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# The Effects of Freezing and Thawing Rates on Tenderness and Sensory Quality of Beef Subprimals

Jerilyn Hergenreder
*University of Nebraska-Lincoln*, jerilynhergenreder@gmail.com

# The Effect of freezing and thawing Rates on Tenderness and Sensory Quality of Beef Subprimals

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Jerilyn E. Hergenreder

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# The Effects of Freezing and Thawing Rates on Tenderness and Sensory Quality of Beef Subprimals

Jerilyn E. Hergenreder, M.S.

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Advisor: Chris R. Calkins

To evaluate processing methods for frozen beef subprimals, the effects of freezing and thawing rates on tenderness and sensory properties were evaluated. There were six treatments: fresh-never-frozen 14-day wet aged, fresh-never-frozen 21-day wet aged, blast frozen–fast thawed, blast frozen–slow thawed, conventionally frozen–fast thawed, and conventionally frozen–slow thawed (all frozen subprimals were aged for 14d prior to freezing). Three subprimal cuts - ribeye rolls (n = 90), strip loins (n = 90), and sirloins (n = 90) - were utilized with three replications of five samples per treatment per week (total of 9 weeks, N = 270). Blast freezing occurred by placing spacers between the boxes of meat on pallets at -28° C with high air velocity for 3 – 5 d until all the meat was frozen, and then the pallets were moved to a -28°C freezer for storage. Conventional freezing occurred with boxes of meat stacked on pallets and placed in a -28° C freezer with minimal air movement, the pallets were left in the freezer until shipping. Fast thawing of subprimals (to an internal temperature of -2° to 0° C) occurred by immersion in a circulating water bath (< 12° C) for 21 hrs, and slow thawing of subprimals occurred over a two week period by placing individual subprimals on tables at 0° C. Purge loss was measured after thawing. Steaks (2.5 cm thick) were cut from the *longissimus thoracis* (LT), *longissimus lumborum* (LL), and *gluteus medius* (GM) for Warner-Bratzler shear force (WBS) and trained sensory evaluation. Sensory samples were rated for tenderness,

juiciness, connective tissue, and off-flavor after cooking to 71° C. Slow thawed subprimals had the greatest amount of purge loss ($P < 0.001$) in the LT, LL and GM. Fast thawed subprimals were equal or had less purge loss to fresh-never-frozen 14- and 21-d aged subprimals ($P < 0.0001$) in the LT, LL and GM. For LL and GM steaks, frozen treatments were equal or lower in WBS values to fresh-never-frozen 14- and 21-d aged steaks. For LL and LT steaks, slow thawed steaks we equal or lower in WBS when compared to fast thawed steaks ($P = 0.01$). No differences were detected in WBS among the GM steaks ($P = 0.08$). There were no differences in sensory tenderness within the LL, LT, and GM ($P > 0.05$). Juiciness in the LL and GM ($P > 0.05$) did not differ among treatments. The LT fresh-never-frozen 14- and 21-d aged product was juicier than the frozen product ($P = 0.001$). Differences were not detected in connective tissue in the LT or GM ($P > 0.05$). A greater amount of connective tissue was detected in the slow thawed LL compared to the fast thawed LL ($P = 0.02$). There were no differences in off-flavor in the LT and LL ($P > 0.05$). Conventionally frozen-fast thawed steaks had the strongest prevalence of off-flavor ($P = 0.02$) in the GM. Overall, freezing rate did not affect purge loss, and neither freezing nor thawing rates had significant meaningful effects on Warner-Bratzler shear force and sensory and were comparable to fresh-never-frozen subprimals.

Key words: Beef, freezing method, thawing method

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Table of Contents

# INTRODUCTION

The goal of this study was to evaluate processing methods for frozen beef subprimals. The effects of freezing and thawing rates on purge loss, tenderness and sensory properties were evaluated. Typically in the U.S., meat is either stored fresh before selling or frozen and stored for later use. Most of the steaks in the U.S. are sold as fresh steaks and have a wide range of postmortem aging. The fresh steaks range from 3 – 83 days of aging in the retail case with the average days of aging at 22.6, and a range 7 – 136 days of aging in foodservice with the mean aging time being 30.1 days (Savell et. al., 2007). The desired aging period for beef is at least 11 days postmortem (Smith et. al., 1978). With this range it is hard to guarantee a high quality consistent eating experience to consumers.

Freezing meat increases tenderness due to cellular disruption by the freezing process (Hiner et al., 1945; Shanks et al., 2002). Others have found that freezing does not affect tenderness or sensory traits (Paul and Child, 1937). An increase in drip loss has been observed when freezing meat (Paul and Child, 1937). However, freezing meat at faster rates decreases purge loss because the majority of the ice crystals are intramuscular, causing less damage to the fiber allowing for the moisture to be maintained within the fiber (Grujic et al., 1992; Hiner et al., 1945; Paul and Child, 1937; Petrovic et al., 1993; Ramsbottom and Koonz, 1939). If meat can be frozen and thawed with minimal drip loss and no adverse affects on shear force and sensory attributes, a company could offer a more consistent product to the consumers.

In addition to supplying the consumers with a more consistent product, meat companies may also be able to save money. The cost of subprimals primarily used for steaks fluctuates throughout the year. The summer months are popular for steaks, increasing the prices of these subprimals, and the winter months are more popular for roasts, decreasing the demand of the steak subprimals (Namken et al., 1994). The prices of subprimals can also dramatically vary from year to year depending on the economy of the country. From 2006 – 2010 the ribeye roll experienced a decrease in price as high as 35% while the price of the clod heart increased as much as 40% due to the declining economy (USDA Annual Meat Trade Reviews, 2006; 2007; 2008; 2009; 2010).

The objective of this study was to evaluate freezing and thawing procedures for fresh subprimals. More specifically, this study focused on two objections: 1) determine if freezing method had significant effects on purge loss, tenderness and sensory attributes, and 2) determine if thawing methods had significant effects on purge loss, tenderness and sensory attributes.

## REVIEW OF LITRATURE

### Economics

Data from the previous five years of the USDA Annual Meat Trade Reviews (USDA Annual Meat Trade Reviews, 2006; 2007; 2008; 2009; 2010) shows the price of cuts fluctuate throughout the year. Temperature and season have a significant effect on price (Marion and Walker, 1978). The large subprimals primarily used for roasts stay at a fairly steady price throughout the year. These cuts slightly increase in price in the winter or cooler months of the year. Namken et al. (1994) found that demand for cuts used mostly for roasts were highest from November through February from 1980-1990.

The data from the past 5 years of the USDA Annual Meat Trade Reviews show that the largest price decrease in the shoulder clod and gooseneck occurs in May and June (shoulder clod down 7% and gooseneck down 12%, from January price). Marion and Walker (1978) found that sales of all beef products sampled except for the round were the highest in the warm summer months and autumn quarters.

Higher cost subprimals primarily used for steaks experience more drastic price changes throughout the seasons then the subprimals used mostly for roasts do. The strip loin and top sirloin butt follow the same seasonality demand throughout the year. The strongest warm season demand for strip steaks during the year is the period which contains Memorial Day (Namken et al., 1994). The top sirloin butt has the highest demand in the spring and summer, with a seasonal pattern that is pronounced and regular (Namken et al., 1994). Namken et al. (1994) reported that November-December were the months that demand for strip loins and top sirloin butts were at their lowest. The trends held true for more recent data (USDA Annual Meat Trade Reviews, 2006; 2007; 2008; 2009; 2010). Strip loin prices were up has high as 31% when looked at on a weekly basis and 29% on a monthly basis in the summer months, particularly May, when compared to January prices. Strip loin prices decrease up to 12% on a weekly basis and 10% on a monthly basis in November and December when compared to January prices. Top sirloin butts follow the same trend with price spikes up 30% on a weekly basis and 23% on a monthly basis in May, with the other summer months still having higher prices when compared to January's prices. The top sirloin butt decreased as much as 15% on a

weekly basis and 12% on a monthly basis in December when compared to prices from January.

Namken et al. (1994) found that seasonal demand for the ribeye was erratic, but at its highest relative price in November-December and lowest in January to April. The USDA Annual Meat Trade Reviews (2006; 2007; 2008; 2009; 2010) show the same trends (Appendices 29 - 40) reported by Namken et al. (1994) for the prices from 1980-1990. The ribeye experienced an increase of 13% on a weekly basis and 12% on a monthly basis primarily in July, and an increase of 30% on a weekly basis and 20% on a monthly basis in November and December when compared to January prices. The ribeye only decreased in price in February when compared to January (4% on a weekly basis, and 2% on a monthly basis). Overall, the months with the lowest demand for ribeye are January and February, and the months having the highest demand for ribeyes are November and December.

Several studies have found that seasonality tends to be the main driver behind the change in prices (Capps, Jr. et al. 1994; Marion and Walker, 1978; Namken et al., 1994). Capps, Jr. et al. (1994) also found that marketing costs were generally significant determinants of wholesale beef cut prices, however the impacts are relatively small in magnitude. Another study found an increase in beef advertising costs was associated with an increase in beef sales, however that effect was relatively small as well (Funk et al., 1977). Namken et al. (1994) found that theory and observation in the market suggests that a substitute (purchasing pork or chicken instead of beef) relation exists, but the

seasonal demand changes appear to be so strong they apparently mask the influence of other factors.

To save money many further processing companies purchase subprimals when the subprimals are at lower prices and freeze them. An anonymous beef industry source stated companies do 2 "power buys" a year in which they obtain the majority of the product they will need throughout the year. This requires the company to freeze the meat to keep the quality. When meat is lower priced the company is freezing everything they are buying, and when the prices of the subprimals are expensive they are not freezing any of it (Anonymous Beef Industry Source, 2011). Every time the product is moved it costs money, so when subprimals are expensive everything is kept fresh. Too conventionally freeze meat costs 0.1 cents more per pound than keeping it fresh. To blast freeze costs 0.2 cents more per pound then it costs to store fresh meat (Anonymous Beef Industry Source, 2011). To temper the meat costs another 0.1 cents per pound, and every time the meat is handled and moved it costs about 0.1 cents per pound (Anonymous Beef Industry Source, 2011). With 2 annual buys, the preference is to have subprimals frozen for 3-9 months with the target being 5 months (Anonymous Beef Industry Source, 2011). This makes it possible to capitalize on product prices throughout the year. When prices are at their highest very little fresh product is purchased. Instead frozen product is tempered for use (Anonymous Beef industry Source, 2011). It is important to factor in storage, freezing, and tempering prices into the overall cost of a subprimal.

**Postmortem Aging**

Postmortem aging of meat has long been known to improve meat tenderness. There are many proteolytic enzymes involved in the tenderization of meat through postmortem aging. Research has also been done to determine the sufficient days of aging to improve tenderness.

The use of vacuum bags to age meat has become widely used because storing meat in vacuum bags to age rather than leaving the carcass intact takes up less room (Minks and Stringer, 1972). By using vacuum bags to age meat, the meat can age in transit and experience less drip (purge) loss. The use of vacuum bags also decreases the amount of bacterial contamination on the meat (Minks and Stringer, 1972).

The proteolysis of key myofibrillar proteins is the principle reason for improvement of tenderness during postmortem aging (Koohmaraie, 1994). The degradation of the proteins results in greater fragmentation of myofibrils, with the most fragmentation at or near the Z-line (Huff and Parrish, 1993; Koohmaraie, 1994; Parrish et al., 1973; Taylor et al., 1995). Goll et al., (1992) reported that 90% or more of the tenderization that occurs during postmortem storage in the first 7-10 days is due to calpains. Some forms of calpain enzymes bind to myofibrillar structures resulting in proteolytic degradation and tenderization (Boehm et al., 1998). Caplains mainly degrade titin, nebulin and troponin-T as well vinculin, desmin and dystrophin which are all proteins constituting costameres (Boehm et al., 1998; Taylor et al., 1995). Calpains do not degrade actin and myosin (Koohmaraie, 1994; Taylor et al., 1995).

The two large myofibrillar proteins that are broken down are titin and nebulin. Titin and nebulin are anchored at their N- and C-terminal ends respectively, in the Z-disk (Taylor et al., 1995). Each titan molecule spans from the Z-line to the M-line (Furst et al., 1988). Nebulin composes part of the skeletal muscle thin filaments (Huff-Lonergan et al., 1995). Titin and nebulin together make up the $N_2$ lines which have been reported to be largely degraded in 3 days postmortem (Taylor et al., 1995). Huff-Lonergan et al. (1995) reported that titin was completely degraded at 14 days postmortem and nebulin was completely degraded 7 days postmortem. Animals reported to be more tender experienced faster degradation of titin (7 days) and nebulin (3 days) postmortem (Huff-Lonergan et al., 1995). Bandman and Zdanis (1988) found that titin breakdown starts the $1^{st}$ day of aging postmortem and is completely broken down by 3 weeks. Troponin-T is also degraded in postmortem beef and is positioned periodically along the thin filaments (Olson et al., 1977). All three of these proteins are located within the I-band regions of intact myofibril, and their combined disruption may contribute significantly to myofibril fragmentation (Huff-Lonergan et al., 1995).

Three of the eight proteins that constitute the costameres are degraded by calpains (Taylor et al., 1995). Taylor et al. (1995) found that the degradation of costameres may significantly weaken the muscle structure. The costamere structures are lost during the first 24 to 72 hours postmortem, and this parallels the loss of $N_2$ lines in postmortem meat (Taylor et al., 1995). The loss of the costameres and the $N_2$ lines during the same time period results in a major increase in tenderness (Taylor et al., 1995).

The ultra structural changes observed postmortem are usually gaps or tears in the I-band area or near the Z-disks (Huff and Parrish, 1993; Koohmaraie, 1994; Parrish et al., 1973; Taylor et al., 1995). These tears in the I-band began to appear after 3 days postmortem and become increasingly larger with longer periods of time postmortem (Ouali, 1990).

Nishimura et. al. (1998) concluded that shear values decreased rapidly up to 10 days postmortem due to myofibrillar structures weakening and structural changes in perimysial connective tissue do not occur within the first 10 days. Huff and Parrish (1993) concluded that connective tissue had less to do with postmortem tenderization than did myofibrillar tenderization that occurred as myofibrils became more fragmented with increased days postmortem. However, after 10 days postmortem there is structural weakening of the endomysium and perimysium (Nishimura et al, 1998). Nishimura et al. (1996) reported that endomysium degraded into individual collagen fibrils, and thick sheets of perimysium separated into collagen fibers 4-8 μm in diameter for beef aged for more than 14 days postmortem. Even though changes in connective tissue do not parallel tenderization during aging of meat, connective tissue can have an impact on tenderness. Muscle enzymes do not act on connective tissue, so older animals that have higher levels of connective tissue do not respond to aging (Bouton and Harris, 1972).

Taylor et al. (1995) reported that 65-80% of all postmortem tenderization occurs the first 3-4 days when the costameres and $N_2$ lines are degraded. Most studies evaluating days of aging postmortem are done on day 3 or 4 and then in 7-day increments. Huff and Parrish (1993) found that aging meat past 3 days postmortem

significantly decreased shear values, with 7 day postmortem steaks having significantly lower shear force values than 3 day postmortem steaks. Miller et al. (1997) and Jeremiah and Gibson (2003) reported that aging beef for 14 days significantly lowered Warner-Bratzler shear force values compared to 7 days of aging. Smith et al. (1978) recommended that beef be aged for at least 11 days to achieve optimal tenderness response. Several studies have shown a significant decrease in shear force values up to 20 days of aging (Huff and Parrish, 1993; Jennings et al., 1978; Jeremiah and Gibson; 2003). Conversely George et al. (1999) found that strip loin steaks with fewer than 7-days aging were significantly tougher. There was no difference in shear force values of strip loin steaks aged 7 – 35 days however, these are all days aging post fabrication and not postmortem (George et al., 1999).

Postmortem aging is done to improve palatability and tenderness is only one part of palatability. Smith et al. (1978) found that aging beef for 11 days was associated with a significant increase in flavor desirability, tenderness and overall palatability. Miller et al. (1997) showed that aging beef for 14 days significantly improved all sensory traits compared to beef aged for 7 days. Sapp et al. (1999) found that steaks aged for 21 days were more tender and palatable than steaks aged for 7 or 14 days. Aging beef for 14 days rather than 3 days improved tenderness and beef flavor intensity ratings and decreased the percentage of those ratings of less than or equal to 5.0 on an 8-point sensory scale (Wheeler et al., 1999). However, Jennings et al. (1978) found there were no substantial improvements in palatability between beef aged for 10 days versus beef aged for 20 days.

In summary, postmortem aging of beef improves tenderness and palatability (Huff and Parrish, 1993; Smith et al., 1978). Studies have also shown that 3 days of aging is not sufficient to maximize tenderness (Smith et al., 1978; Wheeler et al., 1999). Aging meat for 14 days postmortem has been suggested to improve the consistency of beef tenderness and palatability (Miller et al., 1997; Wheeler et al., 1999).

**Freezing and Thawing Meat**

Freezing rate and ice formation within meat has been studied, with the majority of studies concluding that freezing meat at a faster rate decreases purge loss (Bevilacqua et al., 1979; Hiner et al., 1945; Petrovic et al., 1993; Ramsbottom and Koonz, 1939). When meat is frozen ice crystals or dendrites form within the meat. The rate at which the meat is frozen highly correlates with the formation of the dendrites and where they form. The initial freezing point of meat is -1°C, and at -7°C 80% of the water within meat is frozen (Bevilacqua et al, 1980).

The effects of freezing rates on formation of intra- and extra-cellular ice have been studied. More specifically, Menegalli et al. (1978) evaluated the characteristics and shape of the ice at different freezing rates. The type of ice structure formed depends on the temperature gradient especially in large samples of meat (Bevilacqua et al., 1979; Menegalli et al., 1978). Menegalli et al. (1978) observed the complex behavior of freezing meat which derives from dendritic ice crystal growth. Dendritic growth starts on the outside of the cell, growing in those cells as small crystals until they touch and join to become larger crystals, penetrating further into the meat (Menegalli et al., 1978). Only 6% of ice is formed during dendritic solidification (the majority of extracellular fluid is

frozen); the rest of the freezing is completed through cooling of the dendritic skeleton which was initially formed (Menegalli et al., 1978). Bevilacqua et al. (1980) and Menegalli et al. (1978) have defined three zones of freezing. The first region is very close to the outside of the sample or the portion of the sample in contact with the freezer. This is where nucleation (proteins catalyze the formation of ice crystals) takes place, and the ice in this zone is small crystals within the fibers. Intracellular ice is observed at short characteristic freezing times (less than 4 min) (Bevilacqua et al, 1979; Bevilacqua et al., 1980). The intracellular ice was shaped like needles and resulted in minimal damage to the fibers (Bevilacqua et al., 1980). The second zone is more distant from the surface, and this is the region where dendrites are found intra- and extra- cellularly. There are a smaller number of intracellular crystals and the dendrites get larger in size (Bevilacqua et al., 1979; Bevilacqua et al., 1980). The extracellular ice columns grow faster than intracellular ice in this zone (Bevilacqua et al., 1980). The third zone is the center of the cut. This is where extracellular ice is exclusively found. The ice crystals are much larger in size as they move towards the thermal center because the cooling effect takes longer to reach the center allowing larger ice crystals to form, greatly deforming fibers (Bevilacqua et al, 1979; Bevilacqua et al., 1980; Menegalli et. al., 1978). Bevilacqua et. al. (1979) and Hiner et al. (1944) found that the extracellular ice grows at the expense of water from inside of the cell because the interfibrillar fluid became concentrated through the freezing process. The fibers suffer from dehydration, becoming distorted and contract, adopting irregular shapes. The extracellular ice grows in columns towards the interior of the meat in the opposite direction of the heat flux (Bevilacqua et al., 1980).

Changes in freezing rate are followed by changes in location and size of ice crystals. When meat is frozen at a slower rate or warmer temperatures, there is considerably more damage done to the fibers and myofibrils (Hiner et al., 1945; Paul and Child, 1937; Petrovic et al., 1993). Freezing meat at warmer temperatures or slower rates allows more time for water to be drawn out of the fibers by the ice crystals resulting in greater weight loss during freezing, thawing and cooking, a lower water binding capacity and tougher meat (Petrovic et al., 1993). Slower freezing also allows for larger ice crystals to form within the meat that are so large that the fibers rupture (Hiner et al., 1945). Furthermore the biochemical reactions which lead to meat deterioration do not stop at freezing temperatures above -20°C (Grujic et al., 1993). Freezing meat at temperatures below the eutectic point (lowest possible temperature of solidification for any mixture of specified constituents) (-70°C) results in a greater number of smaller ice crystals within the fibers, and a significant disturbance of the muscle ultrastructure (Grujic et al., 1993; Petrovic et al., 1993). Freezing meat at this cold of a temperature (-70°C) had an adverse effect on quality (Grujic et al., 1993; Petrovic et. al., 1993). The meat is drier than meats frozen at a warmer temperature because many of the cells are destroyed by the extremely cold temperature (-70°C) and are unable to soak up and support all of the moisture loss during freezing (Grujic et al., 1993; Petrovic et al., 1993). Several papers reported that faster and colder freezing rates resulted in less drip loss because the cells did not experience as much damage and can still maintain the water (Grujic et al., 1993; Hiner et al., 1945; Paul and Child, 1937; Petrovic et al., 1993; Ramsbottom and Koonz, 1939). The colder the temperature the less time there is for

water to transfer out of the cell (Hiner et al., 1945). The optimum conditions for freezing are reported to be at a rate of 2 - 5 cm/h at a temperature between -40 to -60°C (Petrovic et al., 1993).

The majority of these studies were done on single steaks. Ramsbottom and Koonz (1939) found that the rate of freezing does not appear to be an important factor in the control of drip loss, if the volume of meat is large in comparison with the area of the cut surface of the muscle tissue. The large cut has the opportunity to reabsorb the "frozen out" water (Ramsbottom and Koonz, 1939). If the volume of meat is small in comparison with the area of the cut surface freezing rate is important because with a faster rate the amount of drip loss can be materially reduced (Ramsbottom and Koonz, 1939). Paul and Child (1937) found that frozen beef roasts had significantly greater total moisture loss than fresh, never-frozen roasts. Freezing, thawing and cooking losses were significantly greater if roasts were thawed at 175°C than if they were thawed at 24-25°C, however the thawing temperature did not affect drip loss, total moisture or tenderness of roasts (Paul and Child, 1937). Overall, Paul and Child (1937) found that total moisture loss, drip loss and tenderness of cooked beef roasts were unaffected by freezing and by different thawing temperatures.

Freezing meat is thought to affect tenderness due to the cell disruption from the ice crystals (Hiner et al., 1945). Paul and Child (1937) found that tenderness was unaffected by freezing or different thawing temperatures. This conclusion contradicts other research. Hiner et al. (1945) found less and less resistance to shear as freezing temperature decrease, while Shanks et al. (2002) discovered that frozen steaks had lower

Warner-Bratzler shear force values than fresh steaks. Another study found that there was not a significant effect on palatability due to freezing (Lee et al., 1950).

**Tenderness**

Beef tenderness can be affected by many things. Tenderness is reported to be the most important palatability attribute to the consumer (Smith et al., 1978; Miller et al., 1995), with 51% of the consumers considering tenderness the attribute they most want in a steak at home and in a restaurant (Huffman et al., 1996). The National Beef Tenderness Survey (Savell et al., 2007) reported a range of 3 – 83 days of aging in the retail case with the average days of aging at 22.6, and a range 7 – 136 days of aging in foodservice with the mean aging time being 30.1 days. The broad ranges of days of aging can highly affect tenderness of beef and overall consumer acceptance. Miller et al. (2001) reported that the industry produces about 15 – 20% tough steaks that are sold to consumers.

The variability in aging and overall tenderness of beef led researchers to find a way to determine acceptable tenderness levels for consumers. The Warner-Bratzler shear force device provides an objective assessment of meat tenderness (Shackelford et al., 1991). The first tenderness threshold values for Warner-Bratzler shear force (WBS) were reported at 4.6 kg for retail and 3.9 kg for food service (Shackelford et al., 1991). These values were further supported by other studies (4.1 Huffman et al., 1996; 4.3 kg Miller et al., 1995; 4.3 kg Miller et al., 2001). Steaks having a WBS of 4.6 kg or less have a 50% chance of being rated slightly tender or higher, while steaks with a WBS of 3.9 kg or less have a 68% chance of being rated slightly tender or better (Shackelford et. al., 1991). Miller et al. (2001) found that the transition of WBS values between tough and tender

occurred between 5.2 kg and 4.3 kg in the home and 5.0 kg and 4.6 kg in the restaurant, with consumers tolerating slightly tougher meat in the restaurant setting. George et al. (1999) reported that the average WBS value for top sirloin steaks was 3.46 kg and 3.05 kg for strip loin steaks with 76% of top sirloin steaks and 74% of top loin steaks having WBS values between 2 – 4 kg.

Miller et al. (1995) compared tenderness with overall acceptability and found that tenderness accounted for 44% of the variation in overall acceptability in homes and 53% in restaurants. Boleman et al. (1997) conducted a study to see if consumers could differentiate steaks that had been previously categorized by shear force as tender (2.27 – 3.58 kg), intermediate (4.08 – 5.40 kg), and tough (5.90 – 7.21 kg). The study found that 94.6% of the consumers bought steaks from the tender category even though they were priced $1.10/kg more than the intermediate group, implying that consumers are willing to pay for tenderness.

