RESEARCH REPORT
PORK QUALITY

Title: **Influence of commercial deep chilling processes on early postmortem events in muscle that affect ultimate fresh pork tenderness and processing quality – NPB #12-086**

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Industry Summary:

Recent observations and evidence have supported the conclusion that rapid chilling (deep chilling) of pork carcasses in commercial processing plants has the potential to decrease pork tenderness. This is of concern because a loss in quality experienced by the consumer will have a detrimental impact on pork demand in global and domestic markets. The current experiment took an approach to carefully dissect the impact of deep chilling on pork carcasses by evaluating the effect of chilling protocol on pork quality *within carcasses*. This experiment was designed to investigate the direct effect of rapid on the quality of the center cut loin, and also on cuts from the ham, tenderloin, and shoulder. A second objective centered on determining the explanation for difference in tenderness. Finally, an experiment was conducted to determine the effect of the deep chilling process on quality characteristics of a cured and cooked ham.

The results of the study confirm observations that deep chilling of pork carcasses has the potential to decrease tenderness in fresh pork. The results do point out that this effect is not consistent with other muscles. In fact, no other cuts evaluated (from ham, tenderloin, and shoulder) were negatively affected by deep chilling. No consistent alterations in other quality features were observed with deep chilling. The effect of chilling on pork loin tenderness appears to be related to a tendency for the deep chilling method to slow down the normal "aging" process in the loin. Deep chilling of pork carcasses in this study had no consistent or significant effect on cured and cooked ham yields or ham color. In conclusion, deep chilling of pork carcasses does result in less tender center loin chops, but few consistent or meaningful differences in quality or processing parameters of other cuts in the pork carcass. The results suggest that processors should monitor the effects of chilling processes on center loin chop tenderness and consider methods to mitigate the observed consequence of decreased tenderness. Future investigations should address how features of pigs, carcasses and muscles (weight, fat content, metabolic profile) that make this outcome less likely to affect consumer perceived value and eating experience.

III. Keywords:
Pork, Chilling, Tenderness, Sensory Quality, Loin, Ham, Shoulder, Tenderloin

Scientific Abstract:

The objective of the project was to determine the extent to which deep chilling of pork carcasses affects the quality of fresh pork. Specifically the aims of the study were to evaluate the impact of rapid chilling on sensory quality, processing quality, and biochemical properties of pork. On four different days (November 2nd, 2012, slaughter two on February 8, 2013, slaughter three on May 29, 2013) ten carcasses were selected for the experiment. . Carcasses selected were required to be in the range of 86 to 91 kg hot carcass weight and 54 to 57% fat free lean. Carcasses were split immediately after processing and 1 side was deep chilled and the other chilled at 4°C. Deep chilling protocol resulted in a significantly more rapid chilling. Temperature in the loin at 3 hours postmortem was 15°C colder in deep chilled sides compared to those chilled at 4°C (4°C vs. 20°C). Additional manual pH and temperature measurements were taken at 0, 4 and 24 hours postmortem. Samples were taken 24 hours *post-mortem* from the *Psoas Major* (PM), *Longissimus Dorsi* (LD), *Semimembranosus* (SM), and *Triceps Brachii* (TB). Muscles were then packed on ice and transported to Iowa State University. Samples were weighed before vacuum packaging and held for sensory analysis by trained panel. Aged cut pH, color, purge, marbling score, and Minolta L, a and b values were measured. Tenderloin roasts and shoulder cushion roasts were cooked in a convection oven to 68°C. Loin chops and top ham chops were cooked to 68°C. Cooked cuts were used to measure Warner Bratzler Shear force (WBS), Star Probe, and trained Sensory panel evaluation. Bottom hams (biceps femoris and semitendinosus) will be processed within 5 days of slaughter. Hams were pumped to 25 percent of green weight with a brine containing sodium chloride (11%), sugar (6.6%), sodium tripolyphosphate (2.2%), sodium erythorbate (0.295%) and sodium nitrite (0.08%). After tumbling, and maceration, hams will be cooked and then chilled. Ham yield, (pre and post chilling), slicing yield, color and color stability were documented. Samples from every muscle were evaluated for degradation of desmin. At 1 d postmortem calpain autolysis and calpastatin activity were determined in LD samples. Four hour loin pH was significantly greater in deep chilled carcasses (6.34 vs. 6.09). Loin chops (aged 10 days) from deep chilled carcasses had higher WBS values, indicating less tender product. Few other differences in fresh pork loin were noted. Tenderloin cuts (aged 7 days) had greater purge loss in the deep chilled cuts, but the deep chilled tenderloin was determined to be more juicy, more tender, less chewy, and had lower WBS values than the tenderloin from the same carcass that were conventionally chilled. No meaningful or consistent differences in fresh pork quality were noted in comparison of deep chilled and conventionally chilled triceps brachii and semimembranosus. Deep chilling clearly slowed down the rate of inactivation of calpastatin as 24 h calpastatin activity was 10 % greater in loins from deep chilled carcasses compared to their conventionally chilled counterparts. Interestingly, a 40% greater abundance of glycogen phosphorylase was detected in the deep chilled loin cuts at 1 d postmortem. This indicates a greater propensity for glycolysis after 1 d postmortem. This was observed as pH continued to decline in those cuts. Deep chilling did not affect the processing yield or color of cured and cooked hams. deep chilling of pork carcasses does result in less tender center loin chops, but few consistent or meaningful differences in quality or processing parameters of other cuts in the pork carcass. The consistent decrease in loin tenderness may be related to slower metabolism and protein degradation in early postmortem muscle.

