treatment (Table 4). Yellowness of meat is most affected by the form of myoglobin present (Lindahl et al., 2001). It is not certain that this is the cause of the differences in b* values in the ham because the forms of myoglobin were not measured in the present study. Dwell time affected ($P < 0.05$) the hue angle in the BF; longer dwell times led to greater hue angles. An increase in hue angle values is an indicator of meat discoloration (Hunt and Mancini, 2002).

Neither treatment affected the subjective measures of color, firmness, wetness, and marbling (Table 5). Therefore, lengthening dwell and scald times under conditions similar to those used in this study would not lead to a reduction of meat eligible for premium programs sorted by subjective appraisal.

Treatment differences for L* values were not detected, but a* values were significantly greater ($P < 0.05$) for carcasses with longer scald times. The difference in a* values in the present study may be attributed to small temperature (39.8 vs. 40.0°C at scalding) and pH (6.30 vs. 6.19 at 45 min) differences between the scald times. High temperatures early PM combined with lower pH may decrease enzymatic activity involved in oxygen utilization, resulting in improved color stability (Renner, 1999). This phenomenon is similar to the effect that electrical stimulation can have on the color of meat from beef and lamb carcasses. Electrical stimulation has previously been shown to improve color and color stability through increased glycolytic rates in beef (Cross et al., 1979; Hall et al., 1980) and lamb (Riley et al., 1980) carcasses.

Drip loss in the LM after 1 and 5 d of storage was not affected by treatments (Table 5). Purge loss (measured

Table 5. Subjective quality, drip loss, purge loss, and Warner-Bratzler shear force (WBS) least squares means for dwell time and scald time processes (n = 64)

Item	Dwell time		Scald time		SEM
	5 min	10 min	5 min	8 min	
Loin quality scores					
NPB color ¹	2.5	2.6	2.6	2.6	0.1
JCS ¹	2.3	2.5	2.4	2.4	0.1
Firmness ²	1.8	1.9	1.9	1.9	0.1
Wetness ²	1.8	2.1	2.0	1.9	0.1
Marbling ³	1.6	1.7	1.6	1.6	0.1
Drip loss, ⁴ %					
d 1	2.16	2.09	2.06	2.18	0.25
d 5	4.10	3.93	3.99	4.04	0.25
Purge loss, ⁵ %					
Sirloin	3.60	3.14	3.40	3.34	0.20
SM	3.50	3.37	3.49	3.39	0.22
BF	3.10	3.17	3.39	2.87	0.22
Loin chop WBS, kg					
d 3	3.39 ^w	3.78 ^x	3.52	3.65	0.12
d 5	3.45	3.59	3.44	3.61	0.12
d 7	3.49	3.68	3.42 ^z	3.76 ^y	0.12

^{w,x}For dwell comparisons within a row, means without a common letter differ ($P < 0.05$).

^{y,z}For scald comparisons within a row, means without a common letter differ ($P < 0.05$).

¹National Pork Board (NPB) and Japanese (JCS) color scores are based on a 1 (pale) to 6 (dark) scale assigned by a trained panel (n = 3).

²Firmness and wetness values are based on a 3-point scale (1 = soft, wet to 3 = firm, dry) assigned by a trained panel (n = 3).

³Marbling scores are correlated to the amount of i.m. lipid assigned by a trained panel (n = 3).

⁴Drip loss was measured as percentage of product lost in LM chops after 1 and 5 d of aging.

⁵Purge loss was measured on the sirloin, semimembranosus (SM), and biceps femoris (BF) after 7 d of storage in a vacuum bag.

on the sirloin, SM, and BF after 7 d of storage in a vacuum bag) was also unaffected by dwell and scald treatments (Table 5). With similar PM temperatures and pH values between treatments, significant differences in the water-holding properties were not expected.

Increasing dwell time from 5 to 10 min resulted in greater WBS values in LM chops aged 3 d ($P < 0.05$; Table 5). Scald time significantly affected WBS at d 7; the 5-min scald duration had lower ($P < 0.05$) WBS values. Delaying the time from stunning to evisceration on the slaughter floor could lead to tougher meat; time to evisceration had a positive correlation ($P < 0.05$) to WBS measurements after 3 d ($r = 0.279$) and 7 d ($r = 0.252$) of aging. A trend for a dwell \times scald interaction ($P < 0.10$) existed for WBS values after 3 and 7 d of aging; extended treatment times tended to result in greater WBS values. It is important to note again the interval from stunning to entry in the cooler was standardized for all carcasses. Therefore, time to evisceration may play a small role in determining the variation in WBS values. Overall, shortening of the dwell and scald duration could improve tenderness of pork loin chops.

IMPLICATIONS

This study demonstrates that when time into the cooler is constant, dwell and scald duration only minimally affect pork quality. Therefore, dwell and scald duration, by themselves, do not warrant specific consideration from processors wanting to improve pork quality. However, given the improvements in quality that may result from decreased stun to chill time, as reported by other researchers, it may be beneficial for processors to decrease dwell and scald duration in order to decrease total stun to chill time. Because of differences in facilities, it is recommended that individual facilities monitor dwell and scald duration to determine how the duration of stunning to chilling can be minimized.

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