**Beef Flavor and Juiciness**

Beef flavor and juiciness are also attributes contributing to overall palatability and affect overall acceptability of beef steaks (Miller et al., 1995). Flavor may be as important as tenderness in determining consumer palatability (Neeley et al., 1998). Huffman et al. (1996) reported that flavor was rated the most important by 39% of consumers, and juiciness was rated most important by 10% of consumers. In the consumer's home, flavor accounted for the most variation in overall palatability (Huffman et al., 1997)

Parrish et al. (1969) found that flavor and juiciness were more desirable at 4 days of aging rather than at 7 days of aging. Wheeler et al. (1999) contradicted these findings, reporting that aging for 14 days compared to 3 days significantly increased beef flavor intensity ratings, and that juiciness ratings were unaffected. Smith et al. (1978) further supported Wheeler et al. (1998) findings by stating that aging beef for 11 days significantly increases flavor and palatability when compared to steaks with fewer days of aging.

Miller et al. (2001) found that when Warner-Bratzler shear force values were held constant flavor and juiciness became increasingly important to beef consumer satisfaction. Huffman et al. (1996) found that in the home flavor affected overall palatability ratings more than tenderness ratings. Correlation coefficients among consumer palatability attributes showed a strong positive relationship between juiciness, flavor desirability, beef flavor intensity and overall acceptability ($r = 0.77$, 0.86 and 0.79).

**Conclusion**

Producing a high-quality affordable product with a consistent eating experience every time is an industry goal. This is not always easy to do with the price fluctuation throughout the year, as well as variability in product days of aging. The 2006 National Beef Tenderness Survey showed the average length of aging for steaks in restaurant settings to be 30 d (Savell et al., 2007). However, the d of aging ranged from 7 to 136 d, with 29% of the steaks having less than 14 d of aging, causing inconsistency in the tenderness of the steaks.

Postmortem aging is a common practice to produce more tender, palatable product, with the desired aging period being at least 11 days postmortem. Tenderness, juiciness, and beef flavor are important consumer attributes. Freezing does not appear to affect the palatability of the product. By freezing meat after a certain amount of time of postmortem aging, a more consistent product could possibly be produced. This could reduce variation in product aging.

The majority of freezing studies have been done on individual steaks, or small roasts, and not the actual subprimal. This led us to the objectives of this study which were to evaluate freezing and thawing procedures for subprimals. More specifically, this study focused on two objectives: 1) determine if freezing method had significant effects on purge loss, tenderness and sensory attributes, and 2) determine if thawing methods had significant effects on purge loss, tenderness and sensory attributes when compared to fresh, never-frozen subprimals.

# MATERIALS AND METHODS

*Experimental Design*

This study was a completely randomized design. Three different beef muscle groups- *Longissimus thoracis* (LT) (n = 90), *Longissimus lumborum* (LL) (n = 90), *and Gluteus medius* (GM) (n = 90) - were used (Appendix 42). There were six different treatments: 14 d aged fresh, never frozen (14D), 21 d aged fresh, never frozen (21D), blast-frozen, fast-thaw (BF), blast-frozen, slow-thaw (BS), conventional-frozen, fast-thaw (CF), and conventional-frozen, slow thaw (CS). All frozen treatments had 14 d of aging prior to being frozen. There were 15 subprimals per treatment for every muscle group. The study was conducted over 5 consecutive mo. A timeline was established to ensure that all subprimals were selected to allow the required d of aging and d freezing and thawing prior to cutting. The required d were 14 d aging prior to freezing, at least 14 d frozen, either 14 d thawing or 1 d thawing, 14 d aged fresh, never frozen, and 21 d aged fresh, never frozen. Actual cutting of the subprimals into steaks occurred over a 3 wk time period. Five subprimals from a muscle group for each treatment were cut each week, totaling 30 subprimals cut per week. There were a total of 3 freezing days (1 freezing day for each muscle group). All beef subprimals were USDA Choice except for 5 of the fresh, never frozen 21 d aged GM (n = 265 USDA choice and n = 5 USDA select). The 6 treatments were compared for purge loss, shear force, and sensory evaluation within each of the 3 beef subprimal muscles.

*Meat Freezing, Thawing and Cutting*

At 14 d postmortem, 60 rib-eye rolls (*Longissimus Thoracis*, LT), 60 strip loins (*Longissimus Lumborum*, LL), and 60 top sirloin butts (*Gluteus Medius*, GM) were frozen in a -28°C freezer at a warehouse in Denver, CO. Thirty of each subprimal were blast frozen. For blast freezing the boxes of meat were spaced out on a pallet with spacers placed between the layers of boxes, and then placed in a -28°C freezer with high air velocity to allow for more rapid freezing. The subprimals were frozen within 3 -5 d after being placed in the blast freezer. The pallets were then moved to a -28°C freezer for storage. The other 30 of each subprimal were conventionally frozen by leaving the boxes packed tightly on the pallet with minimal air movement. The pallets were left in this -28°C freezer until shipping. The beef subprimals were then shipped to the Loeffel Meat Laboratory at the University of Nebraska Lincoln, NE, in a truck with a refrigerated trailer maintain the -28°C temperature. The subprimals were then unloaded and moved to a -23°C freezer with minimal air movement for storage. All LT, LL, and GM were frozen for a minimum of 14 d. Each wk for 9 wk, 5 blast frozen and 5 conventionally frozen subprimals were numbered, weighed on a Weigh-Tronix scale (Model WI-110, Avery Weigh-Tronix, Fairmont, MN), and then placed on a table in a -1 to 2°C cooler for 14 d to allow for a slow thaw period. Additionally, 5 blast and 5 conventionally frozen subprimals were removed from the freezer, numbered, weighed on a Weigh-Tronix scale (Model WI-110, Avery Weigh-Tronix, Fairmont, MN), and then placed in a water bath with air agitation each wk for 9 wk. The water bath started out at 12°C and decreased in temperature to 0°C in 5°C room in for 21 hr prior to cutting. The water bath temperature

dropped as soon as the subprimals were added (Appendix 41). The fresh, never frozen beef subprimal muscles were shipped to the Loeffel Meat Laboratory at the University of Nebraska, Lincoln, NE from Colorado Premium Greeley, CO, and were aged in a 0°C cooler for 14 and 21 d prior to cutting.

*Gluteus medius* subprimals were cut into 2.54-cm steaks. The lateral half of 2 steaks from the middle of the top sirloin butt were the used for WBS, cooking loss, and sensory evaluation. *Longissimus Lumborum* subprimals were trimmed, and then 2, 2.54-cm steaks were cut from the anterior portion of the LL for WBSF, cooking loss, and sensory evaluation. *Longissimus Thoracis* subprimals were trimmed, and cut into 2, 2.54-cm steaks from the posterior portion of the LT for WBSF, cooking loss, and sensory evaluation.

All WBSF steaks were cooked on the day of cutting. Sensory evaluation steaks were vacuum-packaged and placed in a 4°C cooler until the day they were needed for sensory evaluation. All steaks were cooked within 3 d of being cut.

*Purge Loss*

There were a total of 58 vacuum bags out of 270 vacuum bags that were damaged during the process. A total of 21.5% of the vacuum bags failed. Out of the failed vacuum bags the ribeyes accounted for the majority of broken of bags totaling 30 failed vacuum bags (slow thaw = 10, fast thaw = 19, fresh, never frozen = 1). The sirloins had the least amount of vacuum bag failure with a total of 8 (slow thaw = 3, fast thaw = 5, fresh, never frozen = 0). The strip loins accounted for 20 of the failed vacuum bags (slow thaw = 7, fast thaw = 10, fresh, never frozen = 3). Out of all the failed vacuum bags 21 of

them were in the slow thaw treatment, 34 of them were in the fast thawing treatment, and 3 of them were in the fresh, never frozen treatment.

Purge loss was determined on every subprimal (except the broken bags in fast thaw treatments). Prior to thawing every subprimal was sorted into a treatment group and numbered. The subprimal was weighed on a Weigh-Tronix scale (Model WI-110, Avery Weigh-Tronix, Fairmont, MN) in hundredths of a kilogram (kg). The frozen weight was recorded and then the subprimal was placed in the respective thawing treatment.

Prior to cutting, all thawed and fresh, never frozen subprimals were weighed on Weigh-Tronix scale (Model WI-110, Avery Weigh-Tronix, Fairmont, MN) in hundredths of a kg. The subprimals that experienced weight gain in the fast thawing treatments were removed from the data set for purge loss. The subprimals were then opened, removed from their vacuum-packaging bags and all subprimals were dried with paper towels, and weighed again. The purge was then emptied out of the vacuum-package bag. The bag was washed out, dried off, and weighed.

All of the weights were then entered into Microsoft Office Excel (Microsoft Corporation, 2007). Purge loss was calculated by the equation "purge loss % = (((frozen weight - (dried weight + vacuum-package bag weight)) / frozen weight – vacuum bag weight) x 100".

*Warner-Bratzler Shear Force*

Shear force values were determined on 1 steak from each subprimal. A Type T, copper constant, Precision Fine Wire Thermocouple (OMEGA Engineering, Inc., Stamford, CT) was inserted into the geometric center of every steak. Internal temperature

was monitored using an OMEGA 450 ATT thermometer with a type T thermocouple (OMEGA Engineering, Inc., Stamford, CT). Steaks were cooked on a Hamilton Beach Indoor/Outdoor Grill (Model 31605A, Proctor-Silex Inc., Washington, NC) to an internal temperature of 35°C, flipped, and cooked to a final internal temperature of 71°C. Steaks were covered with food service plastic film and cooled for 20 hours at 4°C before removal of 6 cores (1.27-cm diameter) parallel with the muscle fiber orientation, using a 1.2-cm diameter coring bit. Shearing was done on a Warner-Bratzler Shear Spring Scale (G-R Manufacturing Company, Manhattan, KS). A mean of the peak shear force (kg) of all 6 sheared cores was calculated for each steak.

*Cooking Loss*

Cooking loss was calculated using Microsoft Office Excel (Microsoft Corporation, 2007). The equation used was "cooking loss % = ((fresh weight – cooked weight) / fresh weight) x 100". Steaks were weighed on a Mettler-Toledo scale (Model BD1201, Mettler-Toledo Inc., Columbus, OH) prior to and after cooking. The steaks were placed in a Polypropylene, high barrier tray (Go-Green Packaging, Janesville, WI) to be weighed. All steaks were cooked in the same manner described for Warner-Bratzler shear force.

*Sensory Panel Preparation*

A 7-person trained sensory panel consisting of staff members and graduate students was utilized to evaluate the LT, LL, and GM steaks for attributes of tenderness, connective tissue, juiciness, and flavor. An 8-point hedonic scale was used for tenderness (8 = extremely tender; 1 = extremely tough), connective tissue (8 = no connective tissue;

1 = abundant amount), and juiciness (8 = extremely juicy; 1 = extremely dry). A 4-point hedonic scale was used for flavor (4 = strong off-flavor; 1 = no off-flavor). A total of 45 sessions were held, 15 per beef subprimal muscle. A session consisted of 6 samples: 1 sample from BS, BF, CS, CF, 14D, and 21D. There were 5 sessions a week for 9 weeks.

For sensory panel evaluation, 1 steak per treatment was prepared and cooked in the same manner described for Warner-Bratzler shear force. A Type T, copper constant, Precision Fine Wire Thermocouple (OMEGA Engineering, Inc., Stamford, CT) was inserted into the geometric center of every steak. Internal temperature was monitored using an OMEGA 450 ATT thermometer with a type T thermocouple (OMEGA Engineering, Inc., Stamford, CT). Steaks were cooked on a Hamilton Beach Indoor/Outdoor Grill (Model 31605A, Proctor-Silex Inc., Washington, NC) to an internal temperature of 35°C, flipped, and cooked to a final internal temperature of 71°C (AMSA, 1995). After cooking, steaks were cut into $2cm^3$ pieces for evaluation. During the panel session, samples were held in double broilers to maintain heat. Compusense five (Compusense Inc., Guelph, Canada, 2010) was utilized to collect sensory evaluation. Each panelist would sign into their profile before a session would start. After the panelists were signed in a sample would be served to them one at a time. Each sample was labeled with a random 3-digit number.

Panelists were served in individual booths under red fluorescent lighting. They were instructed to cleanse their palate after each sample with the room temperature double-distilled water and unsalted crackers.

*Statistical Analysis*

Purge loss, cooking loss, Warner-Bratzler shear force, and trained sensory panel data were analyzed using the PROC GLIMMIX procedure of SAS (Version 9.2, Cary, NC, 2002 – 2008). The data collected from each of the 3 subprimal groups were analyzed separately. When significance ($P \leq 0.05$) was indicated by ANOVA, mean separations were performed using the LSMEANS and PDIFF functions of SAS. A CONTRAST statement was used to see if there was significance ($P \leq 0.05$) between blast frozen and conventionally frozen as well as slow thaw and fast thaw subprimals aged for 14- and 21-days.

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**MANUSCRIPT**

Running Head: The Effects of Freezing and Thawing Rates on Tenderness and Sensory Quality of Beef Subprimals

# The Effects of Freezing and Thawing Rates on Tenderness and Sensory Quality of Beef Subprimals[1, 2, 3]

J. E. Hergenreder, J. J. Hosch, K. A. Varnold, A. L. Haack, L. S. Senaratne, S. Pokharel, C. Beauchamp[3], B. Lobaugh[4], C. R. Calkins[5]

Animal Science Department[1], University of Nebraska-Lincoln, 68583-0908

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[3]This project was funded in part by Colorado Premium.

[4]iQ Foods

[5]Correspondence: [A213 Animal Science; (Telephone (402) 472-6314; Fax (402) 472-6362] email address: ccalkins1@unl.edu (Chris R. Calkins).

## Abstract

To evaluate processing methods for frozen beef subprimals, the effects of freezing and thawing rates on tenderness and sensory properties were evaluated. There were six treatments: fresh-never-frozen 14-day wet aged, fresh-never-frozen 21-day wet aged, blast frozen–fast thawed, blast frozen–slow thawed, conventionally frozen–fast thawed, and conventionally frozen–slow thawed (all frozen subprimals were aged for 14d prior to freezing). Three subprimal cuts - ribeye rolls (n = 90), strip loins (n = 90), and sirloins (n = 90) - were utilized with three replications of five samples per treatment per week (total of 9 weeks, N = 270). Blast freezing occurred by placing spacers between the boxes of meat on pallets at -28° C with high air velocity for 3 – 5 d until all the meat was frozen, and then the pallets were moved to a -28°C freezer for storage. Conventional freezing occurred with boxes of meat stacked on pallets and placed in a -28° C freezer with minimal air movement, the pallets were left in the freezer until shipping. Fast thawing of subprimals (to an internal temperature of -2° to 0° C) occurred by immersion in a circulating water bath (< 12° C) for 21 hrs, and slow thawing of subprimals occurred over a two week period by placing individual subprimals on tables at 0° C. Purge loss was measured after thawing. Steaks (2.5 cm thick) were cut from the *longissimus thoracis* (LT), *longissimus lumborum* (LL), and *gluteus medius* (GM) for Warner-Bratzler shear force (WBS) and trained sensory evaluation. Sensory samples were rated for tenderness, juiciness, connective tissue, and off-flavor after cooking to 71° C. Slow thawed subprimals had the greatest amount of purge loss ($P < 0.001$) in the LT, LL and GM. Fast thawed subprimals were equal or had less purge loss to fresh-never-frozen 14- and

21-d aged subprimals ($P < 0.0001$) in the LT, LL and GM. For LL and GM steaks, frozen treatments were equal or lower in WBS values to fresh-never-frozen 14- and 21-d aged steaks. For LL and LT steaks, slow thawed steaks we equal or lower in WBS when compared to fast thawed steaks ($P = 0.01$). No differences were detected in WBS among the GM steaks ($P = 0.08$). There were no differences in sensory tenderness within the LL, LT, and GM ($P > 0.05$). Juiciness in the LL and GM ($P > 0.05$) did not differ among treatments. The LT fresh-never-frozen 14- and 21-d aged product was juicier than the frozen product ($P = 0.001$). Differences were not detected in connective tissue in the LT or GM ($P > 0.05$). A greater amount of connective tissue was detected in the slow thawed LL compared to the fast thawed LL ($P = 0.02$). There were no differences in off-flavor in the LT and LL ($P > 0.05$). Conventionally frozen-fast thawed steaks had the strongest prevalence of off-flavor ($P = 0.02$) in the GM. Overall, freezing rate did not affect purge loss, and neither freezing nor thawing rates had significant meaningful effects on Warner-Bratzler shear force and sensory and were comparable to fresh-never-frozen subprimals.

Key words: Beef, freezing method, thawing method

## Introduction

Inconsistency in tenderness and palatability among steaks is a concern for today's beef industry. The 2006 National Beef Tenderness Survey showed the average length of aging for steaks in restaurant settings to be 30 d (Savell et al., 2007). However, the d of aging ranged from 7 to 136 d, with 29% of the steaks having less than 14 d of aging. This can lead to inconsistency and considerable tenderness variation between products. The desired aging period for beef is at least 11 days postmortem (Smith et. al., 1978). A reason for variation in aging time is fluctuation in supply and demand. Steaks are in a higher demand during the summer months, and roasts are in higher demand during the winter months (Namken et al., 1994). With high demand, steaks may often be prepared with too little aging.

A possible solution to these large variations in aging could be to freeze and store subprimals after a specific degree of aging, increasing the uniformity of steaks sold in restaurants. Studies have shown that freezing meat increases tenderness due to cellular disruption by the freezing process (Hiner et al., 1945; Shanks et al., 2002). Other studies have found that freezing does not affect tenderness or sensory traits (Paul and Child, 1937). An increase in drip loss has been observed with frozen meat (Paul and Child, 1937). However, freezing meat at faster rates decreases purge loss because the majority of ice crystals are intramuscular and the cells do not experience as much damage and can still maintain the moisture (Grujic et al., 1993; Hiner et al., 1945; Paul and Child, 1937; Petrovic et al., 1993; Ramsbottom and Koonz, 1939). If meat can be frozen and thawed

with minimal drip loss and no adverse affects on tenderness and sensory attributes, a company could offer a more consistent product to consumers.

The objective of this study was to evaluate freezing and thawing procedures for subprimals. More specifically, this study focused on two objectives: 1) determine if freezing method had significant effects on purge loss, tenderness and sensory attributes, and 2) determine if thawing methods had significant effects on purge loss, tenderness and sensory attributes when compared to fresh, never-frozen subprimals aged for 14- and 21-days.

## Materials and Methods

There were 6 treatments: blast frozen – slow thaw (BS), blast frozen – fast thaw (BF), conventionally frozen – slow thaw (CS), conventionally frozen – fast thaw (CF), fresh, never frozen 14 d aged (14D), and fresh, never frozen 21 d aged (21D). At 14 d postmortem, 60 rib-eye rolls (*Longissimus Thoracis,* LT), 60 strip loins (*Longissimus Lumborum*, LL), and 60 top sirloin butts (*Gluteus Medius*, GM) were frozen in a -28°C freezer at a warehouse in Denver, CO. Thirty of each subprimal were blast frozen. For blast freezing the boxes of meat were spaced out on a pallet with spacers placed between the layers of boxes, and then placed in a -28°C freezer with high air velocity to allow for more rapid freezing. The subprimals were frozen within 3 -5 d after placed in the blast freezer. The pallets were then moved to a -28°C freezer for storage until shipping. The other 30 of each subprimal were conventionally frozen by leaving the boxes packed tightly on the pallet with minimal air movement. The pallets were left in this -28°C freezer until shipping. The beef subprimals were then shipped to the Loeffel Meat

Laboratory at the University of Nebraska Lincoln, NE, in a truck with a refrigerated trailer, subprimals arrived at -20 to -15°C. The subprimals were then unloaded and moved to a -23°C freezer with minimal air movement for storage. All LT, LL, and GM were frozen for a minimum of 14 d. The fresh, never frozen subprimals were collected from Colorado Premium throughout the study. Colorado Premium obtained subprimals from cattle slaughtered 14 and 21 d prior to their cutting day. The subprimals were then placed in coolers with ice packs and shipped next day delivery through FedEX to the Loeffel Meat Laboratory at the University of Nebraska Lincoln, NE. Each wk for 9 wk, 5 blast frozen and 5 conventionally frozen subprimals were taken from the freezer and numbered, weighed on a Weigh-Tronix scale (Model WI-110, Avery Weigh-Tronix, Fairmont, MN), and then placed on a table in a -1 to 2°C cooler for 14 d to allow for a slow thaw period. An additional 5 blast and 5 conventionally frozen subprimals were removed from the freezer, numbered, weighed on a Weigh-Tronix scale (Model WI-110, Avery Weigh-Tronix, Fairmont, MN), and then placed in a water bath with air agitation for 21 hr before cutting each wk for 9 wk. The water bath started out at 12°C and decreased in temperature to 0°C in 5°C room. The water bath temperature dropped as soon as the subprimals were added.

All steaks from each of the muscle groups were cut after purge loss data had been collected each wk for 9 wk. *Gluteus medius* subprimals were cut into 2.54-cm steaks. The lateral half of 2 steaks from the middle of the top sirloin butt were used for Warner-Bratzler shear force (WBS), cooking loss, and sensory evaluation. *Longissimus Lumborum* subprimals were trimmed, and then 2, 2.54-cm steaks were cut from the

anterior portion of the LL for WBS, cooking loss, and sensory evaluation. *Longissimus Thoracis* subprimals were trimmed, and cut into 2, 2.54-cm steaks from the posterior portion of the LT for WBS, cooking loss, and sensory evaluation.

All WBS steaks were cooked on the day of cutting. Sensory evaluation steaks were vacuum-packaged and placed in a 4°C cooler until the day they were needed for sensory evaluation. All steaks were cooked within 3 d of being cut.

*Purge Loss*

There were a total of 58 vacuum bags out of 270 vacuum bags that were damaged during the process. A total of 21.5% of the vacuum bags failed. Out of the failed vacuum bags the ribeyes accounted for the majority of broken of bags totaling 30 failed vacuum bags (slow thaw = 10, fast thaw = 19, fresh, never frozen = 1). The sirloins had the least amount of vacuum bag failure with a total of 8 (slow thaw = 3, fast thaw = 5, fresh, never frozen = 0). The strip loins accounted for 20 of the failed vacuum bags (slow thaw = 7, fast thaw = 10, fresh, never frozen = 3). Out of all the failed vacuum bags 21 of them were in the slow thaw treatment, 34 of them were in the fast thawing treatment, and 3 of them were in the fresh, never frozen treatment.

Purge loss was determined on every subprimal (except the broken bags in fast thaw treatments). Prior to thawing every subprimal was sorted into a treatment group and numbered. The subprimal was weighed on a Weigh-Tronix scale (Model WI-110, Avery Weigh-Tronix, Fairmont, MN) in hundredths of a kilogram (kg). The frozen weight was recorded and then the subprimal was placed in the respective thawing treatment.

Before cutting, all thawed and fresh, never frozen subprimals were weighed on Weigh-Tronix scale (Model WI-110, Avery Weigh-Tronix, Fairmont, MN) in hundredths of a kg. The subprimals that experienced weight gain in the fast thawing treatments were removed from the data set for purge loss. The subprimals were then opened, removed from their vacuum-packaging bags and all subprimals were dried with paper towels, and weighed again. The purge was then emptied out of the vacuum-package bag. The bag was washed out, dried off, and weighed. All of the weights were then entered into Microsoft Office Excel (Microsoft Corporation, 2007). Purge loss was calculated by the equation "purge loss % = (((frozen weight - (dried weight + vacuum-package bag weight)) / frozen weight – vacuum bag weight) x 100".

*Warner-Bratzler Shear Force and cooking loss*

Shear force values were determined on 1 steak from each subprimal. Steaks were grilled on Hamilton Beach Indoor/Outdoor grills (Model 31605A, Proctor-Silex Inc., Washington, NC). A thermocouple was placed in the geometric center of each steak. Steaks were cooked on one side until the center temperature reached 35°C and then turned over. Cooking continued until the temperature reached 71°C. Steaks were weighed before and after grilling. Cooking loss was calculated. Steaks were placed on a tray and covered with oxygen-permeable film and placed in a 4°C cooler. Twenty hours later, the cooked steaks were cored into of 6 ½-inch cores and sheared on a Warner-Bratzler Shear Spring Scale (G-R Manufacturing Company, Manhattan, KS) to determine WBS.

*Sensory Panel*

For sensory panel evaluation, 1 steak per treatment was prepared and cooked in the same manner described for Warner-Bratzler shear force. A Type T, copper constant, Precision Fine Wire Thermocouple (OMEGA Engineering, Inc., Stamford, CT) was inserted into the geometric center of every steak. Internal temperature was monitored using an OMEGA 450 ATT thermometer with a type T thermocouple (OMEGA Engineering, Inc., Stamford, CT). Steaks were cooked on a Hamilton Beach Indoor/Outdoor Grill (Model 31605A, Proctor-Silex Inc., Washington, NC) to an internal temperature of 35°C, flipped, and cooked to a final internal temperature of 71°C (AMSA, 1995). Upon reaching 71°C steaks were removed from the grill and cut into 1.27 $cm^3$ cubes and kept warm (not more than 15 min) prior to being evaluated. The steaks were served to 4-7 trained panelists while still warm. Panelists evaluated six samples (one per treatment) per session. Sensory panels were conducted in a positive-pressure ventilated room with lighting and cubicles designed for objective meat sensory analysis. Each sample was evaluated for tenderness (8 = extremely tender; 1 = extremely tough), juiciness (8 = extremely juicy; 1 = extremely dry), connective tissue (8 = no connective tissue; 1 = abundant amount) and off-flavor (1 = no off-flavor; 4 = strong off-flavor).

*Statistical Analysis*

Data from each subprimal type was analyzed independently. Purge loss, cooking loss, Warner-Bratzler shear force, and trained sensory panel data were analyzed using the PROC GLIMMIX procedure of SAS (Version 9.2, Cary, NC, 2002 – 2008). When significance ($P \leq 0.05$) was indicated by ANOVA, mean separations were performed

using the LSMEANS and PDIFF functions of SAS. CONTRAST statements were used to test for significance ($P \leq 0.05$) between blast frozen and conventionally frozen as well as slow thaw and fast thaw subprimals.