An overview of the researchable question and its importance to producers.

It is well understood that inadequate chilling will increase the likelihood of production of pork that exhibits PSE (pale, soft and exudative) qualities (Briskey, 1959; recently reviewed by Barbut et al., 2008). Denaturation of myoglobin (Kazemi, et al., 2011) and myosin (Offer, 2001) are clearly the root of the development of poor quality pork. In a report that retains great value to researchers, Offer (1991) focused on myosin denaturation as the primary factor that explains variation in water holding capacity in fresh pork. Offer (1991) proposed a model that demonstrated that increasing the chilling rate causes a remarkable decrease in myosin denaturation and thus an improvement in pork water holding capacity. Rapid chilling can also slow

pH decline as the glycogen de-branching enzyme activity is greatly reduced at temperatures below 15°C (Kyla-Puhju et al., 2005).

Statement of the problem

In the course of meat science investigations in pork quality, the vast majority of the data supported the working understanding that more rapid chilling is advantageous to slow down pH decline and decrease the opportunity for myofibrillar and sarcoplasmic protein denaturation. Recent evidence reported by Shackelford et al. (2012) gave a clue that chilling too rapidly could result in an increase in pork toughness. *In fact, Shackelford et al. (2012) demonstrated that facilities that utilized CO2 stunning and deep chilling produced resulted in a 13 fold increase in frequency of chops measured as excessively tough when compared to conventional spray chilling.* Importantly, the blast chilling in this experiment did not create additional quality advantages in color or water holding capacity. The main difference was that blast chilling resulted in pork with higher shear force values.

There could be several reasons for this observation. One is that the rapid chilling allows cold shortening in pork. Cold shortening is a common observation in rapidly chilled beef and lamb, but seldom in pork. The effect that cooling rate has on muscles is linked to the metabolism of the muscle and the rate at which the pre-rigor postmortem muscle utilizes the energy precursors/ substrates creatine phosphate and ATP. The early postmortem development of rigor proceeds through gradual phases. Immediately after exsanguination, there is a delay period during which very few rigor bonds form and the muscle is still very extensible. During this period, the level of ATP is still constant, in part, because creatine phosphate is still available to regenerate ATP from ADP. Once the available reserves of creatine phosphate are depleted, the level of ATP begins to decline rapidly leading to the loss of the ability of myosin to dissacocciate from actin. Thus the development of rigor bonds proceeds at an increasing rate, leading to the potential shortening of the myofibril – hence this phase is often referred to as the rapid onset phase of rigor development (Bendall and Swatland, 1988). Temperature of the muscle during the pre and post-rigor phase can have a profound effect upon the metabolism of the muscle (Marsh, 1954) and it is most likely the effect of this temperature on muscle metabolism that governs the rate and extent of shortening that is seen at various temperature extremes. Muscle fibers also differ in their rate of ATP use. In addition, oxidative fibers are particularly susceptible to cold temperatures. One of the key events in cold shortening is the accelerated loss of calcium sequestering ability of the sarcoplasmic reticulum, especially in oxidative fibers. Therefore, another factor to consider is the fiber type composition of the muscles. Rapid temperature decline could increase muscle shortening, especially if the muscles contain a high amount of oxidative fibers. In a related observation, psoas major muscles (a proportional greater amount of oxidative fibers) demonstrate a rapid pH decline that is likely stimulated by chilling and a less developed sarcoplasmic reticulum (Melody et al. 2003).

With respect to the effect of temperature, rigor shortening is affected dramatically by the early postmortem temperature of the muscle. A minimal degree of shortening occurs when pre-rigor muscle is exposed to temperatures in the range of 14-20°C. The extent of shortening that occurs in the range of 0-10°C can result in sarcomeres that are 50 % of their normal length. In direct contrast, a great deal of shortening can occur when the pre-rigor muscle is held at temperatures in the range of 20-40°C. The least amount of rigor shortening occurs when pre-rigor muscle is allowed to go into rigor at 15-20°C. The degree of shortening in this temperature range is about 10%. These observations bring up the obvious implications of how chilling temperatures that carcasses are exposed to can influence the tenderness of meat. Because of microbiological concerns, obviously it is not feasible to hold carcasses/meat at temperatures of 15-20°C during the pre-rigor period. However, it does raise the question of what happens to some of the deeper muscles of the carcass during the cooling period. An example of one possible solution is stepwise chilling in which the temperature is quickly dropped to 10-15°C, held at that temperature for up to 6 hours to allow rigor to proceed, then further chilled to 4°C or less (Rees et al., 2003, Rosenvold et al., 2010). It has been suggested that this type of cooling system would prevent cold shortening, yet would cool the surface of product enough that microbial growth would be limited (Rosenvold, et al., 2010). In the aforementioned experiment conducted by Shackelford et al.

(2012), sarcomere length was not affected by chilling. However, sarcomere length was negatively correlated with shear force, indicating that the less tender pork had myofibrils with shorter sarcomeres.

Temperature has the potential to affect protein degradation as well. Rapid pH decline is very likely to inactivate the calpain enzymes and arrest proteolysis (Barbut et al., 2008). Rapid chilling will likely decrease the activation of calpain in the early postmortem period and perhaps decrease the extent of proteolysis. Gardner et al. (2005) evaluated the effect of pH and temperature on progression proteolysis in pork chilled in a conventional manner (6 h temperature range was 4.7-14.9°C) and documented that lower 6 hour postmortem pork longissimus dorsi temperature was correlated to less activation of μ-calpain and less degradation of desmin. Less activation of μ-calpain and less degradation of desmin are indicative of a product that will demonstrate less proteolysis over time and tend to be less tender (Melody et al. 2004) and perhaps have poorer water holding capacity (Bee et al., 2007; Huff-Lonergan and Lonergan, 2005; Huff-Lonergan et al. 2010). In a different study, Rosevenold et al. (2010) demonstrated that more rapid chilling (4 h loin temperature approximately 4°C) vs. delayed chilling (4 h loin temperature approximately 14°C) resulted in less myofibrillar fragmentation, and less tender pork loin chops. That same experiment showed less no effect of chilling on loin desmin degradation or sarcomere length. Shackelford et al. (2012) showed that deep chill increased shear force, but not protein degradation. However, there was less postmortem degradation in the pork that had higher shear force values.

The literature illustrates that conditions that promote protein denaturation are likely to result in poor quality pork with very little functionality (classically referred to as PSE). Obviously, greater chilling rates can decrease this potential (Offer, 1991). Clearly rapid chilling improves product yield, product color, and fresh pork shelf life. The question of how rapid chilling might affect cold shortening and proteolysis in fresh pork is still not answered.

Description of the approach

U.S. pork producers have made a significant investment in money, energy and resources to improve the efficiency of production of high quality pork for consumers of U.S. pork across the globe. It is important to recognize that chilling processes in place to improve safety, shelf life, yield, and fresh pork quality could have a negative impact on fresh pork tenderness. At this point, there is some evidence that this may be the case (see the included literature review). The results presented here include ***within pork carcass comparisons*** to determine how the rate of chilling of several very important pork cuts (loin chops, tenderloin chops, pork top ham and pork shoulder) influences the development of tenderness of those cuts. One of the key strengths of the approach used in this experiment is that the design to use within pork carcass comparisons.

Objectives:

Determine the influence of chilling rate on fresh pork quality.

Determine the influence of chilling on postmortem proteolysis and protein profile in fresh pork during aging.