## Results and Discussion

There were significant differences in purge loss among all subprimals ($P < 0.0001$) (Table 1). Fast thawed subprimals had equal or lesser purge loss compared to the fresh, never-frozen subprimals. The slow thawed subprimals had the most purge loss ($P < 0.001$). There were no differences in purge loss between blast frozen and conventionally frozen subprimals ($P > 0.05$); the differences were between fast and slow thawing treatments (Table 1). The differences in purge loss between thawing treatments are likely because fast thaw subprimals were thawed to -2 to 0°C, and some of the subprimals were still slightly frozen in the center when cut. The thawed subprimals from the fast thaw treatments still had a colder internal temperature than the slow thawed subprimals upon cutting. The slow thawed subprimals were thawed to 0°C, and had reached 0°C a few days prior to cutting instead of a few hrs prior to cutting.

Strip loin (*Longissimus Lumborum*) and GM frozen steaks were all equal or had lower WBS values compared to 14D and 21D steaks. Slow thawed steaks were equal in WBS to 14D and 21D steaks (Table 1). All slow thawed steaks for the LT and LL were equal or lower ($P < 0.01$) in WBS when compared to fast thaw steaks. The differences in WBS value are suspected to be a result of the thawing treatments. Wheeler et al. (1996) found Longissimus steaks thawed to -2°C before cooking had higher WBS values than steaks thawed to 12°C. Fast thaw subprimals were thawed to -2 to 0°C before steaks

were cut and cooked. The slow thawed subprimals were thawed to 0°C before steaks were cut and cooked. All steaks were similar in temperature when the steaks were placed on the grill. Slow thawed treatments were thawed in 7 – 11 d instead of 14 d. So, the slow thawed treatments had a dwell period prior to being cut allowing for more days of aging. Freezing beef at 1 d postmortem, thawed, and then aged, tenderness is improved (Crouse and Koohmaraie, 1990). Whipple and Koohmaraie (1992) stated that freezing temperature and rate as well as thaw rate may affect the extent to which aging meat after freezing improves tenderness, because of possible detrimental or beneficial effects of freezing itself. No differences were detected in WBS among treatments within the GM ($P = 0.08$).

There were few differences found in the sensory evaluation (Table 2). These finding agree with what Pual and Child (1937). No differences were found in sensory tenderness within the LT, LL and GM ($P > 0.05$). There were no significant differences in juiciness in LL and GM steaks ($P > 0.05$). The 14D and 21D LT steaks were juicier than all frozen steaks ($P < 0.001$). The 14D and 21D LT steaks also experienced less or equal cooking loss compared to all frozen steaks ($P < 0.001$). This may account for the differences in juiciness among the LT steaks. The fresh, never frozen LT steaks had less cooking loss, so they ended up being juicier. There were no significant differences in cooking loss in the LL and GM. For all steaks, frozen treatments were equal to 14D steaks in connective tissue. Differences in connective tissue were not detected in LT and GM steaks ($P > 0.05$). Slow thawed steaks for the LL had less detectable connective tissue than the fast thawed and 21D steaks. The difference in connective tissue in the

samples did not affect overall tenderness ratings because the panelists did not detect a difference in tenderness LL. There were no significant differences detected in off-flavor among the treatments for the LT and LL. The CF had the strongest prevalence of off-flavor ($P = 0.02$) in the GM.

Neither freezing nor thawing rates had significant meaningful effects on Warner-Bratzler shear force or sensory tenderness. Our finding is supported by Paul and Child's (1937) research done on freezing and thawing roasts, in that total moisture, drip loss and tenderness of cooked beef are unaffected by freezing or by different thawing temperatures. Lee et al. (1950) also found no significant effects on palatability due to freezing. Conversely Hiner et al. (1945) found less and less resistance to shear as freezing temperature decreased, and Shanks et al. (2002) found that frozen steaks had lower Warner-Bratzler shear force values than fresh steaks. However, both of these studies (Hiner et al. 1945; Shanks et al. 2002) were done on steaks and not large pieces of meat or subprimals. Steaks and subprimals freeze at different rates because of the difference in thickness and mass, which changes cellular disruption from freezing (Ramsbottom and Koonz, 1939).

Freezing rate did not affect purge loss, which was also found by Ramsbottom and Koonz (1939). Many previous studies have used steaks instead of subprimals. When freezing steaks or smaller pieces of meat freezing temperature does affect drip loss. Several papers reported that faster and colder freezing rates of steaks resulted in less drip loss because the ice crystals form intracellular causing less damage to cell allowing it to maintain moisture (Grujic et al., 1993; Hiner et al., 1945; Paul and Child, 1937; Petrovic

et al., 1993; Ramsbottom and Koonz, 1939). The colder the temperature the less time there is for water to transfer out of the cell (Hiner et al., 1945). When thaw rates were properly managed (the meat is thawed slowly or quickly and the outer surface of the meat does not exceed 7°C), tenderness and sensory attributes were comparable to fresh product. These data suggest that subprimals can be purchased at opportune times, frozen and thawed as needed, and steaks will be equal in quality to fresh, never-frozen product.

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## Tables

**Table 1**

**Least square means of Warner-Bratzler shear force (WBS) and purge loss.**

| | | Treatments[1] | | | | | | | Contrast* | |
|---|---|---|---|---|---|---|---|---|---|---|
| Muscle | Trait | 14d | 21d | BF | BS | CF | CS | *P*-value | Blast Frozen vs. Conventional Frozen | Slow Thaw vs. Fast Thaw |
| ***Longissimus Thoracis*** | | | | | | | | | | |
| | WBS, kg | 3.44$^{c}$ | 3.10$^{c}$ | 4.45$^{a}$ | 3.70$^{bc}$ | 4.21$^{ab}$ | 3.53$^{c}$ | 0.001 | 0.4825 | 0.2897 |
| | Purge Loss, % | 0.68$^{b}$ | 1.01$^{b}$ | 0.98$^{b}$ | 5.30$^{a}$ | 0.72$^{b}$ | 4.49$^{a}$ | <0.0001 | 0.5431 | <0.0001 |
| ***Longissimus Lumborum*** | | | | | | | | | | |
| | WBS, kg | 3.55$^{ab}$ | 3.32$^{abc}$ | 3.55$^{ab}$ | 2.93$^{bc}$ | 3.94$^{a}$ | 2.83$^{c}$ | 0.01 | 0.5177 | 0.0004 |
| | Purge Loss, % | 1.78$^{b}$ | 1.88$^{b}$ | 0.88$^{c}$ | 3.53$^{a}$ | 0.78$^{c}$ | 3.53$^{a}$ | <0.0001 | 0.8171 | <0.0001 |
| ***Gluteus Medius*** | | | | | | | | | | |
| | WBS, kg | 3.35 | 3.21 | 4.08 | 3.48 | 3.51 | 3.54 | 0.08 | 0.2411 | 0.1845 |
| | Purge Loss, % | 1.25$^{bc}$ | 1.56$^{b}$ | 0.79$^{cd}$ | 6.17$^{a}$ | 0.53$^{d}$ | 6.23$^{a}$ | <0.0001 | 0.7060 | <0.0001 |

$^{a, b, c, d}$ Means in the same row having different superscripts are significant at $P = 0.05$.

*P-value for the interaction between freezing process and thawing process.

[1] B = Blast Frozen = spacers placed between boxes of meat and placed in a -28°C freezer with high air velocity, C = Conventional Frozen = boxes of meat placed in a -28°C freezer with minimal air movement, S = Slow Thaw = subprimals set on a table in a 0°C room for 14 days, F = Fast Thaw = subprimals immersed in a circulating water bath (< 12°C) for 21 hrs 14d = Aged for 14d and fresh, never frozen, 21d = Aged for 21d and fresh, never frozen.

**Table 2**

**Least square means of sensory attributes.**

| | | Treatments[1] | | | | | | | Contrast[*] | |
|---|---|---|---|---|---|---|---|---|---|---|
| Muscle | Trait | 14d | 21d | BF | BS | CF | CS | *P*-value | Blast Frozen vs. Conventional Frozen | Slow Thaw vs. Fast Thaw |
| ***Longissimus Thoracis*** | | | | | | | | | | |
| | Tenderness | 5.80 | 5.94 | 5.12 | 5.30 | 5.55 | 5.67 | 0.07 | 0.0613 | 0.4692 |
| | Juiciness | 5.08$^{a}$ | 5.07$^{a}$ | 4.12$^{b}$ | 4.34$^{b}$ | 4.48$^{b}$ | 4.30$^{b}$ | 0.001 | 0.4384 | 0.8965 |
| | Connective Tissue | 5.04 | 5.48 | 4.68 | 4.85 | 5.14 | 5.32 | 0.09 | 0.0268 | 0.3961 |
| | Off-Flavor | 2.10 | 2.14 | 1.88 | 1.97 | 2.05 | 2.02 | 0.30 | 0.1356 | 0.6648 |
| | Cooking Loss | 17.36$^{b}$ | 16.53$^{b}$ | 21.24$^{a}$ | 19.41$^{ab}$ | 22.31$^{a}$ | 20.51$^{a}$ | 0.001 | 0.3511 | 0.1230 |
| ***Longissimus Lumborum*** | | | | | | | | | | |
| | Tenderness | 6.03 | 5.90 | 6.07 | 6.31 | 5.79 | 6.37 | 0.10 | 0.5327 | 0.0194 |
| | Juiciness | 5.63 | 5.24 | 4.99 | 5.03 | 5.32 | 5.19 | 0.17 | 0.1977 | 0.8044 |
| | Connective Tissue | 5.61$^{ab}$ | 5.55$^{b}$ | 5.77$^{ab}$ | 6.04$^{a}$ | 5.37$^{b}$ | 6.02$^{a}$ | 0.02 | 0.1842 | 0.0032 |
| | Off-Flavor | 1.93 | 1.92 | 1.89 | 2.04 | 1.81 | 1.86 | 0.49 | 0.0751 | 0.1722 |
| | Cooking Loss | 20.95 | 16.51 | 17.21 | 19.33 | 19.36 | 17.67 | 0.41 | 0.8728 | 0.8882 |
| ***Gluteus Medius*** | | | | | | | | | | |
| | Tenderness | 5.43 | 5.88 | 5.54 | 5.89 | 5.59 | 5.52 | 0.33 | 0.6811 | 0.8198 |
| | Juiciness | 5.01 | 5.36 | 5.33 | 4.70 | 5.04 | 4.55 | 0.07 | 0.3217 | 0.0108 |
| | Connective Tissue | 4.92 | 5.38 | 5.22 | 5.17 | 5.07 | 5.22 | 0.46 | 0.7670 | 0.7689 |
| | Off-Flavor | 1.90$^{b}$ | 2.01$^{ab}$ | 1.84$^{b}$ | 1.96$^{ab}$ | 2.10$^{a}$ | 1.85$^{b}$ | 0.02 | 0.2296 | 0.2505 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Cooking Loss | 23.44 | 25.03 | 26.11 | 27.79 | 27.49 | 25.67 | 0.40 | 0.8005 | 0.9612 |

[a, b, c, d] Means in the same row having different superscripts are significant at $P = 0.05$.

*P-value for the interaction between freezing process and thawing process.

[1] B = Blast Frozen = spacers placed between boxes of meat and placed in a -28°C freezer with high air velocity, C = Conventional Frozen = boxes of meat placed in a -28°C freezer with minimal air movement, S = Slow Thaw = subprimals set on a table in a 0°C room for 14 days, F = Fast Thaw = subprimals immersed in a circulating water bath (< 12°C) for 21 hrs 14d = Aged for 14d and fresh, never frozen, 21d = Aged for 21d and fresh, never frozen.

## APPENDICIES

### Appendix 1

**Least square means of purge loss (%).**

| | Treatments[1] | | | | | | | Contrast* | |
|---|---|---|---|---|---|---|---|---|---|
| Muscle | 14d | 21d | BF | BS | CF | CS | *P*-value | Blast Frozen vs. Conventional Frozen | Slow Thaw vs. Fast Thaw |
| ***Longissimus Thoracis*** | 0.68$^{b}$ | 1.01$^{b}$ | 0.98$^{b}$ | 5.30$^{a}$ | 0.72$^{b}$ | 4.49$^{a}$ | <0.0001 | 0.5431 | <0.0001 |
| ***Longissimus Lumborum*** | 1.78$^{b}$ | 1.88$^{b}$ | 0.88$^{c}$ | 3.53$^{a}$ | 0.78$^{c}$ | 3.53$^{a}$ | <0.0001 | 0.8171 | <0.0001 |
| ***Gluteus Medius*** | 1.25$^{bc}$ | 1.56$^{b}$ | 0.79$^{cd}$ | 6.17$^{a}$ | 0.53$^{d}$ | 6.23$^{a}$ | <0.0001 | 0.7060 | <0.0001 |

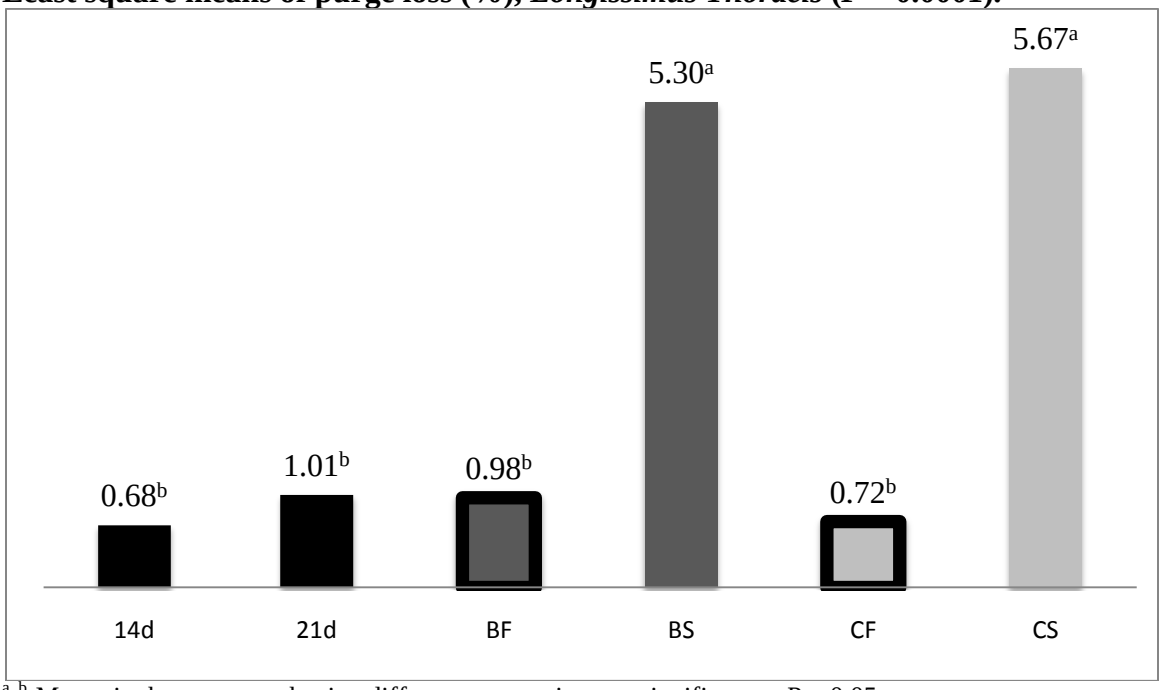
$^{a, b, c, d}$ Means in the same row having different superscripts are significant at $P = 0.05$.

*P-value for the interaction between freezing process and thawing process.

[1] B = Blast Frozen = spacers placed between boxes of meat and placed in a -28°C freezer with high air velocity, C = Conventional Frozen = boxes of meat placed in a -28°C freezer with minimal air movement, S = Slow Thaw = subprimals set on a table in a 0°C room for 14 days, F = Fast Thaw = subprimals immersed in a circulating water bath (< 12°C) for 21 hrs 14d = Aged for 14d and fresh, never frozen, 21d = Aged for 21d and fresh, never frozen.

## Appendix 2

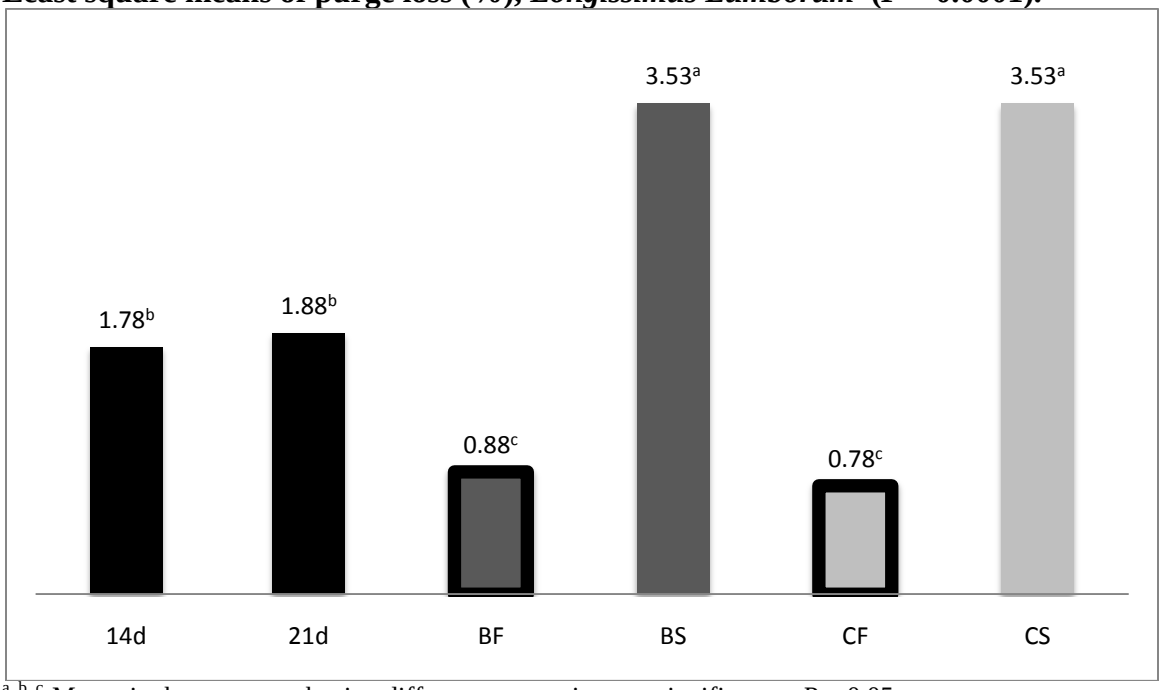
**Least square means of purge loss (%), *Longissimus Thoracis* (*P* < 0.0001).**




[a, b] Means in the same row having different superscripts are significant at *P* = 0.05.
B = Blast Frozen = spacers placed between boxes of meat and placed in a -28°C freezer with high air velocity, C = Conventional Frozen = boxes of meat placed in a -28°C freezer with minimal air movement, S = Slow Thaw = subprimals set on a table in a 0°C room for 14 days, F = Fast Thaw = subprimals immersed in a circulating water bath (< 12°C) for 21 hrs 14d = Aged for 14d and fresh, never frozen, 21d = Aged for 21d and fresh, never frozen.

# Appendix 3

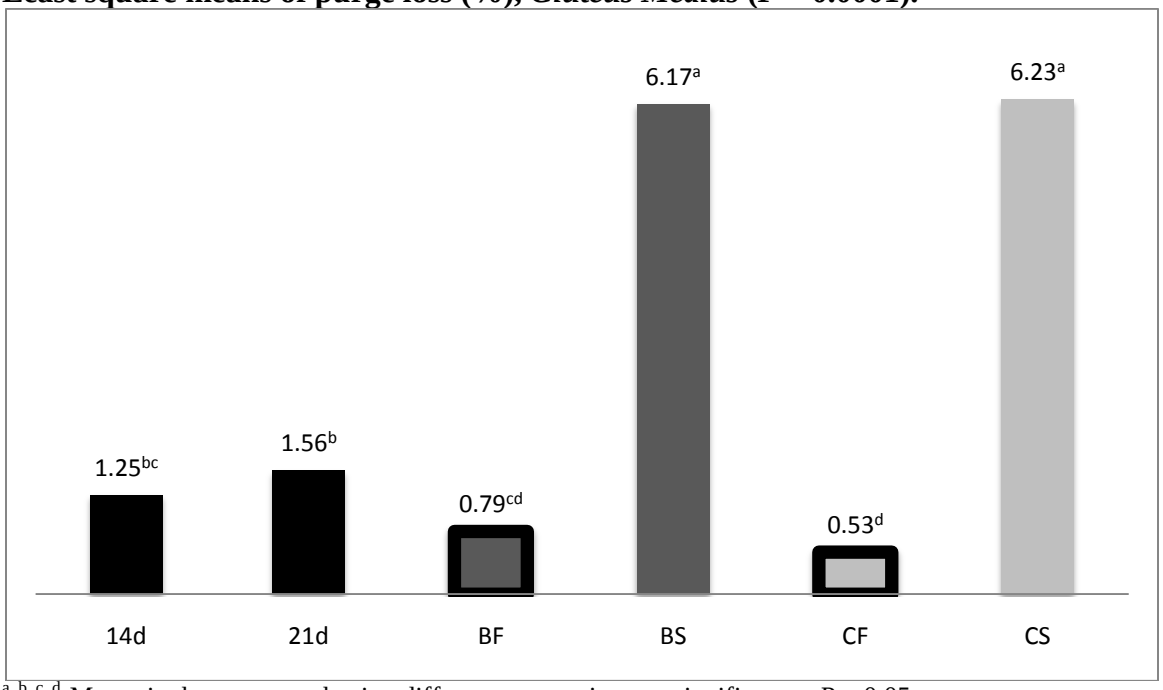
**Least square means of purge loss (%), *Longissimus Lumborum* ($P < 0.0001$).**




[a, b, c] Means in the same row having different superscripts are significant at $P = 0.05$.
B = Blast Frozen = spacers placed between boxes of meat and placed in a -28°C freezer with high air velocity, C = Conventional Frozen = boxes of meat placed in a -28°C freezer with minimal air movement, S = Slow Thaw = subprimals set on a table in a 0°C room for 14 days, F = Fast Thaw = subprimals immersed in a circulating water bath (< 12°C) for 21 hrs 14d = Aged for 14d and fresh, never frozen, 21d = Aged for 21d and fresh, never frozen.

# Appendix 4

**Least square means of purge loss (%), *Gluteus Medius* (*P* < 0.0001).**




a, b, c, d Means in the same row having different superscripts are significant at *P* = 0.05.
B = Blast Frozen = spacers placed between boxes of meat and placed in a -28°C freezer with high air velocity, C = Conventional Frozen = boxes of meat placed in a -28°C freezer with minimal air movement, S = Slow Thaw = subprimals set on a table in a 0°C room for 14 days, F = Fast Thaw = subprimals immersed in a circulating water bath (< 12°C) for 21 hrs 14d = Aged for 14d and fresh, never frozen, 21d = Aged for 21d and fresh, never frozen.

## Appendix 5

**Least square means of WBS (kg).**

| | Treatments[1] | | | | | | | Contrast* | |
|---|---|---|---|---|---|---|---|---|---|
| Muscle | 14d | 21d | BF | BS | CF | CS | *P*-value | Blast Frozen vs. Conventional Frozen | Slow Thaw vs. Fast Thaw |
| ***Longissimus Thoracis*** | 3.44$^{c}$ | 3.10$^{c}$ | 4.45$^{a}$ | 3.70$^{bc}$ | 4.21$^{ab}$ | 3.53$^{c}$ | 0.001 | 0.4825 | 0.2897 |
| ***Longissimus Lumborum*** | 3.55$^{ab}$ | 3.32$^{abc}$ | 3.55$^{ab}$ | 2.93$^{bc}$ | 3.94$^{a}$ | 2.83$^{c}$ | 0.01 | 0.5177 | 0.0004 |
| ***Gluteus Medius*** | 3.35 | 3.21 | 4.08 | 3.48 | 3.51 | 3.54 | 0.08 | 0.2411 | 0.1845 |

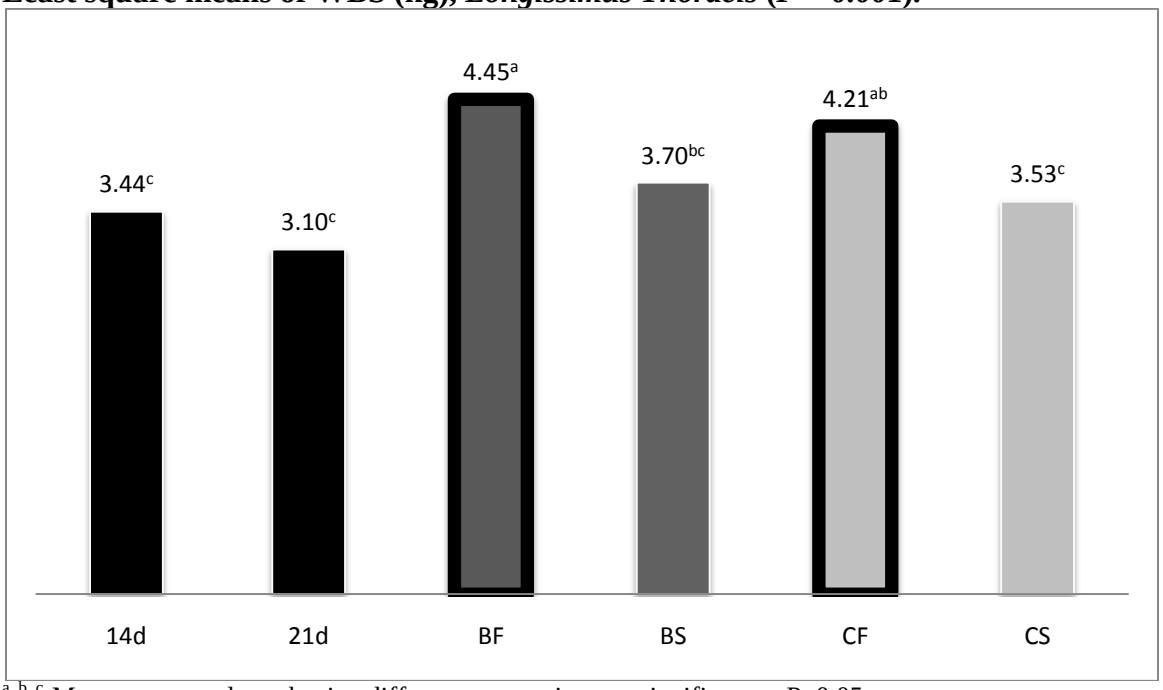
[a, b, c] Means in the same row having different superscripts are significant at $P = 0.05$.

*P-value for the interaction between freezing process and thawing process.

[1] B = Blast Frozen = spacers placed between boxes of meat and placed in a -28°C freezer with high air velocity, C = Conventional Frozen = boxes of meat placed in a -28°C freezer with minimal air movement, S = Slow Thaw = subprimals set on a table in a 0°C room for 14 days, F = Fast Thaw = subprimals immersed in a circulating water bath (< 12°C) for 21 hrs 14d = Aged for 14d and fresh, never frozen, 21d = Aged for 21d and fresh, never frozen.

# Appendix 6

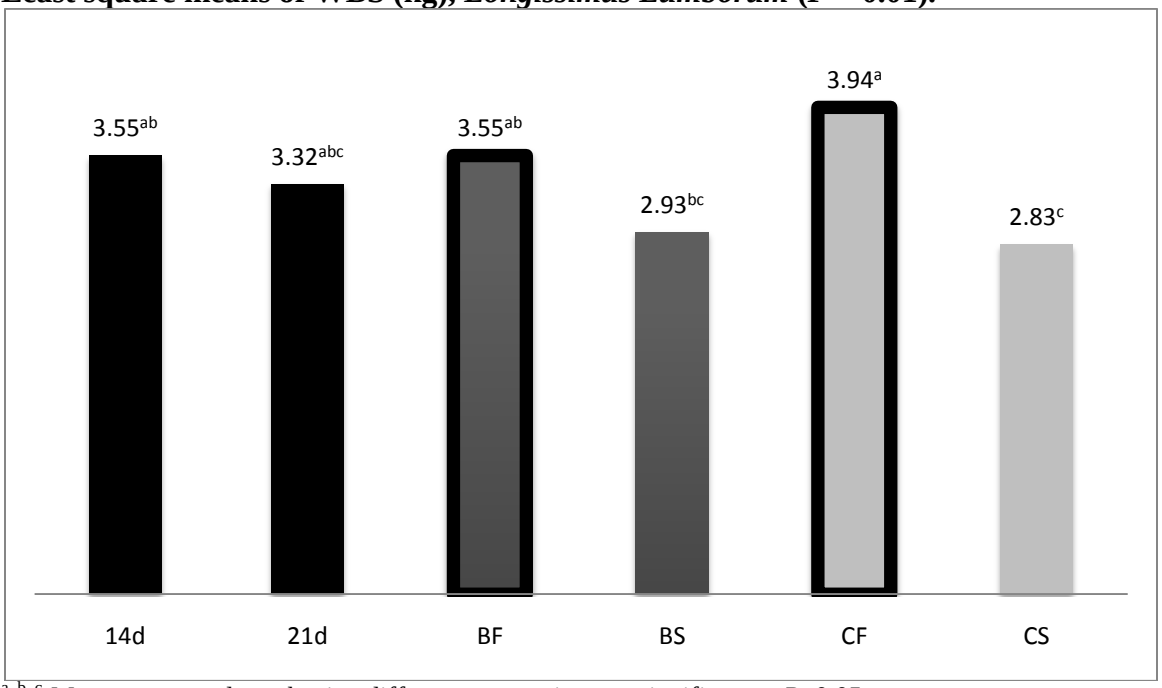
**Least square means of WBS (kg), *Longissimus Thoracis* (*P* = 0.001).**




[a, b, c] Means over a column having different superscripts are significant at *P*=0.05.
B = Blast Frozen = spacers placed between boxes of meat and placed in a -28°C freezer with high air velocity, C = Conventional Frozen = boxes of meat placed in a -28°C freezer with minimal air movement, S = Slow Thaw = subprimals set on a table in a 0°C room for 14 days, F = Fast Thaw = subprimals immersed in a circulating water bath (< 12°C) for 21 hrs 14d = Aged for 14d and fresh, never frozen, 21d = Aged for 21d and fresh, never frozen.

# Appendix 7

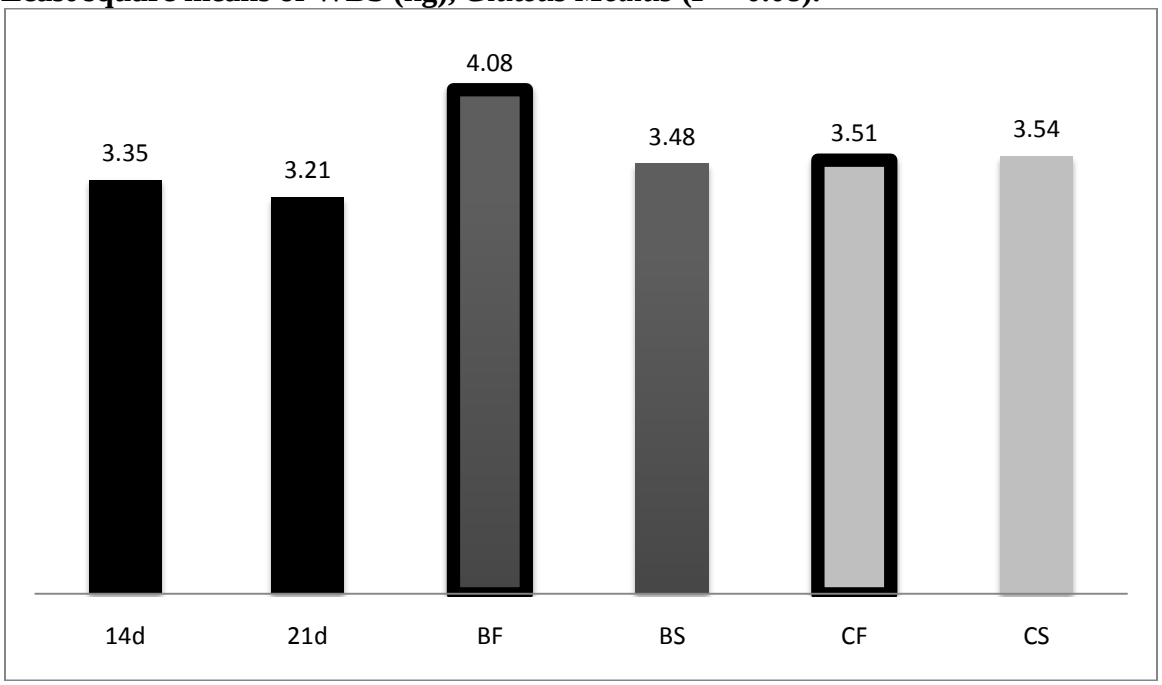
**Least square means of WBS (kg), *Longissimus Lumborum* (*P* = 0.01).**




[a, b, c] Means over a column having different superscripts are significant at *P*=0.05.
B = Blast Frozen = spacers placed between boxes of meat and placed in a -28°C freezer with high air velocity, C = Conventional Frozen = boxes of meat placed in a -28°C freezer with minimal air movement, S = Slow Thaw = subprimals set on a table in a 0°C room for 14 days, F = Fast Thaw = subprimals immersed in a circulating water bath (< 12°C) for 21 hrs 14d = Aged for 14d and fresh, never frozen, 21d = Aged for 21d and fresh, never frozen.

## Appendix 8

**Least square means of WBS (kg), *Gluteus Medius* (*P* = 0.08).**




B = Blast Frozen = spacers placed between boxes of meat and placed in a -28°C freezer with high air velocity, C = Conventional Frozen = boxes of meat placed in a -28°C freezer with minimal air movement, S = Slow Thaw = subprimals set on a table in a 0°C room for 14 days, F = Fast Thaw = subprimals immersed in a circulating water bath (< 12°C) for 21 hrs 14d = Aged for 14d and fresh, never frozen, 21d = Aged for 21d and fresh, never frozen.

## Appendix 9

**Least square means of subjective tenderness.**

| | Treatments[1] | | | | | | | Contrast* | |
|---|---|---|---|---|---|---|---|---|---|
| Muscle | 14d | 21d | BF | BS | CF | CS | *P*-value | Blast Frozen vs. Conventional Frozen | Slow Thaw vs. Fast Thaw |
| ***Longissimus Thoracis*** | 5.80 | 5.94 | 5.12 | 5.30 | 5.55 | 5.67 | 0.07 | 0.0613 | 0.4692 |
| ***Longissimus Lumborum*** | 6.03 | 5.90 | 6.07 | 6.31 | 5.79 | 6.37 | 0.10 | 0.5327 | 0.0194 |
| ***Gluteus Medius*** | 5.43 | 5.88 | 5.54 | 5.89 | 5.59 | 5.52 | 0.33 | 0.6811 | 0.8198 |

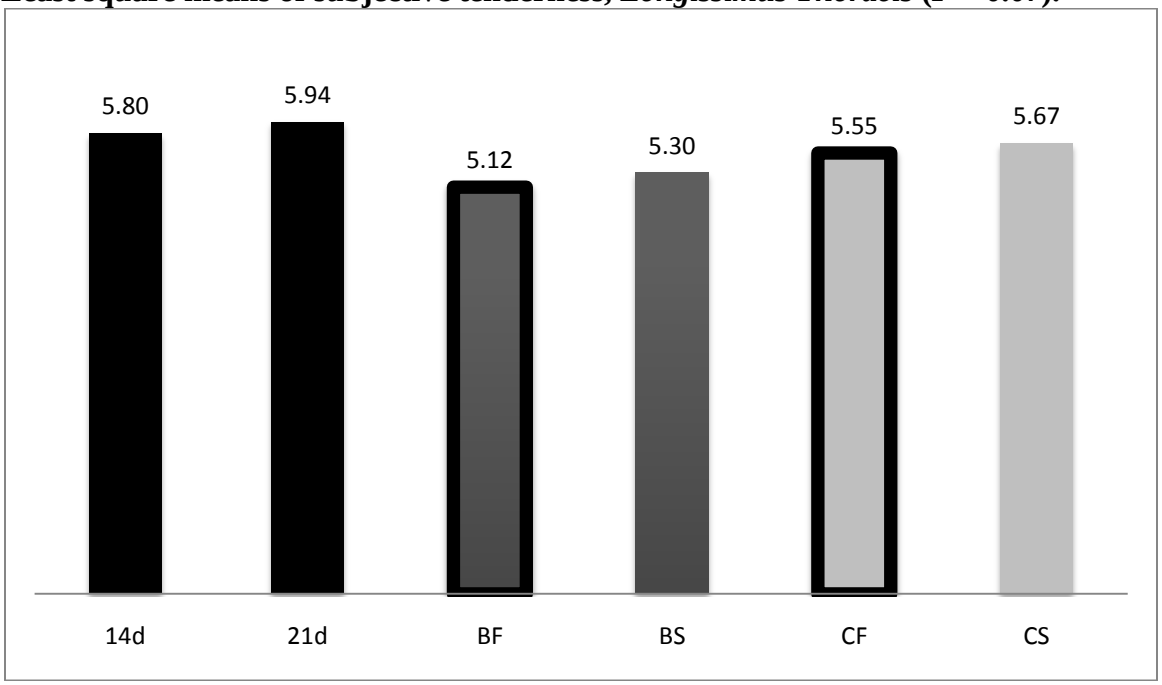
*P-value for the interaction between freezing process and thawing process.

[1] B = Blast Frozen = spacers placed between boxes of meat and placed in a -28°C freezer with high air velocity, C = Conventional Frozen = boxes of meat placed in a -28°C freezer with minimal air movement, S = Slow Thaw = subprimals set on a table in a 0°C room for 14 days, F = Fast Thaw = subprimals immersed in a circulating water bath (< 12°C) for 21 hrs 14d = Aged for 14d and fresh, never frozen, 21d = Aged for 21d and fresh, never frozen.

Tenderness was measured on a scale from 1-8 (1=extremely tough, 8=extremely tender).

## Appendix 10

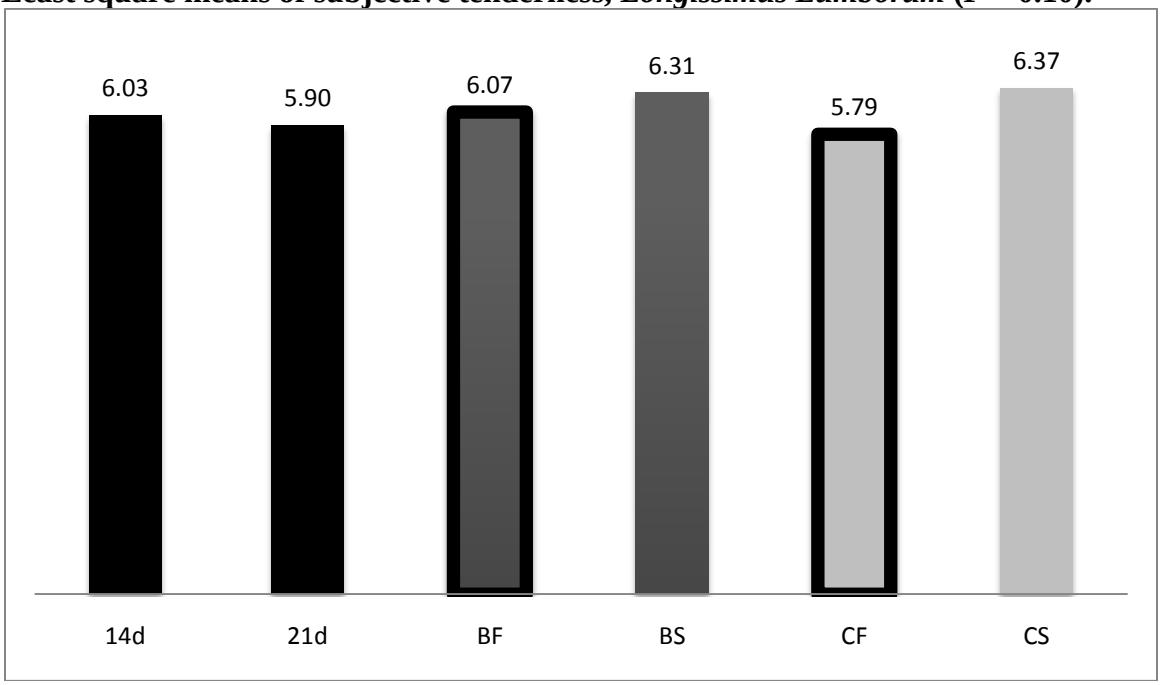
**Least square means of subjective tenderness, *Longissimus Thoracis* (*P* = 0.07).**




B = Blast Frozen = spacers placed between boxes of meat and placed in a -28°C freezer with high air velocity, C = Conventional Frozen = boxes of meat placed in a -28°C freezer with minimal air movement, S = Slow Thaw = subprimals set on a table in a 0°C room for 14 days, F = Fast Thaw = subprimals immersed in a circulating water bath (< 12°C) for 21 hrs 14d = Aged for 14d and fresh, never frozen, 21d = Aged for 21d and fresh, never frozen.
Tenderness was measured on a scale from 1-8 (1=extremely tough, 8=extremely tender).

## Appendix 11

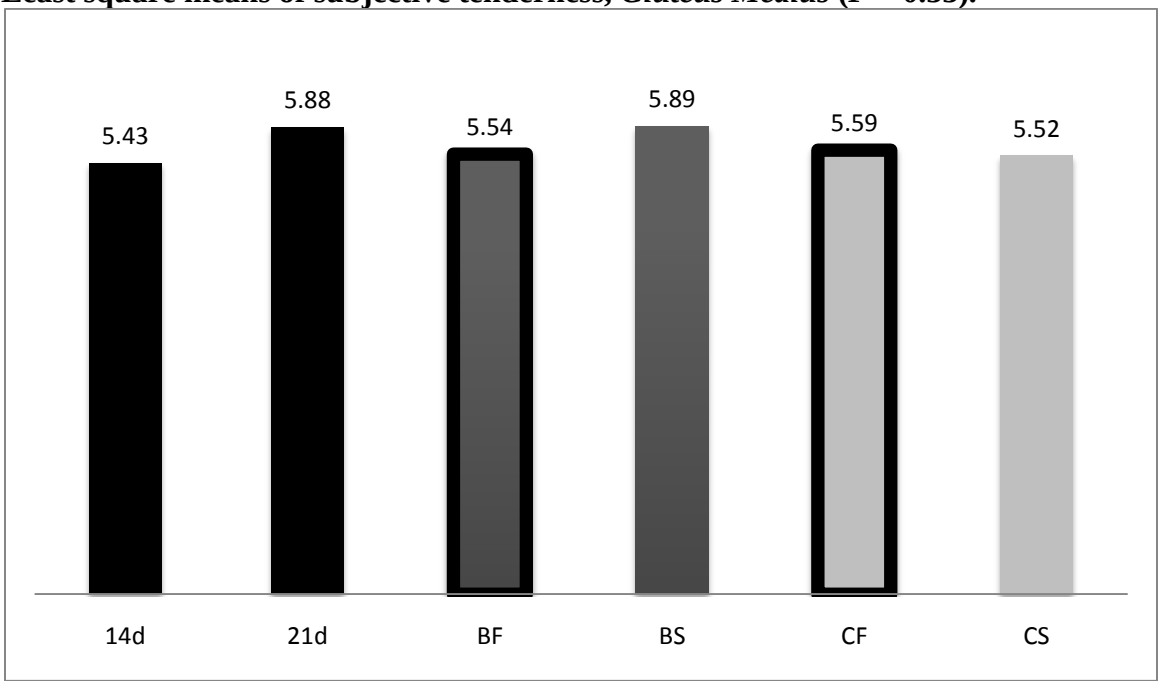
**Least square means of subjective tenderness, *Longissimus Lumborum* (*P* = 0.10).**




B = Blast Frozen = spacers placed between boxes of meat and placed in a -28°C freezer with high air velocity, C = Conventional Frozen = boxes of meat placed in a -28°C freezer with minimal air movement, S = Slow Thaw = subprimals set on a table in a 0°C room for 14 days, F = Fast Thaw = subprimals immersed in a circulating water bath (< 12°C) for 21 hrs 14d = Aged for 14d and fresh, never frozen, 21d = Aged for 21d and fresh, never frozen.
Tenderness was measured on a scale from 1-8 (1=extremely tough, 8=extremely tender).

## Appendix 12

**Least square means of subjective tenderness, *Gluteus Medius* (*P* = 0.33).**




B = Blast Frozen = spacers placed between boxes of meat and placed in a -28°C freezer with high air velocity, C = Conventional Frozen = boxes of meat placed in a -28°C freezer with minimal air movement, S = Slow Thaw = subprimals set on a table in a 0°C room for 14 days, F = Fast Thaw = subprimals immersed in a circulating water bath (< 12°C) for 21 hrs 14d = Aged for 14d and fresh, never frozen, 21d = Aged for 21d and fresh, never frozen.
Tenderness was measured on a scale from 1-8 (1=extremely tough, 8=extremely tender).

## Appendix 13

**Least square means of subjective juiciness.**

| | Treatments[1] | | | | | | | Contrast* | |
|---|---|---|---|---|---|---|---|---|---|
| Muscle | 14d | 21d | BF | BS | CF | CS | *P*-value | Blast Frozen vs. Conventional Frozen | Slow Thaw vs. Fast Thaw |
| ***Longissimus Thoracis*** | 5.08[a] | 5.07[a] | 4.12[b] | 4.34[b] | 4.48[b] | 4.30[b] | 0.001 | 0.4384 | 0.8965 |
| ***Longissimus Lumborum*** | 5.63 | 5.24 | 4.99 | 5.03 | 5.32 | 5.19 | 0.17 | 0.1977 | 0.8044 |
| ***Gluteus Medius*** | 5.01 | 5.36 | 5.33 | 4.70 | 5.04 | 4.55 | 0.07 | 0.3217 | 0.0108 |

[a, b] Means in the same row having different superscripts are significant at $P = 0.05$.

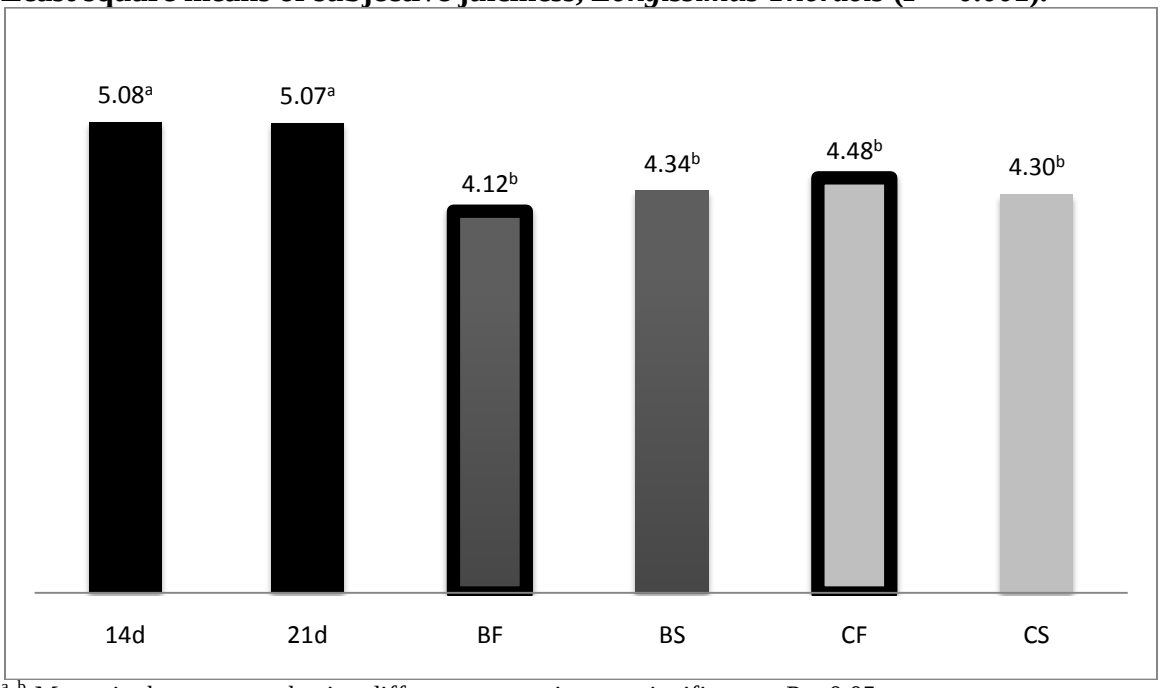
*P-value for the interaction between freezing process and thawing process.

[1] B = Blast Frozen = spacers placed between boxes of meat and placed in a -28°C freezer with high air velocity, C = Conventional Frozen = boxes of meat placed in a -28°C freezer with minimal air movement, S = Slow Thaw = subprimals set on a table in a 0°C room for 14 days, F = Fast Thaw = subprimals immersed in a circulating water bath (< 12°C) for 21 hrs 14d = Aged for 14d and fresh, never frozen, 21d = Aged for 21d and fresh, never frozen.

Juiciness was measured on a scale from 1-8 (1=extremely dry, 8=extremely juicy).

## Appendix 14

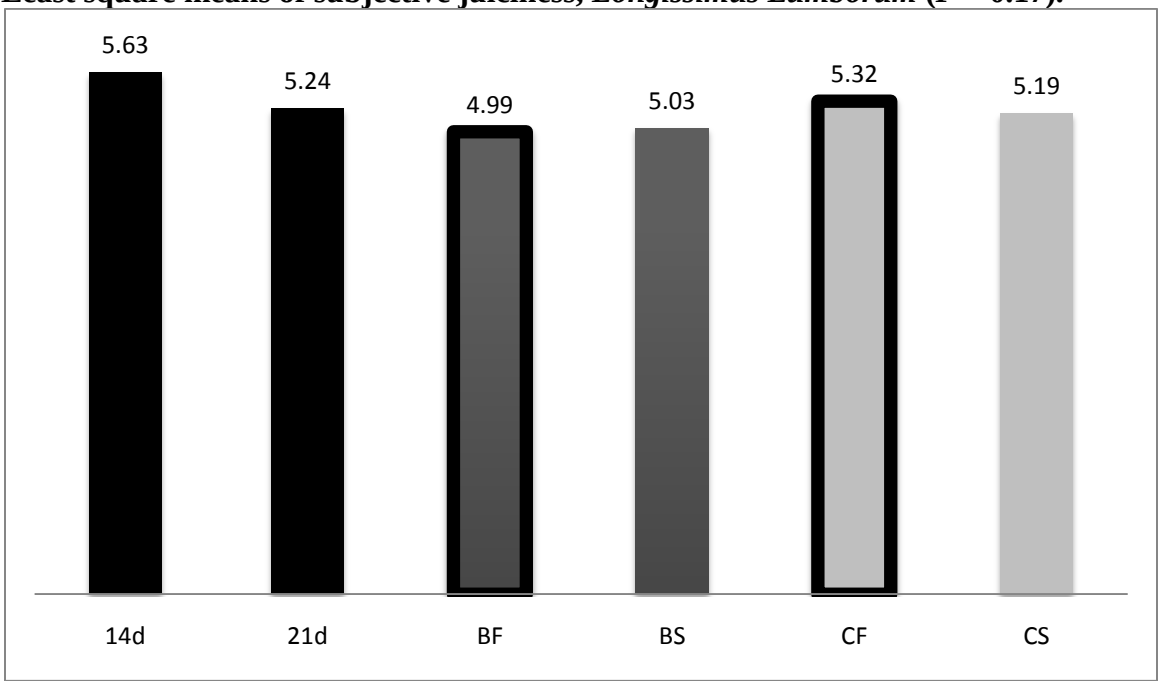
**Least square means of subjective juiciness, *Longissimus Thoracis* (*P* = 0.001).**




[a, b] Means in the same row having different superscripts are significant at *P* = 0.05.
B = Blast Frozen = spacers placed between boxes of meat and placed in a -28°C freezer with high air velocity, C = Conventional Frozen = boxes of meat placed in a -28°C freezer with minimal air movement, S = Slow Thaw = subprimals set on a table in a 0°C room for 14 days, F = Fast Thaw = subprimals immersed in a circulating water bath (< 12°C) for 21 hrs 14d = Aged for 14d and fresh, never frozen, 21d = Aged for 21d and fresh, never frozen.
Juiciness was measured on a scale from 1-8 (1=extremely dry, 8=extremely juicy).