Determine the extent to which chilling rate influences processing characteristics of cured and cooked hams.

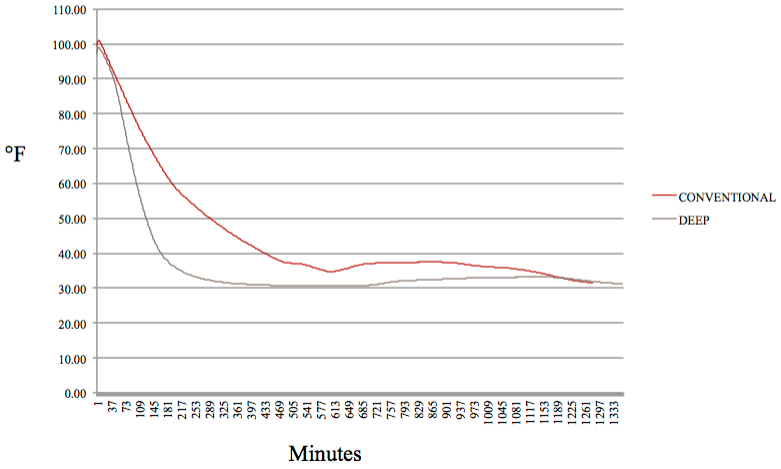
Materials & Methods:

Four replications were conducted (November 2012, February 2013, May 2013, and August 2013. Ten pork carcasses were selected approximately 35 minutes after slaughter. Selection occurred 35 minutes postmortem (prior to entering the chilling regime) and required carcasses to be within a weight range of 87-92 kg and a composition range of 54-57 % Fat Free Lean. Each carcass was split and re-hung with a side from a different carcass. The resulting design is included in Table 1. This design allowed a within carcass comparison of treatment differences. Loin temperature was measured continually and the differences in temperature are noted in Figure 1.

Table 1. Carcass and side assignment to treatment.

Gambrel	Carcass	Side	Chilling regime
1	1	Right	Deep
1	2	Left	Deep
2	1	Right	Conventional
2	2	Left	Conventional
3	3	Right	Deep
3	4	Left	Deep
4	3	Right	Conventional
4	4	Left	Conventional
5	5	Right	Deep
5	6	Left	Deep
6	5	Right	Conventional
6	6	Left	Conventional
7	7	Right	Deep
7	8	Left	Deep
8	7	Right	Conventional
8	8	Left	Conventional
9	9	Right	Deep
9	10	Left	Deep
10	9	Right	Conventional
10	10	Left	Conventional

Figure 1. Chilling rate for conventional and deep chilled carcasses (Loin temperature)



Carcasses were fabricated at 20 hours postmortem and boneless loins, tenderloins, top hams, bottom hams, and shoulder cushions were collected from each side. Loins, tenderloins, top hams and shoulder cushions were used for Objective 1. Loins were used for Objective 2. Bottom hams were vacuum packaged and used for objective 3.

Determine the influence of chilling rate on fresh pork quality.

Ultimate pH was measured on all cuts at 30 postmortem. Cuts were evaluated after aging: Tenderloins (Day 7), Loins (Day 12), top hams (Day 10), and Picnic cushions (Day 14). Aged cut pH, color, purge, marbling score, and Minolta L, a and b values were measured. Tenderloin roasts and shoulder cushion roasts were cooked in a convection oven to 68°C. Loin chops and top ham chops were cooked to 68°C. Cooked cuts were used to measure Warner Bratzler Shear force, Star Probe, and trained Sensory panel evaluation.

Determine the influence of chilling on postmortem proteolysis and protein profile in fresh pork during aging.

Samples from each muscle were aged at 2°C for 2 and 7 days. Autolysis μ-calpain, and degradation of troponin T, and desmin were determined on all samples (Rowe et al., 2004). Calpastatin activity was measured in all loin samples and protein profile was determined on samples aged 2 days (Lonergan et al. 2001). Loin samples were extracted to determine protein profile differences due to differences in chilling using 2D-DIGE (Anderson et al., 2012). Eight carcasses were used for the DIGE experiment.

Determine the extent to which chilling rate influences processing characteristics of cured and cooked hams

Bottom hams (biceps femoris and semitendinosus) will be processed within 5 days of slaughter. Hams were pumped to 25 percent of green weight with a brine containing sodium chloride (11%), sugar (6.6%), sodium tripolyphosphate (2.2%), sodium erythorbate (0.295%) and sodium nitrite (0.08%). After tumbling, and maceration, hams will be cooked and then chilled. Ham yield, (pre and post chilling), slicing yield, color and color stability were documented.

Results:

Determine the influence of chilling rate on fresh pork quality.

Different muscles and cuts were affected in various ways. This within carcass comparison allows very controlled comparisons. No significant differences in quality were noted in the triceps brachii muscle (shoulder cushion), documenting that chilling procedure could not be expected to affect water holding capacity, color or sensory quality of fresh pork shoulder cuts (Table 2).

Table 2. Effect of chilling protocol on physical and sensory properties of fresh shoulder roast from triceps brachii (14 days postmortem).

	Conventional Chilling	Deep Chilling	SEM	P-Value
Purge (%)[a]	0.99	0.97	0.005	0.92
Cook loss (%)[b]	18.3	17.87	0.010	0.63
pH (14 day)	6.01	6.03	0.03	0.86
Marbling score[c]	2.8	3.0	0.07	0.06
Color Score[d]	3.5	3.5	0.07	0.63
L Value[e]	35.6	35.5	0.33	0.84
a* value[e]	16.0	16.0	0.09	0.96
b* value[e]	2.6	2.5	0.09	0.98
Star probe [f]	4.93	4.99	0.11	0.63
WBS[g]	2.91	3.10	0.09	0.16
Sensory Juiciness[h]	6.8	7.0	0.15	0.25
Sensory Tenderness[h]	6.7	6.7	0.16	0.99
Sensory Chewiness[h]	3.8	4.1	0.19	0.28
Sensory Flavor[h]	3.5	3.3	0.07	0.20
Sensory Off-flavor[h]	1.1	1.0	0.04	0.33

[a] Percent product lost during postmortem storage in a vacuum sealed bag.
[b] Percent product lost during cooking for sensory evaluation (68°C).
[c] Marbling score based on National Pork Board standards
[d] Color score based on National Pork Board Standards
[e] Minolta L*, a* and b* values (Lightness, degree of redness, and degree of yellow)
[f] Force necessary to compress a cooked chop to 20 % of its original height with a five pointed star probe (kg).
[g] Force necessary to shear a 1.3 cm core of cooked meat with a Warner-Bratzler shear device (kg).
[h] Sensory score on a 10 point scale (10 points = greatest degree of juiciness, tenderness, chewiness, flavor, and off-flavor; 1= least degree of juiciness, tenderness, chewiness, flavor, and off-flavor).

Sensory quality of fresh pork tenderloin in response deep chilling has not been reported in the literature. Using this controlled design, we document that deep chilled tenderloins have greater purge loss in storage. We hypothesize that this is due to freezing of this exterior muscle (exterior to the dressed carcass). Despite this purge loss difference, deep chilling resulted in more tender and juicy pork tenderloin (Table 3).

Table 3. Effect of chilling protocol on physical and sensory properties of fresh tenderloin roast from psoas major (tenderloin) (7 days postmortem).

	Conventional Chilling	Deep Chilling	SEM	P-Value
Purge (%)[a]	0.47	0.74	0.05	0.02
Cook loss (%)[b]	10.99	10.44	0.05	0.23
pH (10 day)	6.01	6.02	0.03	0.90
Color Score[c]	3.8	4.0	0.09	0.11
L Value[d]	39.0	39.0	0.48	0.98
a* value[d]	14.7	14.6	0.23	0.80
b* value[d]	1.4	1.4	0.11	0.91
Star probe [e]	2.40	2.39	0.07	0.91
WBS[f]	2.55	2.47	0.07	0.48
Sensory Juiciness[g]	7.5	8.3	0.17	<0.01
Sensory Tenderness[g]	7.9	8.6	0.20	<0.05
Sensory Chewiness[g]	2.8	2.1	0.16	<0.01
Sensory Flavor[g]	3.5	3.7	0.09	0.12
Sensory Off-Flavor[g]	1.3	1.3	0.11	0.93

[a] Percent product lost during postmortem storage in a vacuum sealed bag.
[b] Percent product lost during cooking for sensory evaluation (68°C).
[c] Color score based on National Pork Board Standards
[d] Minolta L*, a* and b* values (Lightness, degree of redness, and degree of yellow)
[e] Force necessary to compress a cooked chop to 20 % of its original height with a five pointed star probe (kg).
[f] Force necessary to shear a 1.3 cm core of cooked meat with a Warner-Bratzler shear device (kg).
[g] Sensory score on a 10 point scale (10 points = greatest degree of juiciness, tenderness, chewiness, flavor, and off-flavor; 1= least degree of juiciness, tenderness, chewiness, flavor, and off-flavor).