## Appendix 15

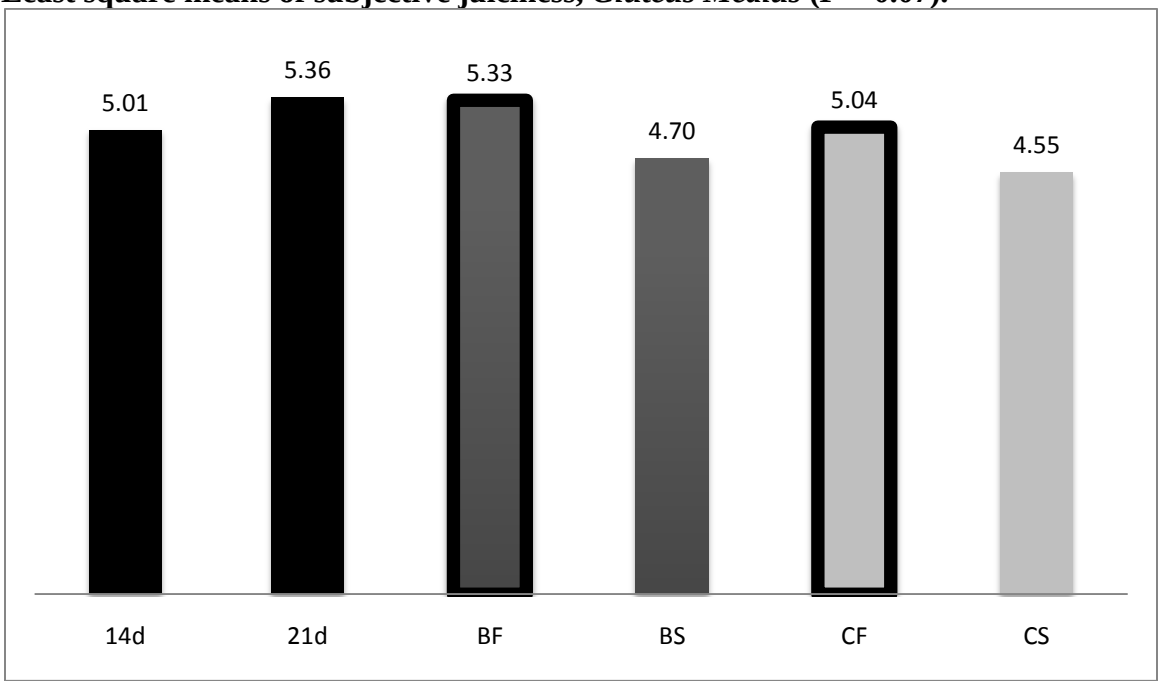
**Least square means of subjective juiciness, *Longissimus Lumborum* (*P* = 0.17).**




B = Blast Frozen = spacers placed between boxes of meat and placed in a -28°C freezer with high air velocity, C = Conventional Frozen = boxes of meat placed in a -28°C freezer with minimal air movement, S = Slow Thaw = subprimals set on a table in a 0°C room for 14 days, F = Fast Thaw = subprimals immersed in a circulating water bath (< 12°C) for 21 hrs 14d = Aged for 14d and fresh, never frozen, 21d = Aged for 21d and fresh, never frozen.
Juiciness was measured on a scale from 1-8 (1=extremely dry, 8=extremely juicy).

## Appendix 16

**Least square means of subjective juiciness, *Gluteus Medius* (*P* = 0.07).**




B = Blast Frozen = spacers placed between boxes of meat and placed in a -28°C freezer with high air velocity, C = Conventional Frozen = boxes of meat placed in a -28°C freezer with minimal air movement, S = Slow Thaw = subprimals set on a table in a 0°C room for 14 days, F = Fast Thaw = subprimals immersed in a circulating water bath (< 12°C) for 21 hrs 14d = Aged for 14d and fresh, never frozen, 21d = Aged for 21d and fresh, never frozen.
Juiciness was measured on a scale from 1-8 (1=extremely dry, 8=extremely juicy).

## Appendix 17

**Least square means of subjective connective tissue.**

| | Treatments[1] | | | | | | | Contrast* | |
|---|---|---|---|---|---|---|---|---|---|
| Muscle | 14d | 21d | BF | BS | CF | CS | *P*-value | Blast Frozen vs. Conventional Frozen | Slow Thaw vs. Fast Thaw |
| ***Longissimus Thoracis*** | 5.04 | 5.48 | 4.68 | 4.85 | 5.14 | 5.32 | 0.09 | 0.0268 | 0.3961 |
| ***Longissimus Lumborum*** | 5.61$^{ab}$ | 5.55$^{b}$ | 5.77$^{ab}$ | 6.04$^{a}$ | 5.37$^{b}$ | 6.02$^{a}$ | 0.02 | 0.1842 | 0.0032 |
| ***Gluteus Medius*** | 4.92 | 5.38 | 5.22 | 5.17 | 5.07 | 5.22 | 0.46 | 0.7670 | 0.7689 |

[a, b] Means in the same row having different superscripts are significant at $P = 0.05$.

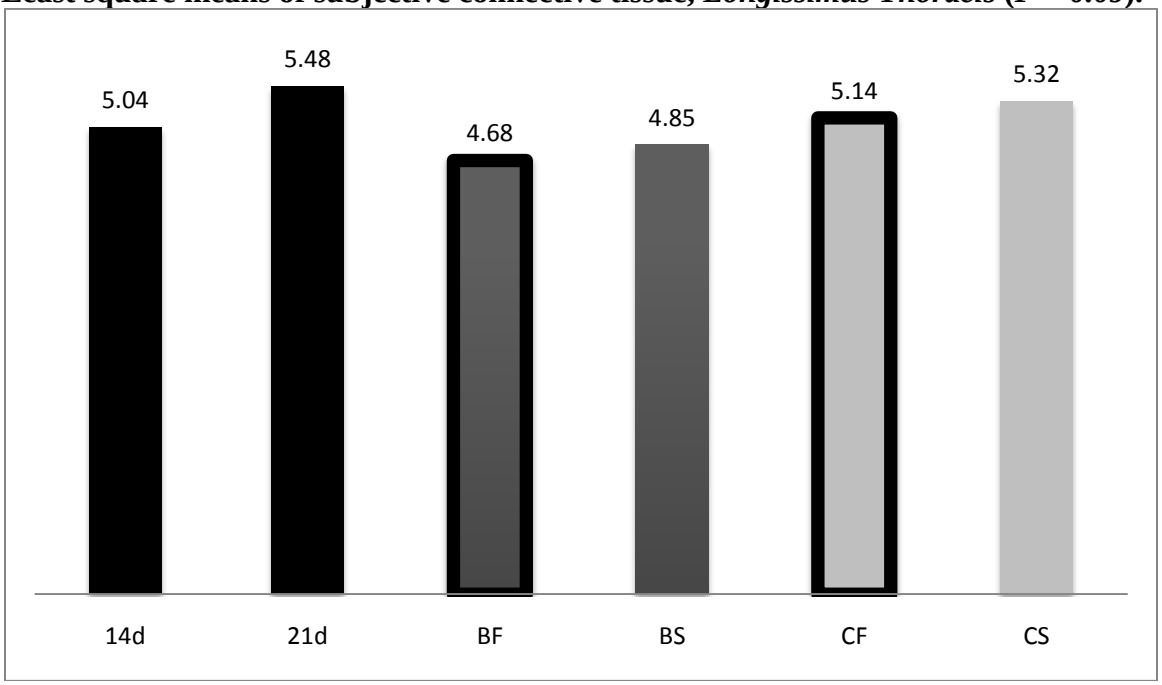
*P-value for the interaction between freezing process and thawing process.

[1] B = Blast Frozen = spacers placed between boxes of meat and placed in a -28°C freezer with high air velocity, C = Conventional Frozen = boxes of meat placed in a -28°C freezer with minimal air movement, S = Slow Thaw = subprimals set on a table in a 0°C room for 14 days, F = Fast Thaw = subprimals immersed in a circulating water bath (< 12°C) for 21 hrs 14d = Aged for 14d and fresh, never frozen, 21d = Aged for 21d and fresh, never frozen.

Connective Tissue was measured on a scale from 1-8 (1=abundant amount, 8=no connective tissue).

## Appendix 18

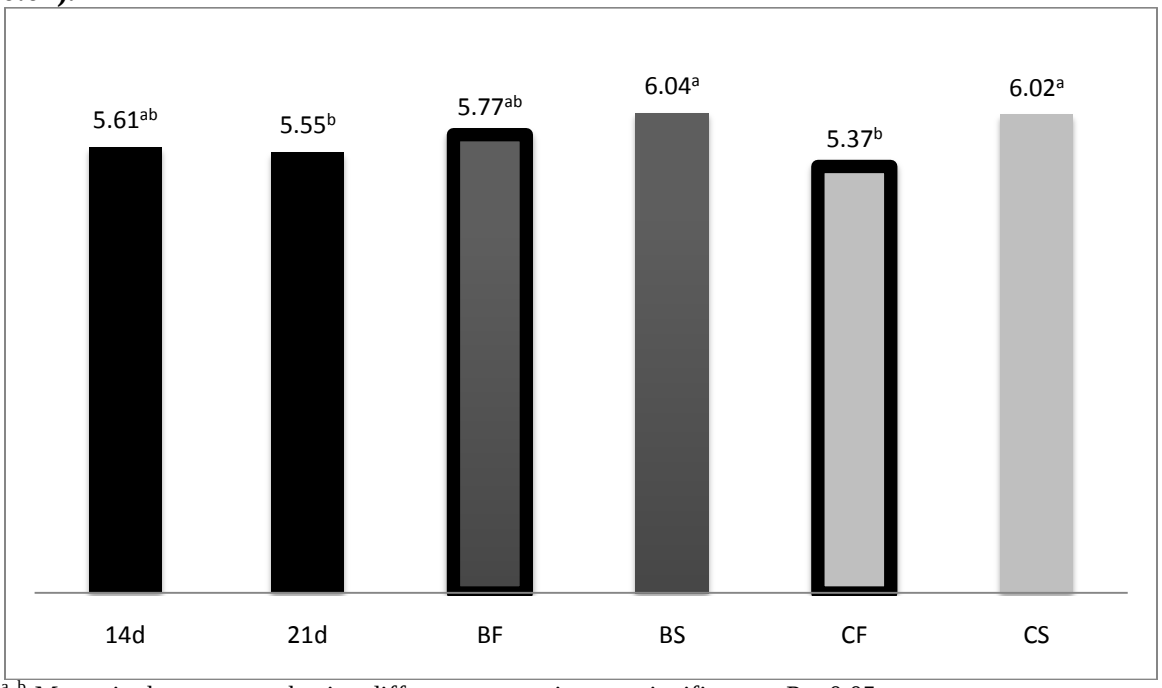
**Least square means of subjective connective tissue, *Longissimus Thoracis* (*P* = 0.09).**




B = Blast Frozen = spacers placed between boxes of meat and placed in a -28°C freezer with high air velocity, C = Conventional Frozen = boxes of meat placed in a -28°C freezer with minimal air movement, S = Slow Thaw = subprimals set on a table in a 0°C room for 14 days, F = Fast Thaw = subprimals immersed in a circulating water bath (< 12°C) for 21 hrs 14d = Aged for 14d and fresh, never frozen, 21d = Aged for 21d and fresh, never frozen.
Connective Tissue was measured on a scale from 1-8 (1=abundant amount, 8=no connective tissue).

## Appendix 19

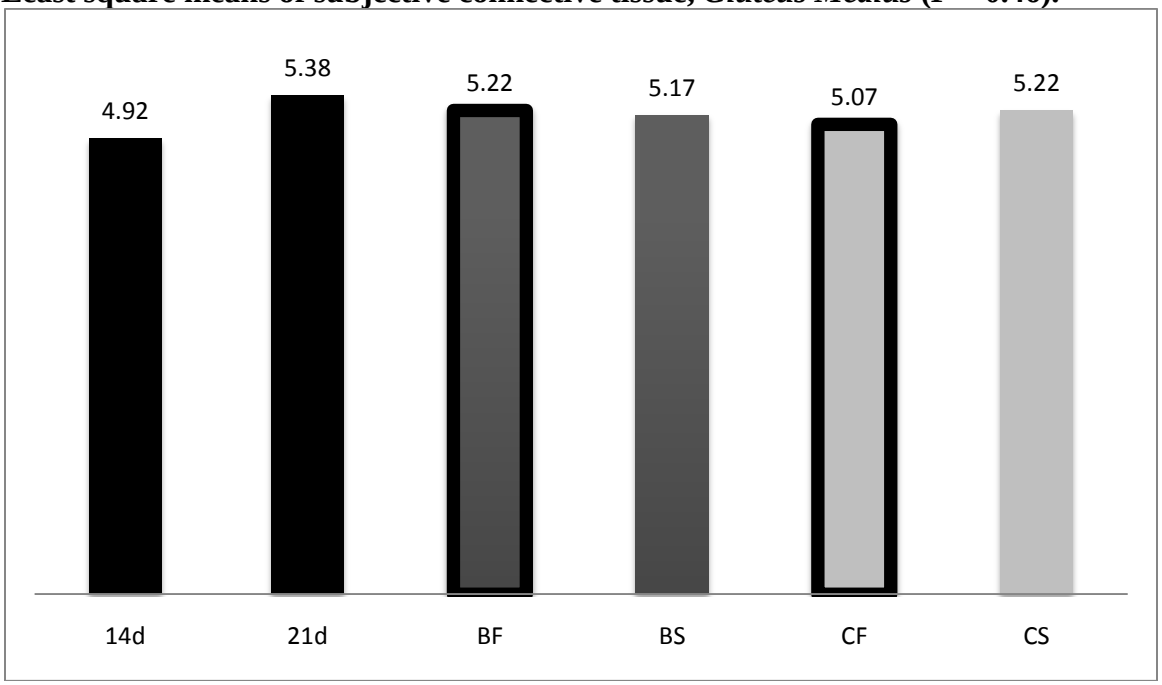
**Least square means of subjective connective tissue, *Longissimus Lumborum* (*P* = 0.02).**




[a, b] Means in the same row having different superscripts are significant at *P* = 0.05.
B = Blast Frozen = spacers placed between boxes of meat and placed in a -28°C freezer with high air velocity, C = Conventional Frozen = boxes of meat placed in a -28°C freezer with minimal air movement, S = Slow Thaw = subprimals set on a table in a 0°C room for 14 days, F = Fast Thaw = subprimals immersed in a circulating water bath (< 12°C) for 21 hrs 14d = Aged for 14d and fresh, never frozen, 21d = Aged for 21d and fresh, never frozen.
Connective Tissue was measured on a scale from 1-8 (1=abundant amount, 8=no connective tissue).

## Appendix 20

**Least square means of subjective connective tissue, *Gluteus Medius* (*P* = 0.46).**




B = Blast Frozen = spacers placed between boxes of meat and placed in a -28°C freezer with high air velocity, C = Conventional Frozen = boxes of meat placed in a -28°C freezer with minimal air movement, S = Slow Thaw = subprimals set on a table in a 0°C room for 14 days, F = Fast Thaw = subprimals immersed in a circulating water bath (< 12°C) for 21 hrs 14d = Aged for 14d and fresh, never frozen, 21d = Aged for 21d and fresh, never frozen.
Connective Tissue was measured on a scale from 1-8 (1=abundant amount, 8=no connective tissue).

## Appendix 21

**Least square means of subjective off flavor.**

| | Treatments[1] | | | | | | | Contrast* | |
|---|---|---|---|---|---|---|---|---|---|
| Muscle | 14d | 21d | BF | BS | CF | CS | *P*-value | Blast Frozen vs. Conventional Frozen | Slow Thaw vs. Fast Thaw |
| ***Longissimus Thoracis*** | 2.10 | 2.14 | 1.88 | 1.97 | 2.05 | 2.02 | 0.30 | 0.1356 | 0.6648 |
| ***Longissimus Lumborum*** | 1.93 | 1.92 | 1.89 | 2.04 | 1.81 | 1.86 | 0.49 | 0.0751 | 0.1722 |
| ***Gluteus Medius*** | 1.90[b] | 2.01[ab] | 1.84[b] | 1.96[ab] | 2.10[a] | 1.85[b] | 0.02 | 0.2296 | 0.2505 |

[a, b] Means in the same row having different superscripts are significant at $P = 0.05$.

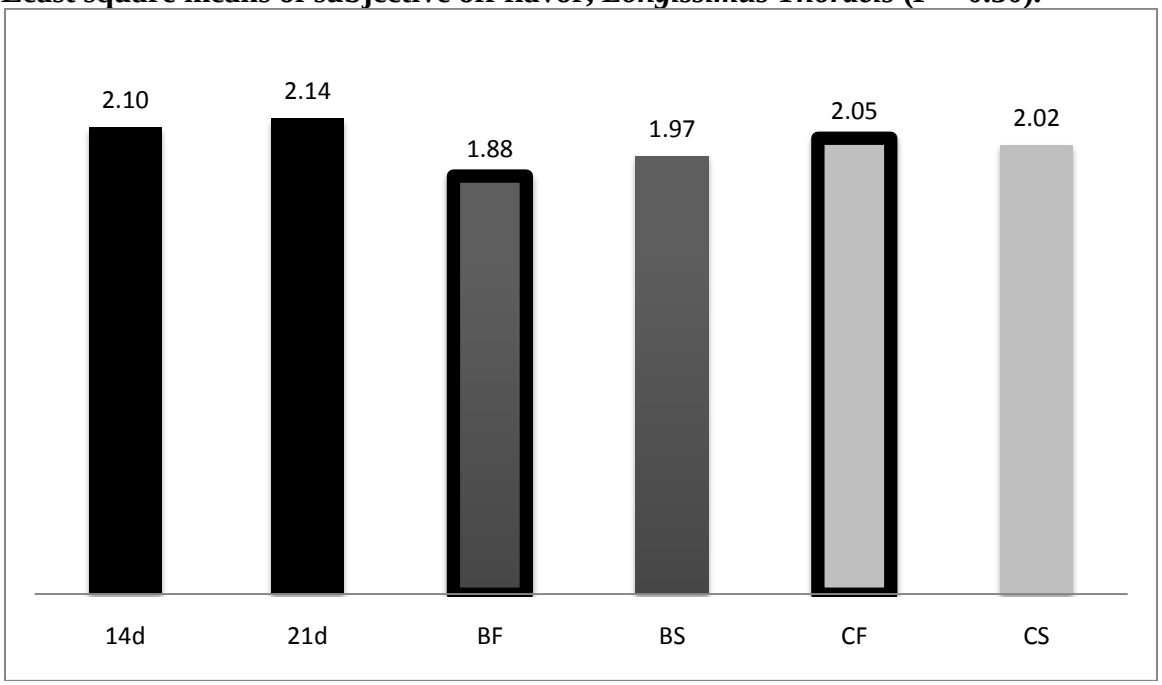
*P-value for the interaction between freezing process and thawing process.

[1] B = Blast Frozen = spacers placed between boxes of meat and placed in a -28°C freezer with high air velocity, C = Conventional Frozen = boxes of meat placed in a -28°C freezer with minimal air movement, S = Slow Thaw = subprimals set on a table in a 0°C room for 14 days, F = Fast Thaw = subprimals immersed in a circulating water bath (< 12°C) for 21 hrs 14d = Aged for 14d and fresh, never frozen, 21d = Aged for 21d and fresh, never frozen.

Off -Flavor was measured on a scale from 1-4 (1=no off-flavor, 4=strong off-flavor).

## Appendix 22

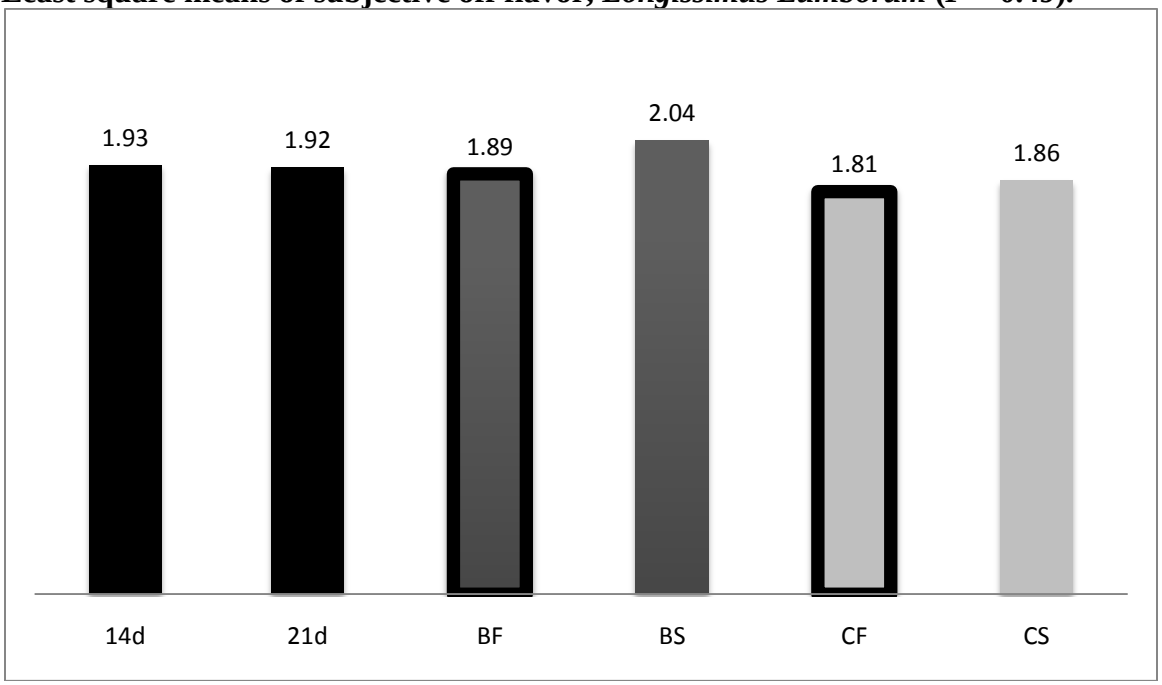
**Least square means of subjective off flavor, *Longissimus Thoracis* (*P* = 0.30).**




B = Blast Frozen = spacers placed between boxes of meat and placed in a -28°C freezer with high air velocity, C = Conventional Frozen = boxes of meat placed in a -28°C freezer with minimal air movement, S = Slow Thaw = subprimals set on a table in a 0°C room for 14 days, F = Fast Thaw = subprimals immersed in a circulating water bath (< 12°C) for 21 hrs 14d = Aged for 14d and fresh, never frozen, 21d = Aged for 21d and fresh, never frozen.
Off -Flavor was measured on a scale from 1-4 (1=no off-flavor, 4=strong off-flavor).

## Appendix 23

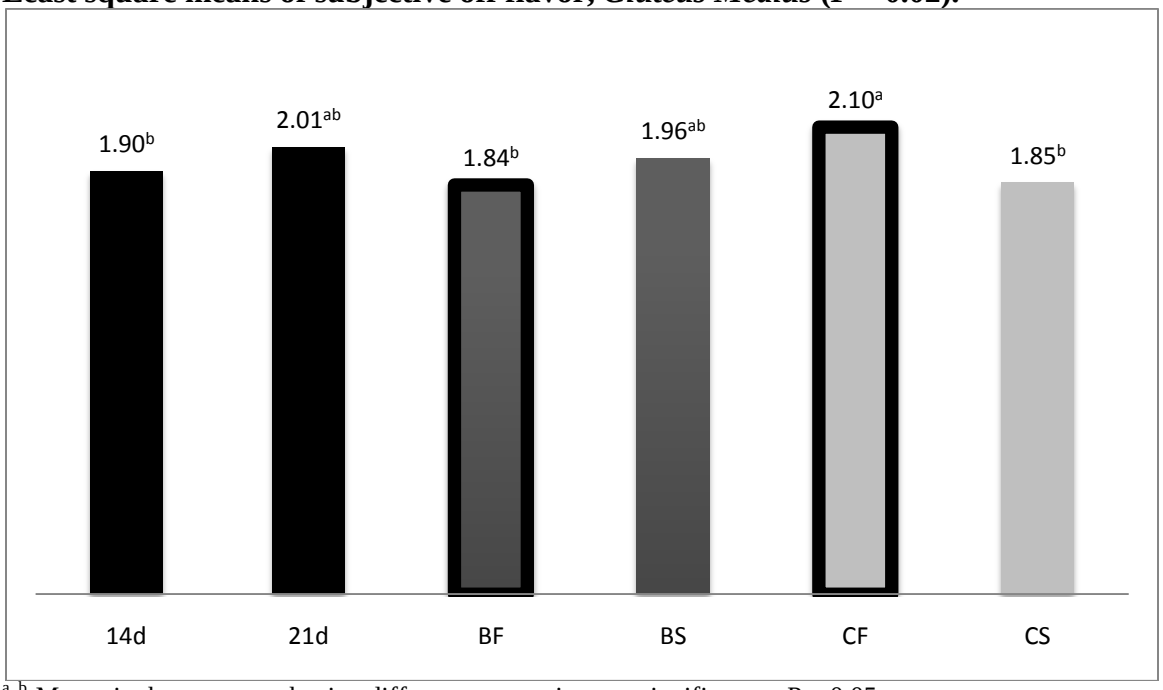
**Least square means of subjective off flavor, *Longissimus Lumborum* (*P* = 0.49).**




B = Blast Frozen = spacers placed between boxes of meat and placed in a -28°C freezer with high air velocity, C = Conventional Frozen = boxes of meat placed in a -28°C freezer with minimal air movement, S = Slow Thaw = subprimals set on a table in a 0°C room for 14 days, F = Fast Thaw = subprimals immersed in a circulating water bath (< 12°C) for 21 hrs 14d = Aged for 14d and fresh, never frozen, 21d = Aged for 21d and fresh, never frozen.
Off -Flavor was measured on a scale from 1-4 (1=no off-flavor, 4=strong off-flavor).