Aged fresh pork loin pH, water holding capacity and color were not affected by deep chilling. However, deep chilling resulted in greater WBS values and suggested less tender pork . A sensory tenderness difference supported this finding, but only on the first and fourth slaughter group. We are continuing investigations to determine what this might indicate. Sarcomere length was not affected by deep chilling (Table 4).

Table 4. Effect of chilling protocol on physical and sensory properties of fresh pork loin chops from the longissimus dorsi. (12 days postmortem)

	Conventional Chilling	Deep Chilling	SEM	P-Value
Purge (%)[a]	2.21	2.28	0.01	0.82
Cook loss (%)[b]	18.73	20.6	0.01	0.03
pH (10 day)	5.68	5.67	0.02	0.85
Marbling score[c]	2.2	2.3	0.11	0.73
Color Score[d]	2.5	2.5	0.09	0.92
L Value[e]	49.1	49.1	0.38	0.95
a* value[e]	13.7	13.8	0.13	0.61
b* value[e]	2.8	2.9	0.08	0.43
Star probe [f]	5.26	5.33	0.13	0.21
WBS[g]	3.17	3.64	0.11	<0.05
Sensory Juiciness[h]	7.1	7.0	0.15	0.75
Sensory Tenderness[h]	7.0	6.6	0.19	0.19
Sensory Chewiness[h]	3.7	4.0	0.24	0.33
Sensory Flavor[h]	3.6	3.6	0.10	0.94
Sensory Off-flavor[h]	1.5	1.3	0.12	0.18
Sarcomere Length (µm)	1.41	1.40	0.01	0.43

[a] Percent product lost during postmortem storage in a vacuum sealed bag.
[b] Percent product lost during cooking for sensory evaluation (68°C).
[c] Marbling score based on National Pork Board standards
[d] Color score based on National Pork Board Standards
[e] Minolta L*, a* and b* values (Lightness, degree of redness, and degree of yellow)
[f] Force necessary to compress a cooked chop to 20 % of its original height with a five pointed star probe (kg).
[g] Force necessary to shear a 1.3 cm core of cooked meat with a Warner-Bratzler shear device (kg).
[h] Sensory score on a 10 point scale (10 points = greatest degree of juiciness, tenderness, chewiness, flavor, and off-flavor; 1= least degree of juiciness, tenderness, chewiness, flavor, and off-flavor).

Deep chilling had few consistent effects on fresh top ham (Table 5). Deep chilling did show a small decrease in ham "a" color value, but the practical significance of such a difference is not large.

Table 5. Effect of chilling protocol on physical and sensory properties of fresh ham chops from semimembranosus. (10 days postmortem)

	Conventional Chilling	Deep Chilling	SEM	P-Value
Purge (%)[a]	2.74	2.69	0.005	0.81
Cook loss (%)[b]	19.33	18.54	0.005	0.17
pH (10 day)	5.75	5.80	0.03	0.26
Marbling score[c]	2.3	2.4	0.09	0.30
Color Score[d]	3.0	3.2	0.09	<0.05
L Value[e]	41.8	41.2	0.46	0.40
a* value[e]	15.6	15.3	0.12	<0.05
b* value[e]	2.7	2.5	0.09	0.17
Star probe [f]	5.81	5.80	0.19	0.90
WBS[g]	4.23	4.22	0.19	0.91
Sensory Juiciness[h]	6.9	6.9	0.10	0.80
Sensory Tenderness[h]	6.1	5.9	0.20	0.37
Sensory Chewiness[h]	4.8	5.1	0.22	0.33
Sensory Flavor[h]	3.4	3.4	0.07	0.38
Sensory Off-Flavor[h]	1.3	1.1	0.05	0.12

[a] Percent product lost during postmortem storage in a vacuum sealed bag.
[b] Percent product lost during cooking for sensory evaluation (68°C).
[c] Marbling score based on National Pork Board standards
[d] Color score based on National Pork Board Standards
[e] Minolta L*, a* and b* values (Lightness, degree of redness, and degree of yellow)
[f] Force necessary to compress a cooked chop to 20 % of its original height with a five pointed star probe (kg).
[g] Force necessary to shear a 1.3 cm core of cooked meat with a Warner-Bratzler shear device (kg).
[h] Sensory score on a 10 point scale (10 points = greatest degree of juiciness, tenderness, chewiness, flavor, and off-flavor; 1= least degree of juiciness, tenderness, chewiness, flavor, and off-flavor).

Determine the influence of chilling on postmortem proteolysis and protein profile in fresh pork during aging.

In a separate experiment, loin samples were collected from carcasses chilled as described in objective 1. Deep chilling resulted in a trend for greater WBS values, significantly greater star probe values, and greater calpastatin activity (Table 6). In this experiment, loin pH at 32 h was greater in response to deep chilling. It is noteworthy that deep chilling resulted in a protein profile that had a 40% greater abundance of glycogen phosphorylase in sample taken 1 d postmortem. We hypothesize that this allowed pH decline to continue in the deep chilled loins. It is most likely that deep chilling only decreased the rate of glycolysis and not the extent. A greater abundance of metabolic enzymes, including fructose bisphosphate aldolase, glyceraldehyde 3-phosphatase and phosphoglucomutase were all in lesser abundance due to deep chilling. Since this experiment was within carcass, these differences were clearly due to treatment and not any antemortem factors.

Table 6. Parameters of quality in the experiment to determine protein profile differences in pork in response to chilling regime.

	Conventional Chilling	Deep Chilling	SEM	P-Value
WBS (kg)[a]	2.9	3.4	0.3	0.09
Star probe (kg)[b]	6.3	7.1	0.4	0.04
Sensory Tenderness[c]	7.2	6.4	0.4	0.16
Calpastatin activity (u/g tissue)	1.1	1.2	0.04	0.04
32h pH	5.70	5.80	0.03	0.04
12 d pH	5.67	5.68		

[a] Force necessary to shear a 1.3 cm core of cooked meat with a Warner-Bratzler shear device (kg). (
[b]Force necessary to compress a cooked chop to 20 % of its original height with a five pointed star probe (kg).
[c]Sensory score on a 10 point scale (10 points = greatest degree of tenderness; 1= least degree of tenderness).

Determine the extent to which chilling rate influences processing characteristics of cured and cooked hams.

Chilling protocol had no significant impact on the yield or color of cured and cooked hams from the bottom hams (semitendinosus and semitendinosus). We had hypothesized that more rapid chilling would avoid myofibrillar protein denaturation and therefore greater water holding capacity and cook yield. We had also hypothesized that more rapid chilling protocol would result in less myoglobin denaturation and thus a "darker" and "redder" cured ham. Neither hypothesis was supported by the data. In addition, chilling regime did not affect color stability of the ham.

Table 7. Effect of chilling protocol on cook yield and color of cured hams from fresh bottom hams.

Trait	Conventional Chilling	Deep Chilling	Standard Error of mean	P Value
Cured Ham Cook Yield	91.9%	92.1%	0.15	0.28
L*	67.8	68.0	0.58	0.88
a*	16.1	16.2	0.37	0.77
b*	11.9	11.8	0.27	0.70

Discussion:

The results of the study confirm observations that deep chilling of pork carcasses has the potential to decrease tenderness in fresh pork – specifically cuts from the longissimus dorsi. The results do point out that this effect is not consistent with other muscles. In fact, no other cuts evaluated (semimembranosus, triceps brachii, psoas major) were negatively affected by deep chilling. No consistent alterations in other quality features were observed with deep chilling. The effect of chilling on pork loin tenderness appears to be related to a tendency for the deep chilling method to slow down the normal "aging" process in the loin. Deep chilling of pork carcasses in this study had no consistent or significant effect on cured and cooked ham yields or ham color. In conclusion, deep chilling of pork carcasses does result in less tender center loin chops, but few consistent or meaningful differences in quality or processing parameters of other cuts in the pork carcass. The results suggest that processors should monitor the effects of chilling processes on center loin chop tenderness and consider methods to mitigate the observed consequence of decreased tenderness in the pork loin. Future investigations should address how features of pigs, carcasses and muscles (weight, fat content, metabolic profile) that make this outcome less likely to affect consumer perceived value and eating experience.

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