## Appendix 24

**Least square means of subjective off flavor, *Gluteus Medius* (*P* = 0.02).**




[a, b] Means in the same row having different superscripts are significant at *P* = 0.05.
B = Blast Frozen = spacers placed between boxes of meat and placed in a -28°C freezer with high air velocity, C = Conventional Frozen = boxes of meat placed in a -28°C freezer with minimal air movement, S = Slow Thaw = subprimals set on a table in a 0°C room for 14 days, F = Fast Thaw = subprimals immersed in a circulating water bath (< 12°C) for 21 hrs 14d = Aged for 14d and fresh, never frozen, 21d = Aged for 21d and fresh, never frozen.
Off -Flavor was measured on a scale from 1-4 (1=no off-flavor, 4=strong off-flavor).

## Appendix 25

**Least square means of cooking loss (%).**

| | Treatments[1] | | | | | | | Contrast* | |
|---|---|---|---|---|---|---|---|---|---|
| Muscle | 14d | 21d | BF | BS | CF | CS | *P*-value | Blast Frozen vs. Conventional Frozen | Slow Thaw vs. Fast Thaw |
| ***Longissimus Thoracis*** | 17.36[b] | 16.53[b] | 21.24[a] | 19.41[ab] | 22.31[a] | 20.51[a] | 0.0001 | 0.3511 | 0.1230 |
| ***Longissimus Lumborum*** | 20.95 | 16.51 | 17.21 | 19.33 | 19.36 | 17.67 | 0.41 | 0.8728 | 0.8882 |
| ***Gluteus Medius*** | 23.44 | 25.03 | 26.11 | 27.79 | 27.49 | 25.67 | 0.40 | 0.8005 | 0.9612 |

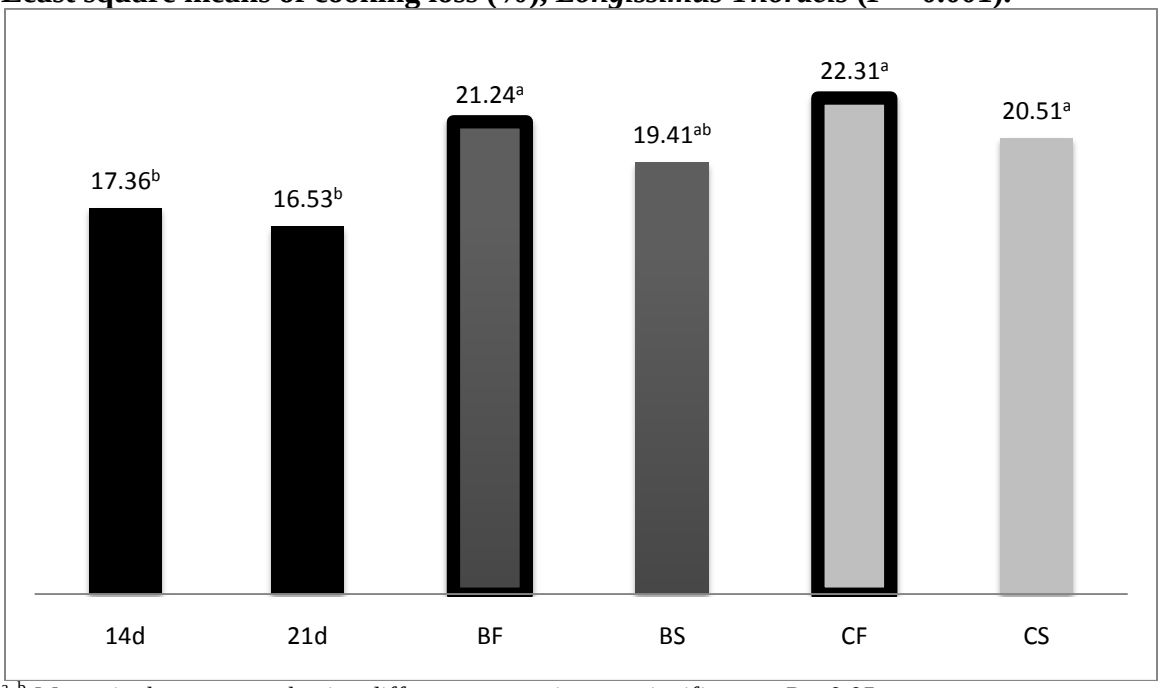
[a, b] Means in the same row having different superscripts are significant at $P = 0.05$.

*P-value for the interaction between freezing process and thawing process.

[1] B = Blast Frozen = spacers placed between boxes of meat and placed in a -28°C freezer with high air velocity, C = Conventional Frozen = boxes of meat placed in a -28°C freezer with minimal air movement, S = Slow Thaw = subprimals set on a table in a 0°C room for 14 days, F = Fast Thaw = subprimals immersed in a circulating water bath (< 12°C) for 21 hrs 14d = Aged for 14d and fresh, never frozen, 21d = Aged for 21d and fresh, never frozen.

## Appendix 26

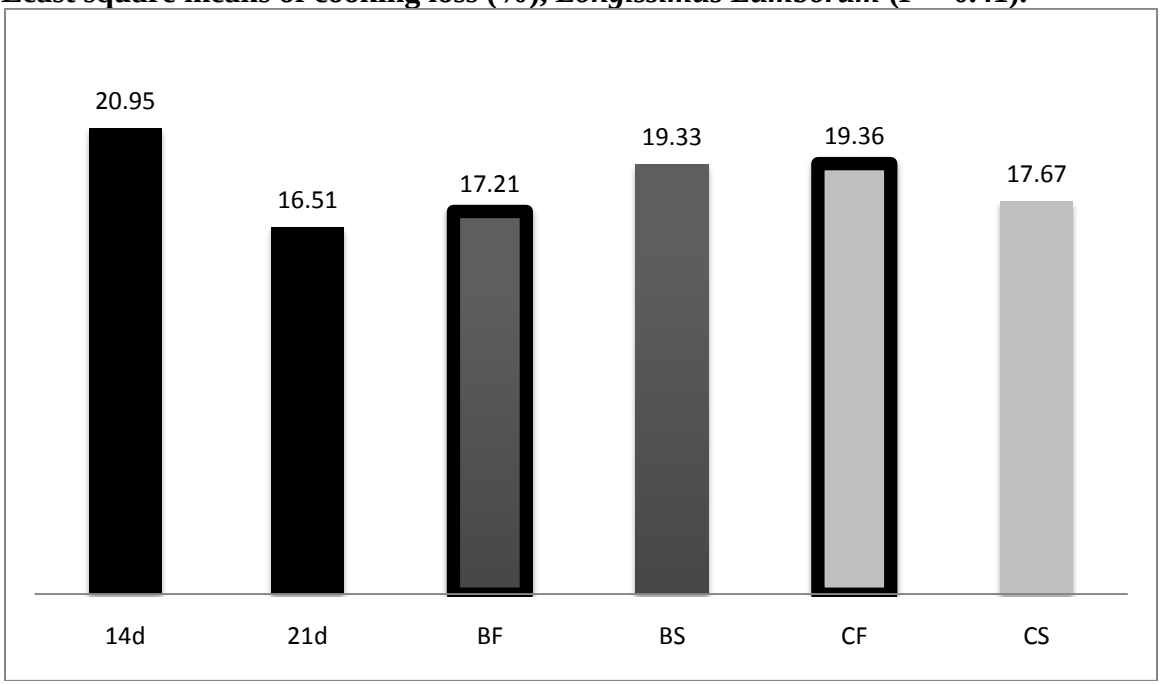
**Least square means of cooking loss (%), *Longissimus Thoracis* (*P* = 0.001).**




[a, b] Means in the same row having different superscripts are significant at *P* = 0.05.
B = Blast Frozen = spacers placed between boxes of meat and placed in a -28°C freezer with high air velocity, C = Conventional Frozen = boxes of meat placed in a -28°C freezer with minimal air movement, S = Slow Thaw = subprimals set on a table in a 0°C room for 14 days, F = Fast Thaw = subprimals immersed in a circulating water bath (< 12°C) for 21 hrs 14d = Aged for 14d and fresh, never frozen, 21d = Aged for 21d and fresh, never frozen.

## Appendix 27

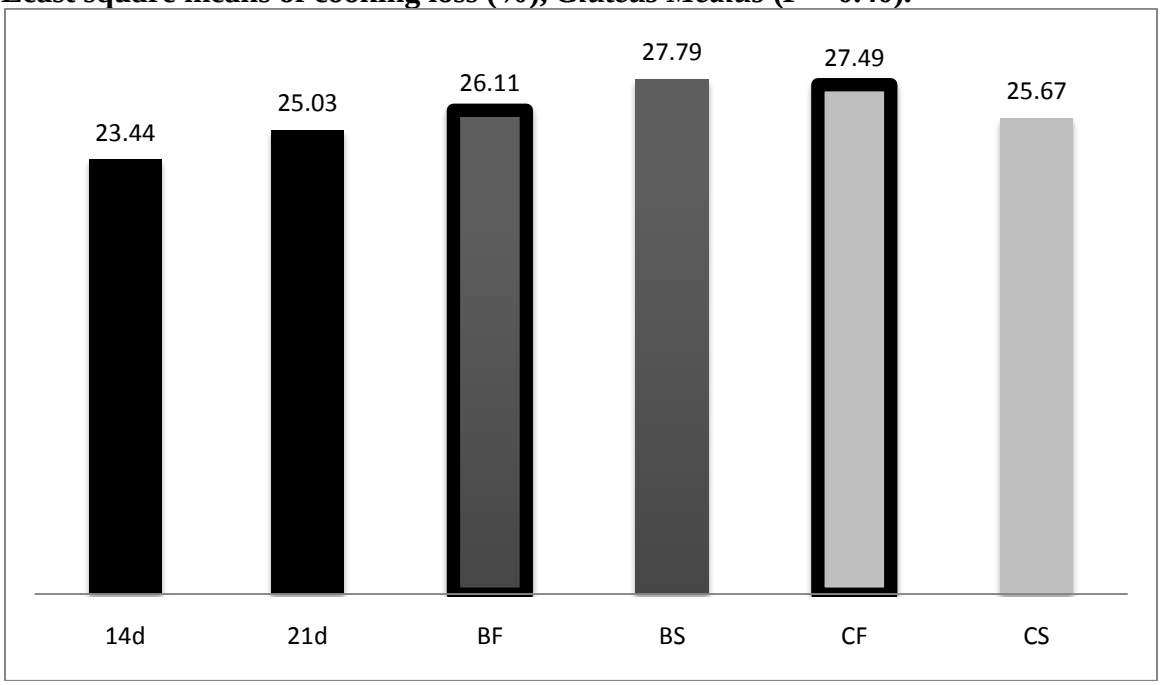
**Least square means of cooking loss (%), *Longissimus Lumborum* (*P* = 0.41).**




B = Blast Frozen = spacers placed between boxes of meat and placed in a -28°C freezer with high air velocity, C = Conventional Frozen = boxes of meat placed in a -28°C freezer with minimal air movement, S = Slow Thaw = subprimals set on a table in a 0°C room for 14 days, F = Fast Thaw = subprimals immersed in a circulating water bath (< 12°C) for 21 hrs 14d = Aged for 14d and fresh, never frozen, 21d = Aged for 21d and fresh, never frozen.

## Appendix 28

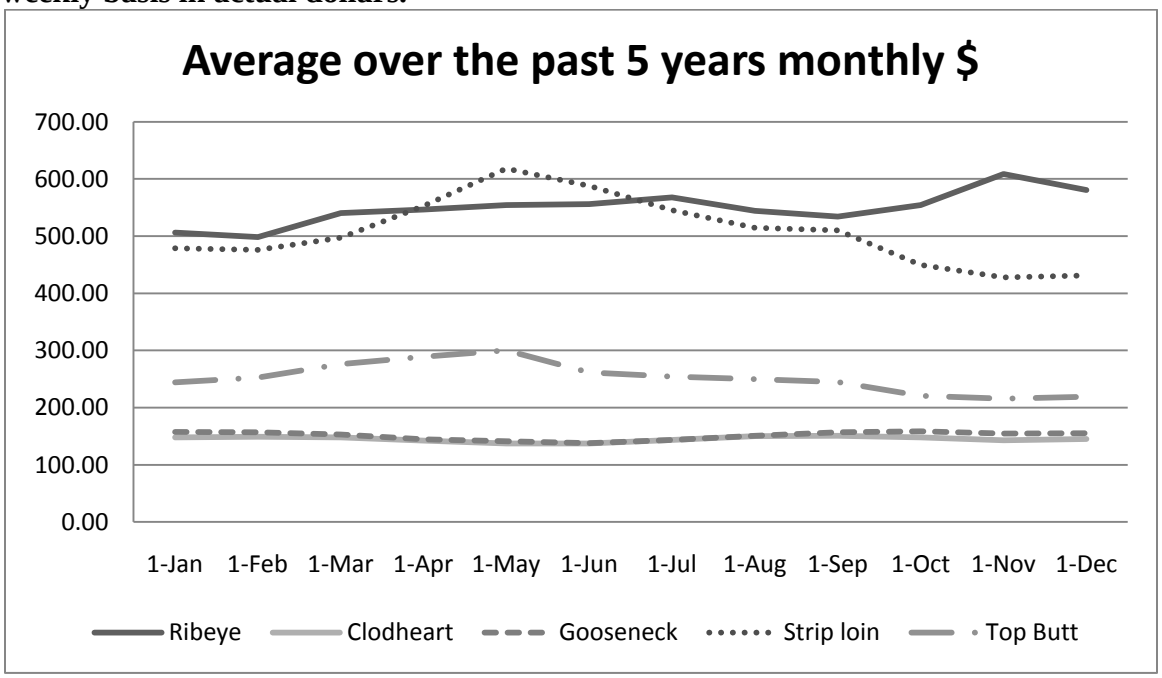
**Least square means of cooking loss (%), *Gluteus Medius* (*P* = 0.40).**

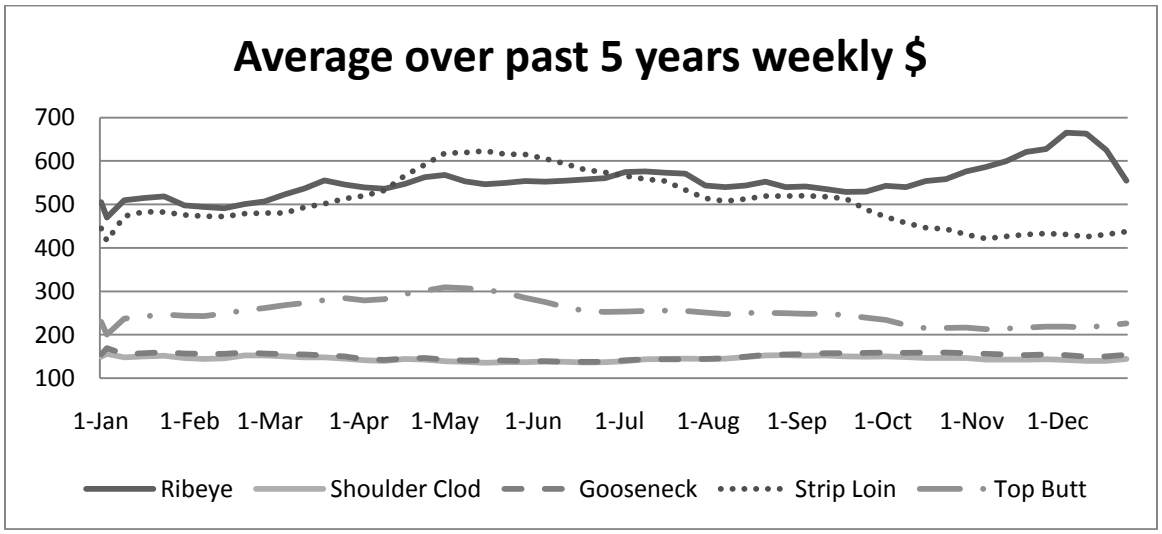



B = Blast Frozen = spacers placed between boxes of meat and placed in a -28°C freezer with high air velocity, C = Conventional Frozen = boxes of meat placed in a -28°C freezer with minimal air movement, S = Slow Thaw = subprimals set on a table in a 0°C room for 14 days, F = Fast Thaw = subprimals immersed in a circulating water bath (< 12°C) for 21 hrs 14d = Aged for 14d and fresh, never frozen, 21d = Aged for 21d and fresh, never frozen.

## Appendix 29

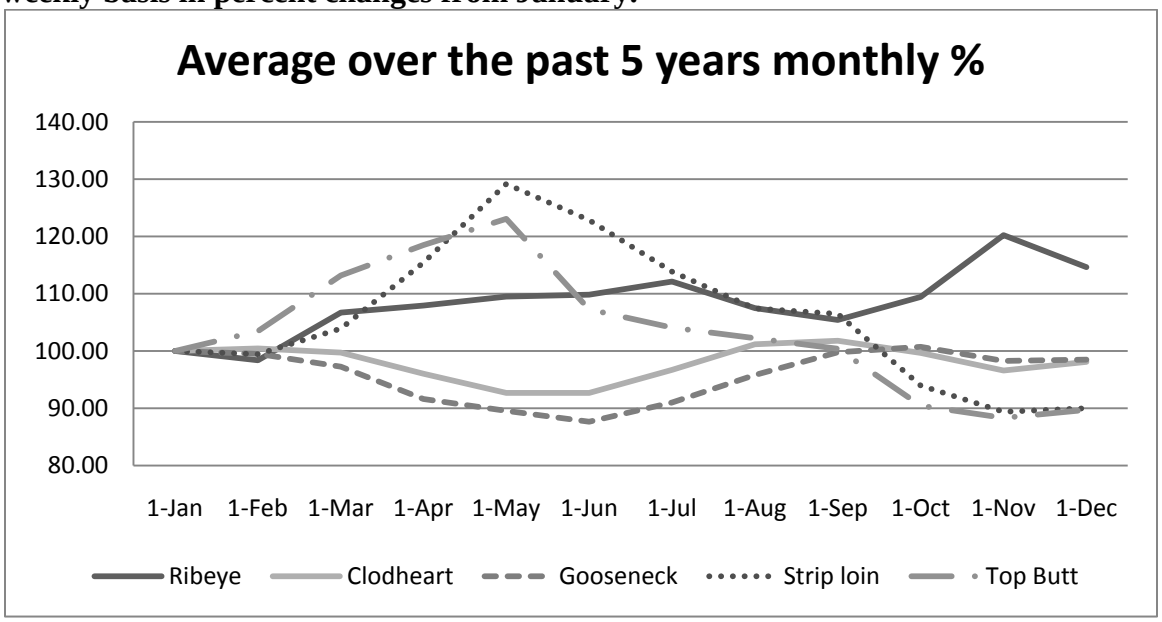
**The average price of 5 different subprimals over the past 5 years on a monthly and weekly basis in actual dollars.**

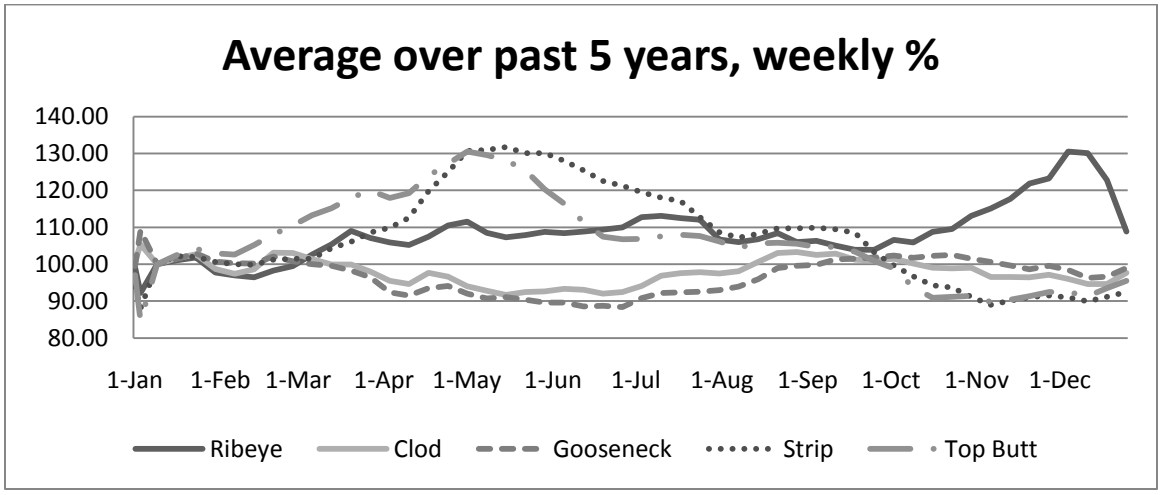


## Appendix 30

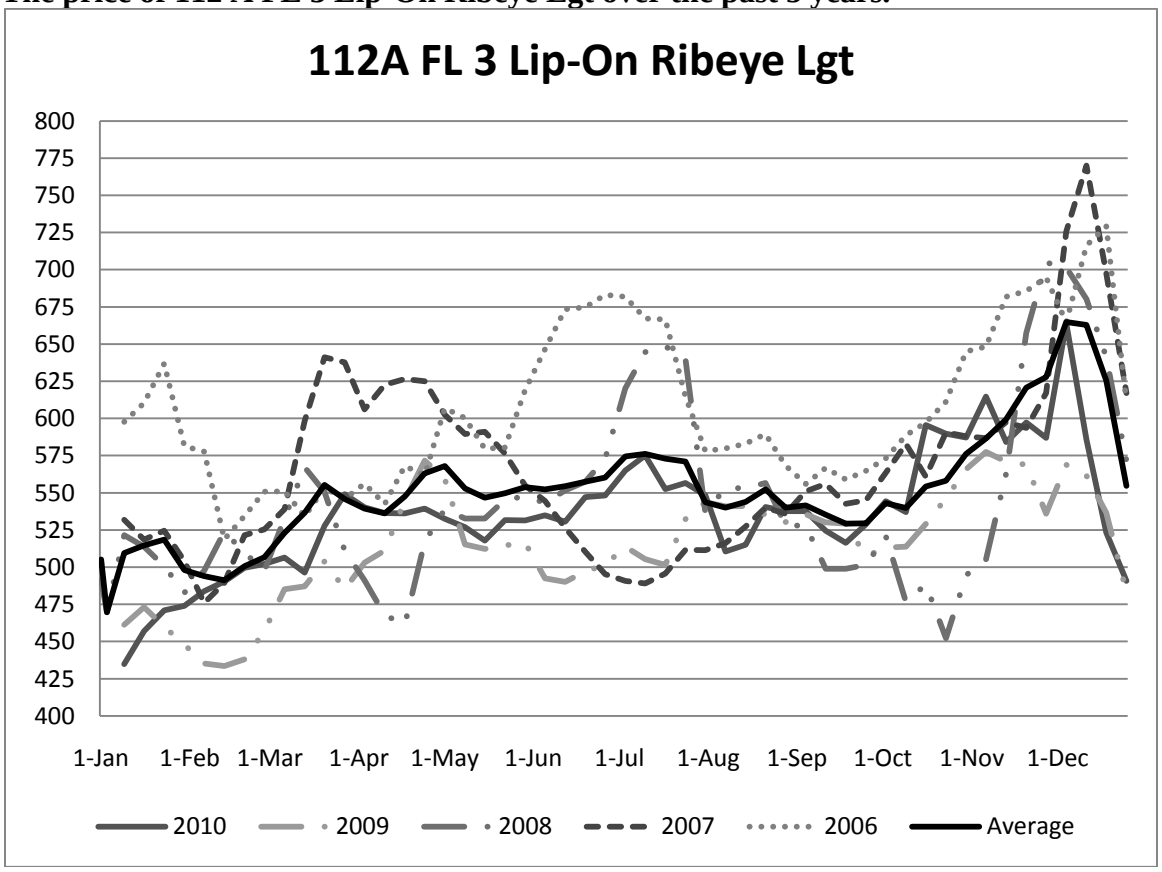
**The average price of 5 different subprimals over the past 5 years on a monthly and weekly basis in percent changes from January.**



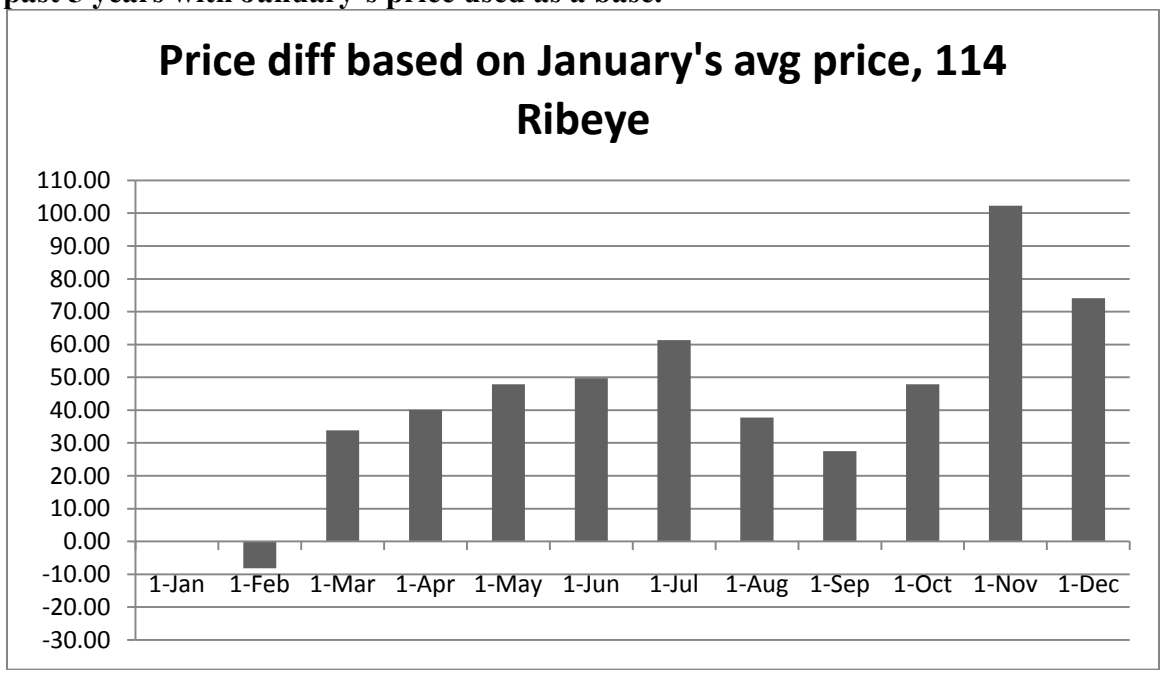
## Appendix 31

**The price of 112 A FL 3 Lip-On Ribeye Lgt over the past 5 years.**



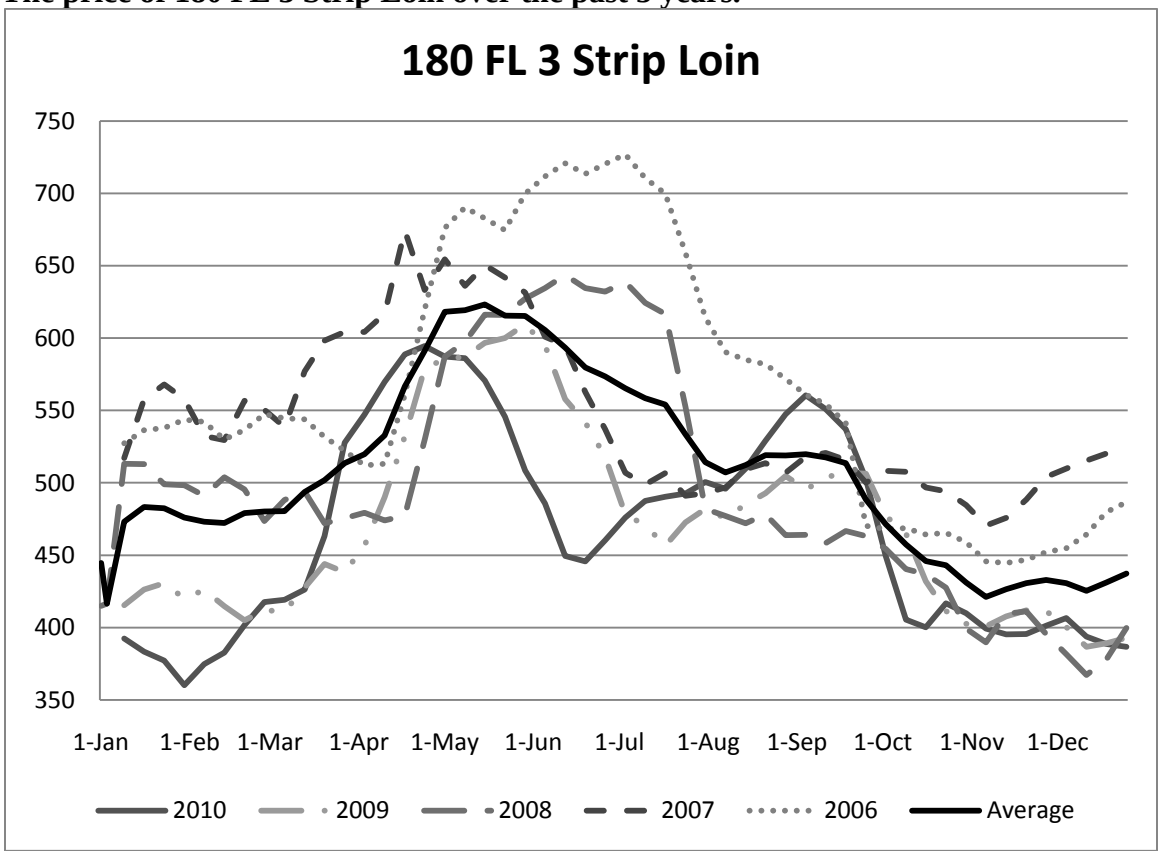
## Appendix 32

**The average price difference of 112 A FL 3 Lip-On Ribeye Lgt over a year for the past 5 years with January's price used as a base.**



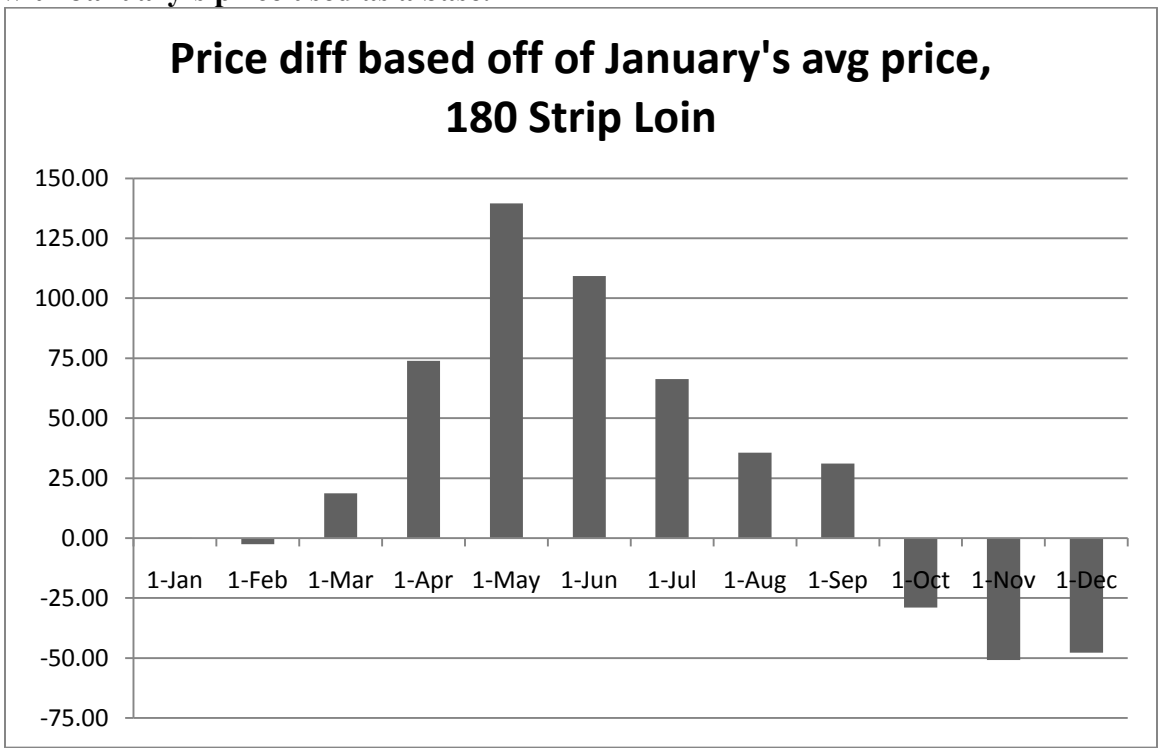
## Appendix 33

**The price of 180 FL 3 Strip Loin over the past 5 years.**



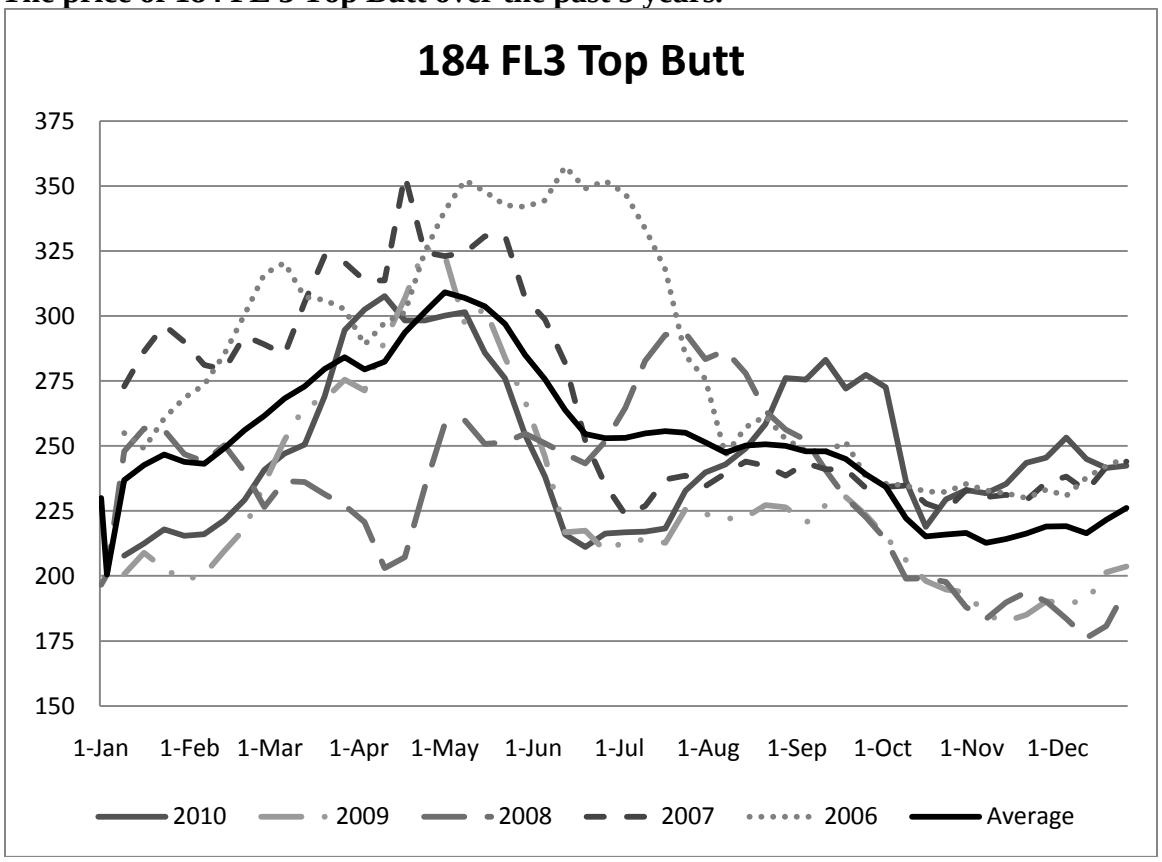
## Appendix 34

**The average price difference of 180 FL 3 Strip Loin over a year for the past 5 years with January's price used as a base.**



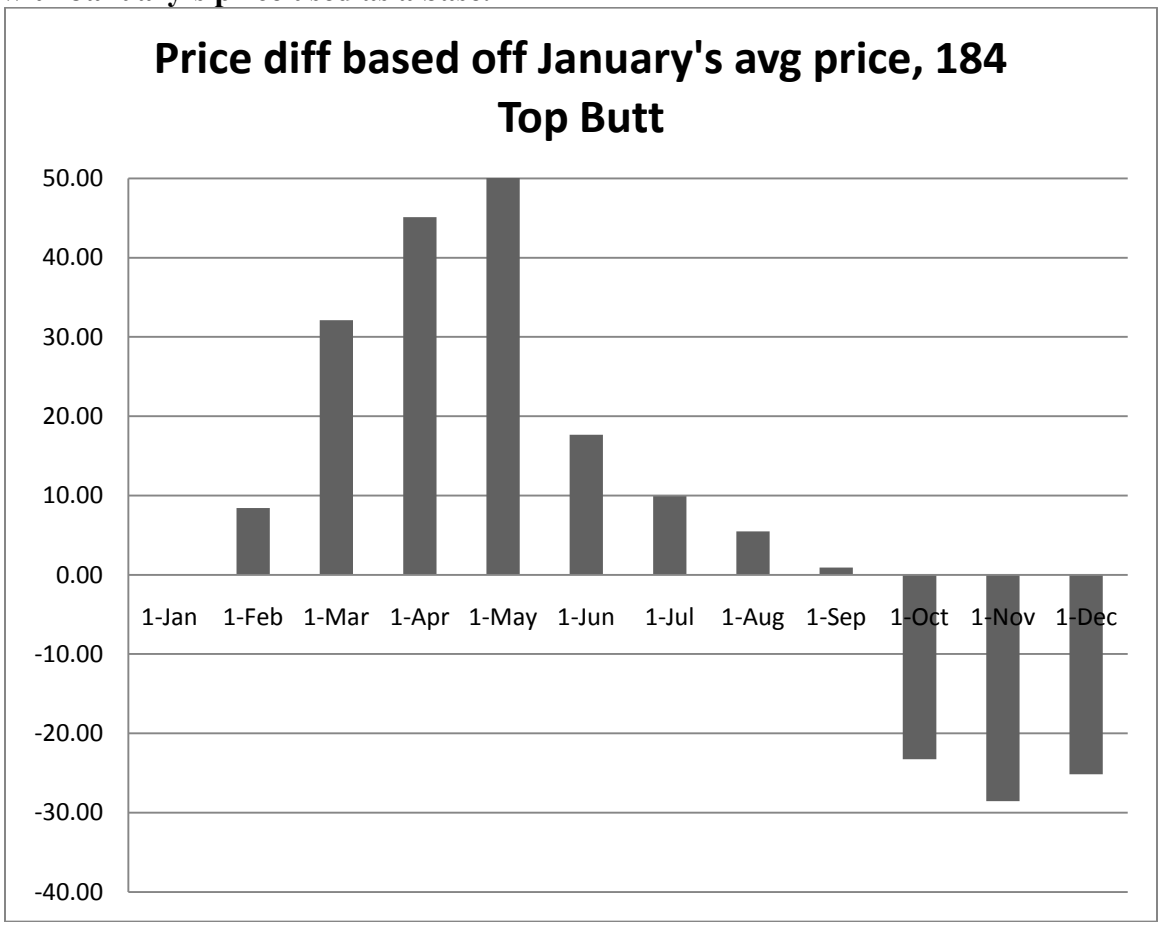
## Appendix 35

**The price of 184 FL 3 Top Butt over the past 5 years.**



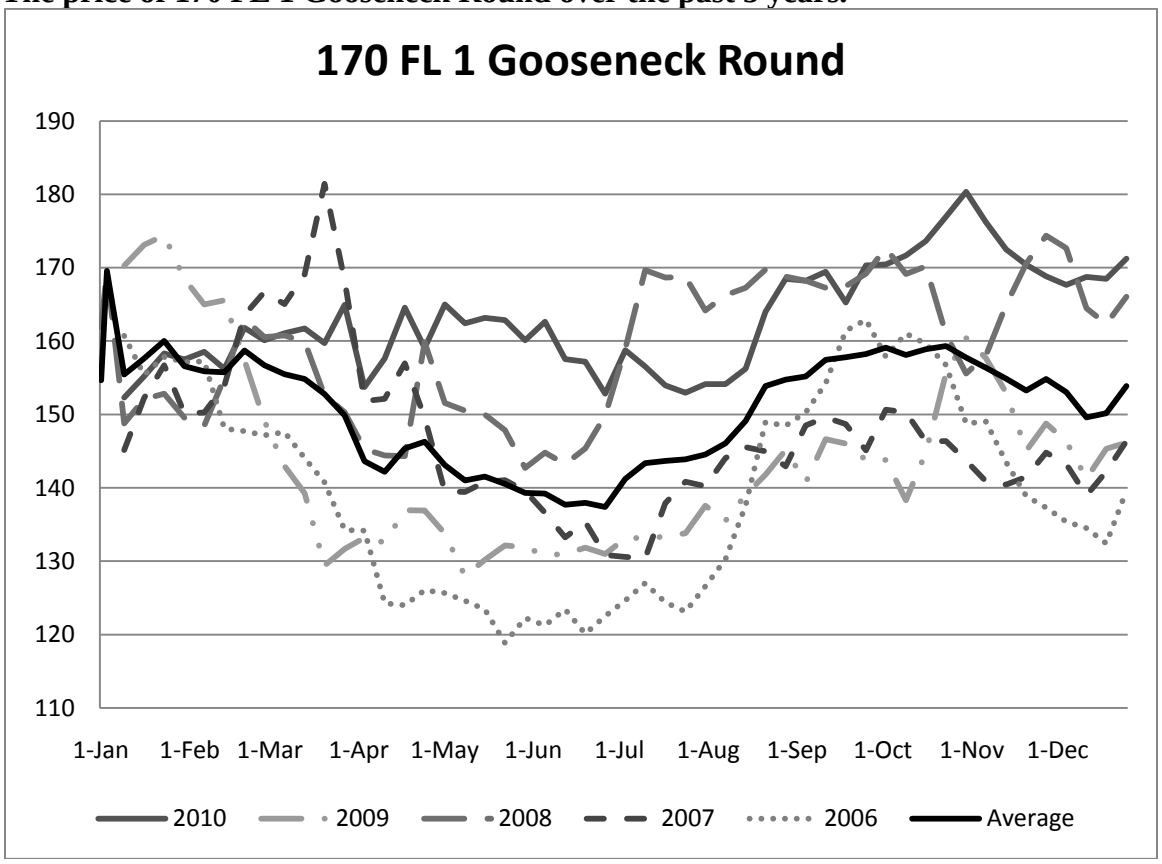
## Appendix 36

**The average price difference of 184 FL 3 Top Butt over a year for the past 5 years with January's price used as a base.**



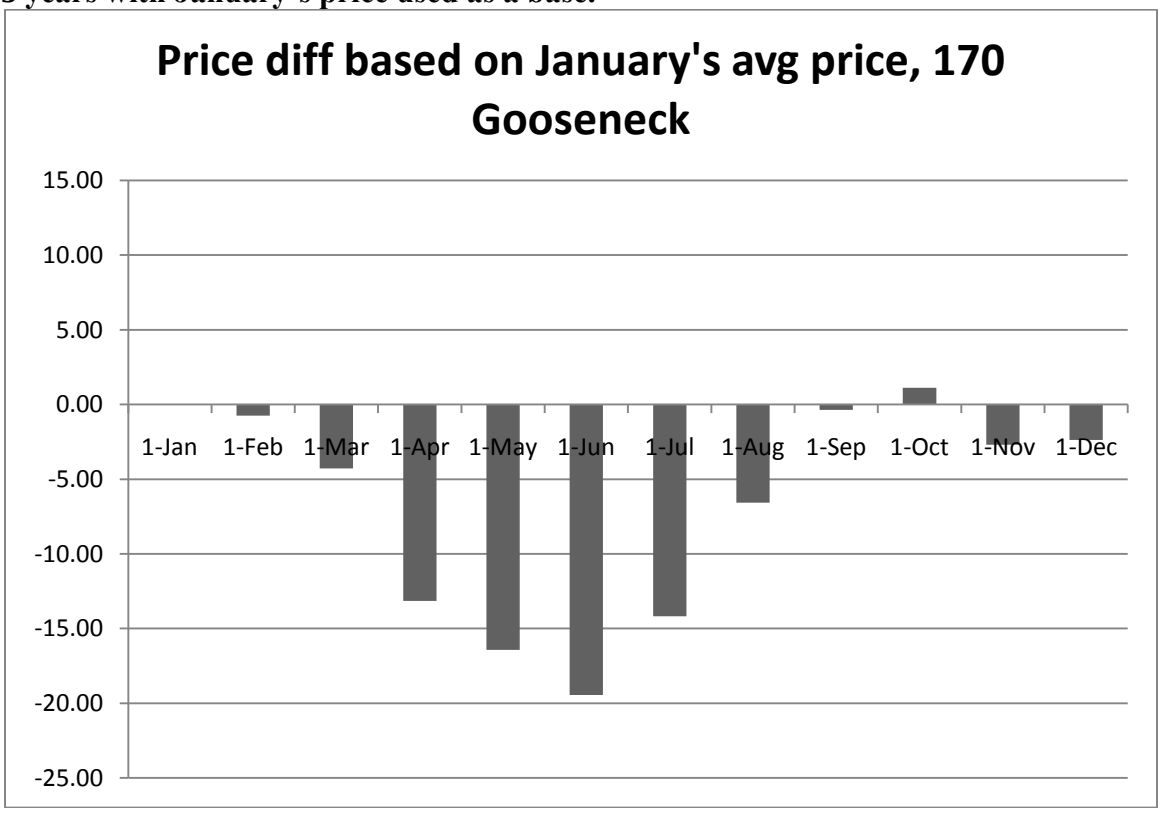
## Appendix 37

**The price of 170 FL 1 Gooseneck Round over the past 5 years.**



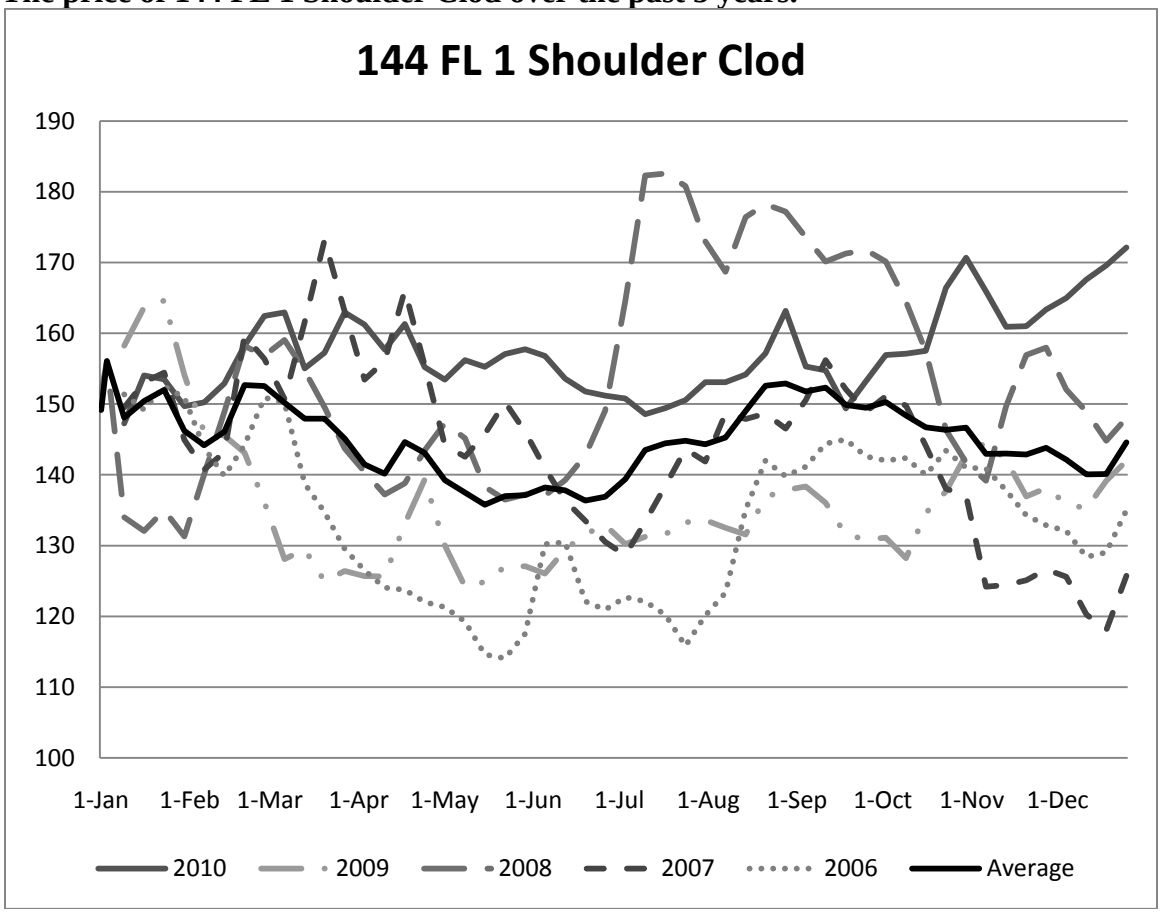
## Appendix 38

**The average price difference of 170 FL 1 Gooseneck Round over a year for the past 5 years with January's price used as a base.**



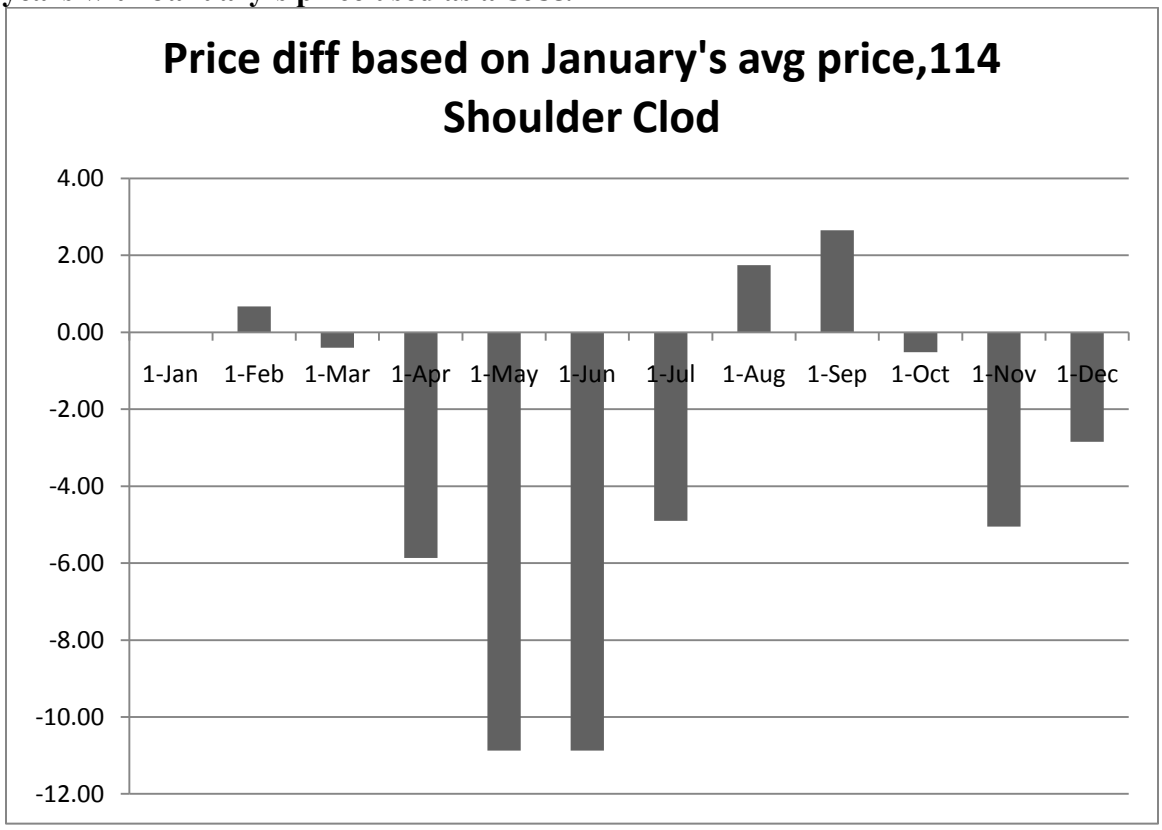
## Appendix 39

**The price of 144 FL 1 Shoulder Clod over the past 5 years.**



## Appendix 40

**The average price difference of 114 FL 1 Shoulder Clod over a year for the past 5 years with January's price used as a base.**



## Appendix 41

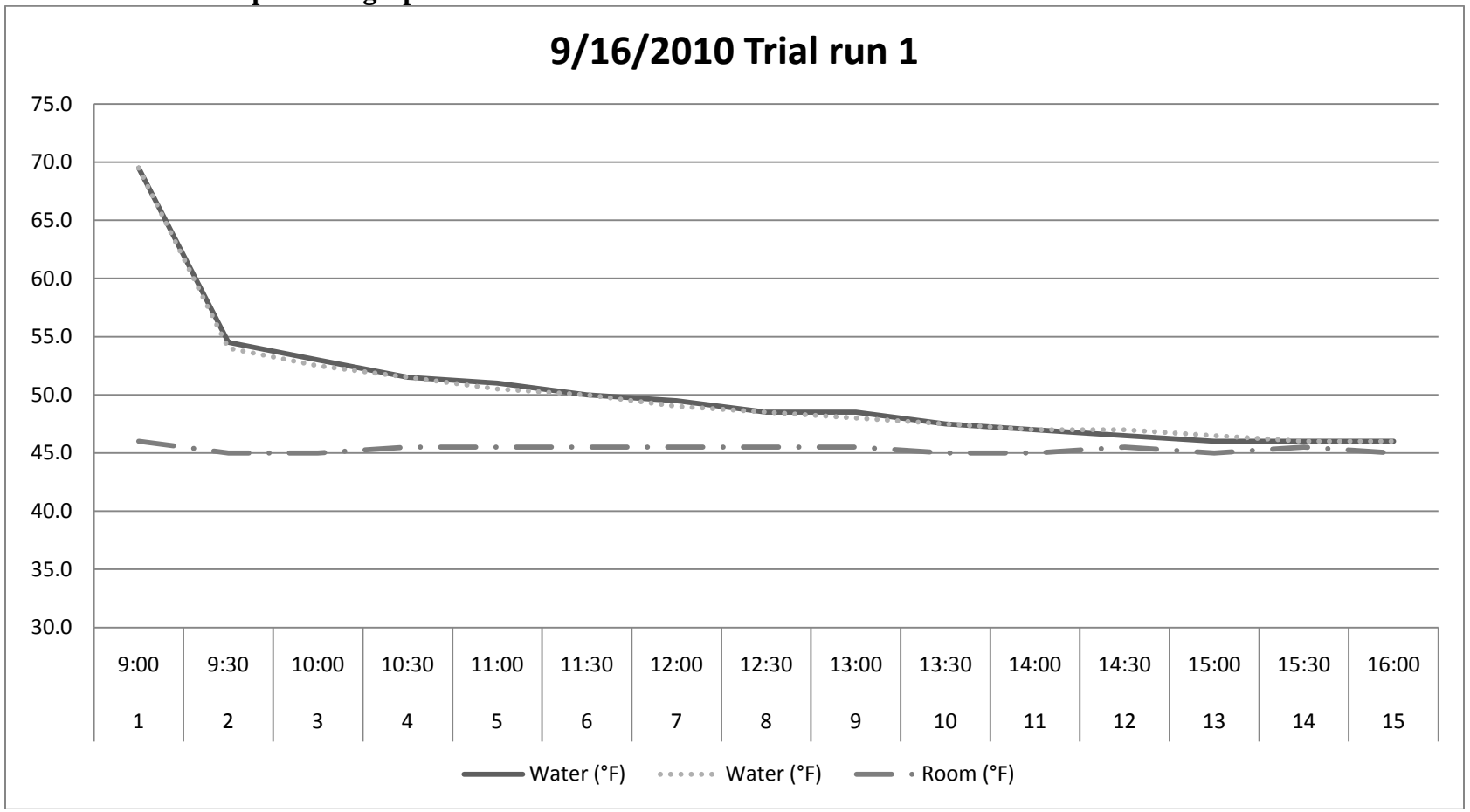
**Fast thawing data collection.**

In order to be able to fast thaw subprimals and sell the meat once they are thawed they must stay under USDA specifications. The surface of the meat cannot exceed 45°F. In order to achieve this, trial runs had to be performed before the actual research started.

The first trial ran was just the water temperature and the room temperature. We wanted to see what the starting temperature of the water was right out of the tap and how long it took the water to get below 50°F. It took 3 ½ hours for the water temperature to reach 50°F.

A trail run placing 10 sirloin subprimals into the water bath was then preformed. The water, surface of the meat and room temperature were all recorded. This time the water bath temperature started out at 55°F. The surface temperature of the meat never exceeded 45°F. The following tables and graphs are the actual data points recorded from the study.

**Water and room temperature graph**

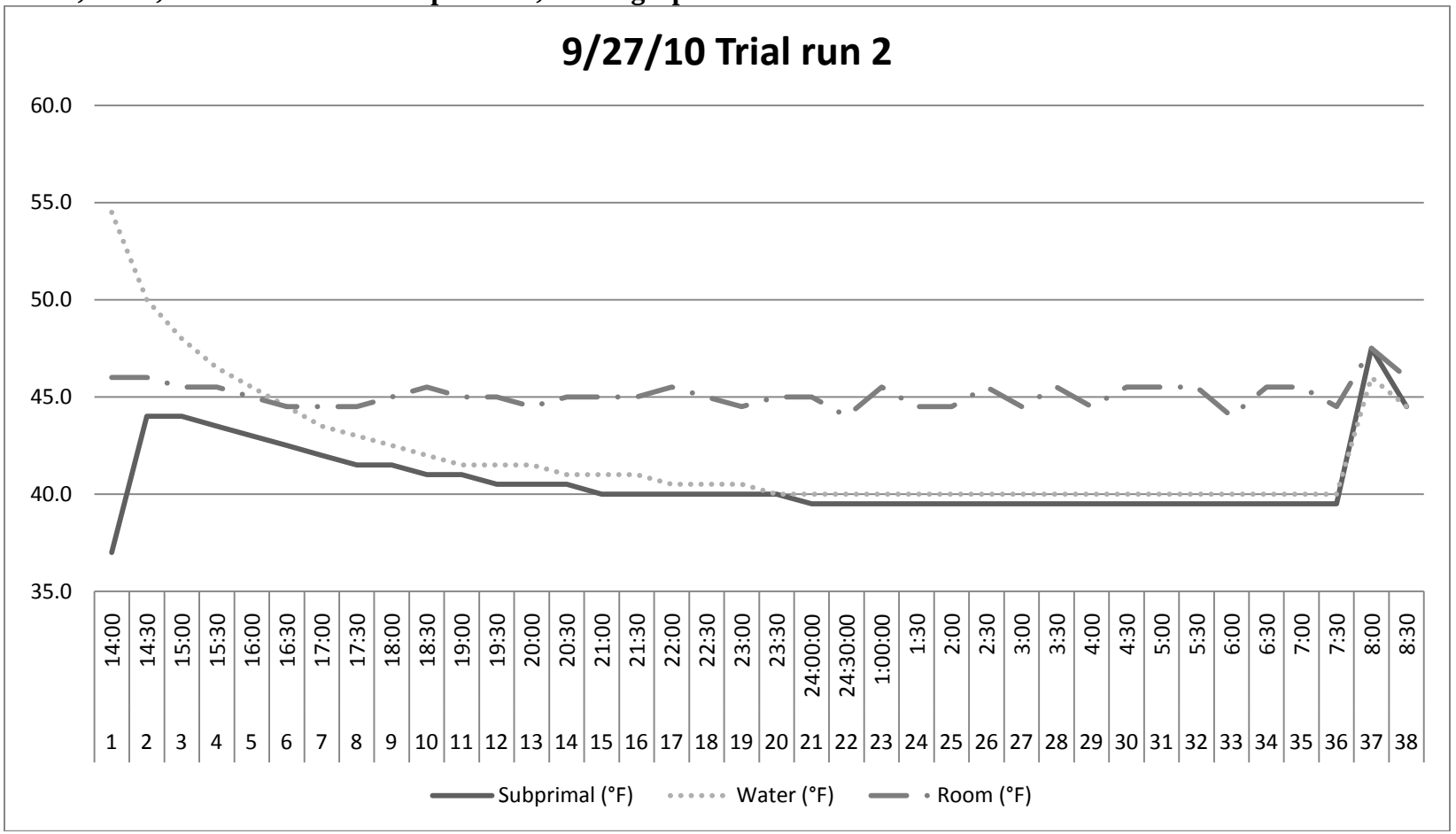


**Water and room temperature table**

9/16/2010 Trial run 1

| Rec. No. | Time | Water (°F) | Water (°F) | Room (°F) |
|---|---|---|---|---|
| 1 | 9:00 | 69.5 | 69.5 | 46.0 |
| 2 | 9:30 | 54.5 | 54.0 | 45.0 |
| 3 | 10:00 | 53.0 | 52.5 | 45.0 |
| 4 | 10:30 | 51.5 | 51.5 | 45.5 |
| 5 | 11:00 | 51.0 | 50.5 | 45.5 |
| 6 | 11:30 | 50.0 | 50.0 | 45.5 |
| 7 | 12:00 | 49.5 | 49.0 | 45.5 |
| 8 | 12:30 | 48.5 | 48.5 | 45.5 |
| 9 | 13:00 | 48.5 | 48.0 | 45.5 |
| 10 | 13:30 | 47.5 | 47.5 | 45.0 |
| 11 | 14:00 | 47.0 | 47.0 | 45.0 |
| 12 | 14:30 | 46.5 | 47.0 | 45.5 |
| 13 | 15:00 | 46.0 | 46.5 | 45.0 |
| 14 | 15:30 | 46.0 | 46.0 | 45.5 |
| 15 | 16:00 | 46.0 | 46.0 | 45.0 |

**Water, room, and meat surface temperature, trail 2 graph**

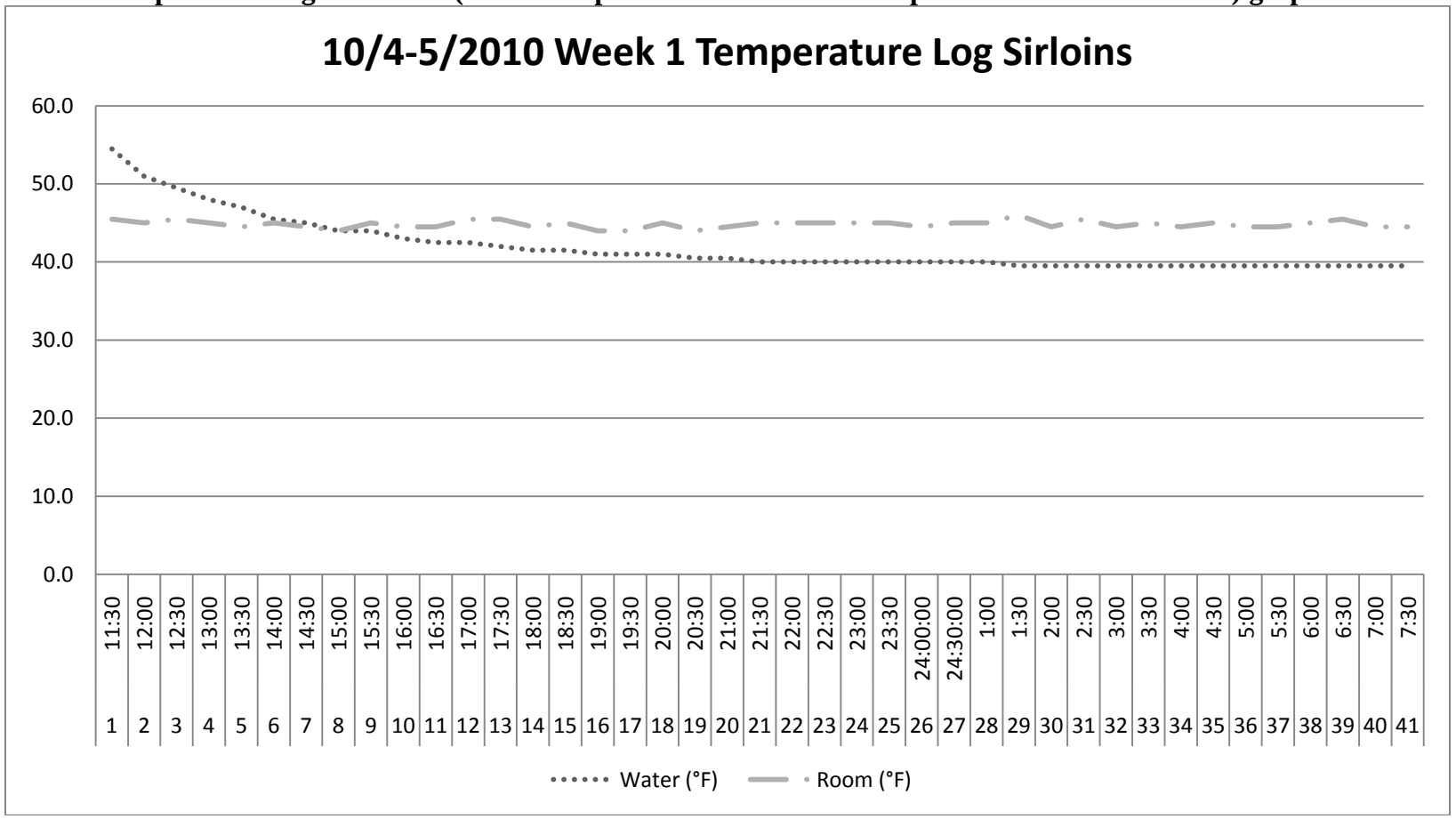


**Water, room, and meat surface temperature, trail 2 table**

9/27/2010 Trial run 2

| Rec. No. | Time | Subprimal (°F) | Water (°F) | Room (°F) |
|---|---|---|---|---|
| 1 | 14:00 | 37.0 | 54.5 | 46.0 |
| 2 | 14:30 | 44.0 | 50.0 | 46.0 |
| 3 | 15:00 | 44.0 | 48.0 | 45.5 |
| 4 | 15:30 | 43.5 | 46.5 | 45.5 |
| 5 | 16:00 | 43.0 | 45.5 | 45.0 |
| 6 | 16:30 | 42.5 | 44.5 | 44.5 |
| 7 | 17:00 | 42.0 | 43.5 | 44.5 |
| 8 | 17:30 | 41.5 | 43.0 | 44.5 |
| 9 | 18:00 | 41.5 | 42.5 | 45.0 |
| 10 | 18:30 | 41.0 | 42.0 | 45.5 |
| 11 | 19:00 | 41.0 | 41.5 | 45.0 |
| 12 | 19:30 | 40.5 | 41.5 | 45.0 |
| 13 | 20:00 | 40.5 | 41.5 | 44.5 |
| 14 | 20:30 | 40.5 | 41.0 | 45.0 |
| 15 | 21:00 | 40.0 | 41.0 | 45.0 |
| 16 | 21:30 | 40.0 | 41.0 | 45.0 |
| 17 | 22:00 | 40.0 | 40.5 | 45.5 |
| 18 | 22:30 | 40.0 | 40.5 | 45.0 |
| 19 | 23:00 | 40.0 | 40.5 | 44.5 |
| 20 | 23:30 | 40.0 | 40.0 | 45.0 |
| 21 | 24:00 | 39.5 | 40.0 | 45.0 |
| 22 | 24:30 | 39.5 | 40.0 | 44.0 |
| 23 | 1:00 | 39.5 | 40.0 | 45.5 |
| 24 | 1:30 | 39.5 | 40.0 | 44.5 |
| 25 | 2:00 | 39.5 | 40.0 | 44.5 |
| 26 | 2:30 | 39.5 | 40.0 | 45.5 |
| 27 | 3:00 | 39.5 | 40.0 | 44.5 |
| 28 | 3:30 | 39.5 | 40.0 | 45.5 |
| 29 | 4:00 | 39.5 | 40.0 | 44.5 |
| 30 | 4:30 | 39.5 | 40.0 | 45.5 |
| 31 | 5:00 | 39.5 | 40.0 | 45.5 |
| 32 | 5:30 | 39.5 | 40.0 | 45.5 |
| 33 | 6:00 | 39.5 | 40.0 | 44.0 |
| 34 | 6:30 | 39.5 | 40.0 | 45.5 |
| 35 | 7:00 | 39.5 | 40.0 | 45.5 |
| 36 | 7:30 | 39.5 | 40.0 | 44.5 |
| 37 | 8:00 | 47.5 | 46.0 | 47.5 |
| 38 | 8:30 | 44.5 | 44.5 | 46.0 |

**Week 1 Temperature Log of Sirloins (thermocouple broke and surface temperature was not recorded) graph.**

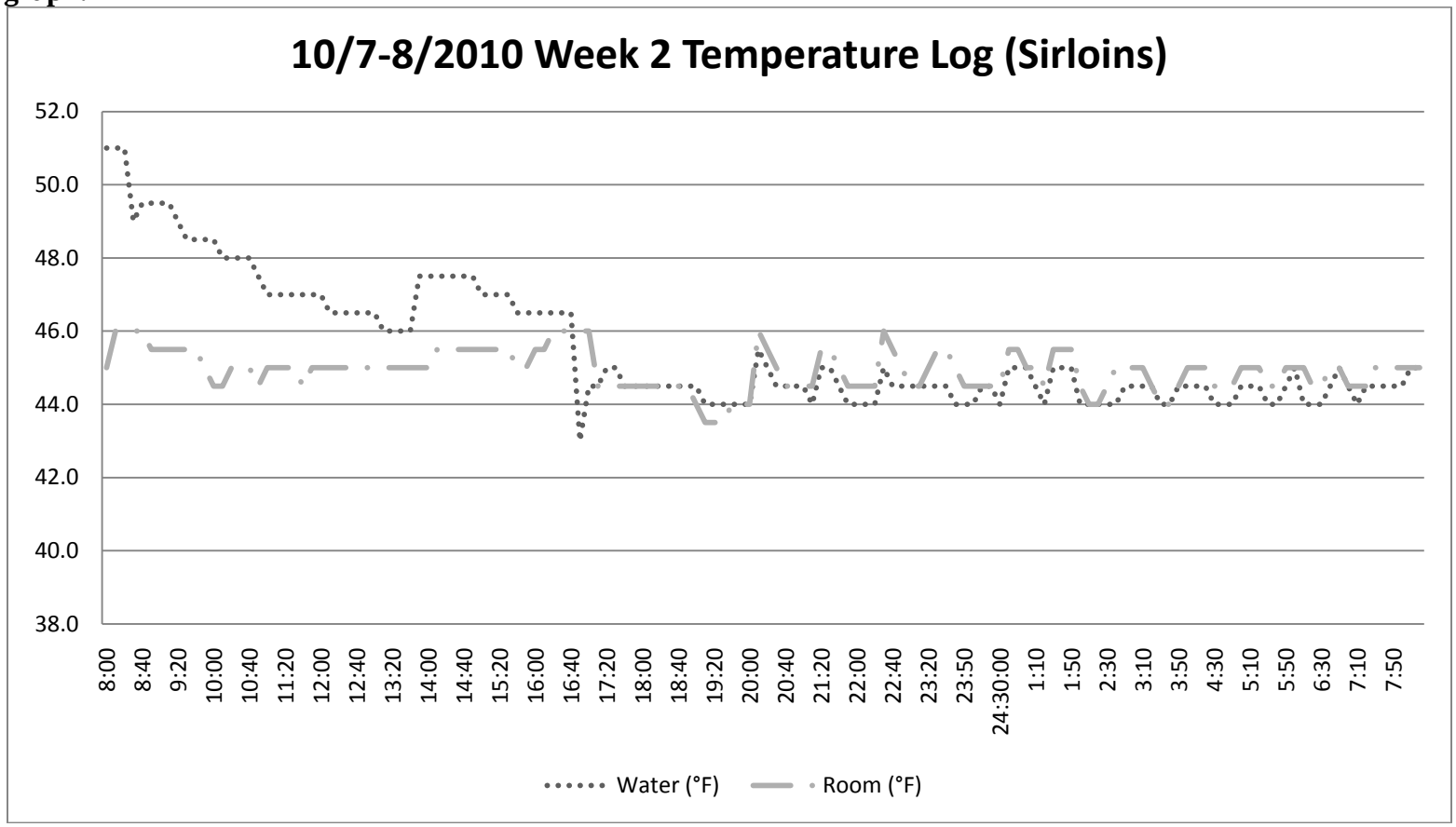


**Week 1 Temperature Log of Sirloins (thermocouple broke and surface temperature was not recorded) table.**

10/4-5/2010 Week 1 Temperature Log of Sirloins

| Rec. No. | Time | Water (°F) | Room (°F) |
|---|---|---|---|
| 1 | 11:30 | 54.5 | 45.5 |
| 2 | 12:00 | 51.0 | 45.0 |
| 3 | 12:30 | 49.5 | 45.5 |
| 4 | 13:00 | 48.0 | 45.0 |
| 5 | 13:30 | 47.0 | 44.5 |
| 6 | 14:00 | 45.5 | 45.0 |
| 7 | 14:30 | 45.0 | 44.5 |
| 8 | 15:00 | 44.0 | 44.0 |
| 9 | 15:30 | 44.0 | 45.0 |
| 10 | 16:00 | 43.0 | 44.5 |
| 11 | 16:30 | 42.5 | 44.5 |
| 12 | 17:00 | 42.5 | 45.5 |
| 13 | 17:30 | 42.0 | 45.5 |
| 14 | 18:00 | 41.5 | 44.5 |
| 15 | 18:30 | 41.5 | 45.0 |
| 16 | 19:00 | 41.0 | 44.0 |
| 17 | 19:30 | 41.0 | 44.0 |
| 18 | 20:00 | 41.0 | 45.0 |
| 19 | 20:30 | 40.5 | 44.0 |
| 20 | 21:00 | 40.5 | 44.5 |
| 21 | 21:30 | 40.0 | 45.0 |
| 22 | 22:00 | 40.0 | 45.0 |
| 23 | 22:30 | 40.0 | 45.0 |
| 24 | 23:00 | 40.0 | 45.0 |
| 25 | 23:30 | 40.0 | 45.0 |
| 26 | 24:00 | 40.0 | 44.5 |
| 27 | 24:30 | 40.0 | 45.0 |
| 28 | 1:00 | 40.0 | 45.0 |
| 29 | 1:30 | 39.5 | 46.0 |
| 30 | 2:00 | 39.5 | 44.5 |
| 31 | 2:30 | 39.5 | 45.5 |
| 32 | 3:00 | 39.5 | 44.5 |
| 33 | 3:30 | 39.5 | 45.0 |
| 34 | 4:00 | 39.5 | 44.5 |
| 35 | 4:30 | 39.5 | 45.0 |
| 36 | 5:00 | 39.5 | 44.5 |
| 37 | 5:30 | 39.5 | 44.5 |
| 38 | 6:00 | 39.5 | 45.0 |
| 39 | 6:30 | 39.5 | 45.5 |
| 40 | 7:00 | 39.5 | 44.5 |
| 41 | 7:30 | 39.5 | 44.5 |

**Week 2 Temperature Log of Sirloins (subprimal thermocouple came loose and subprimal temperature was not recorded) graph.**



**Week 2 Temperature Log of Sirloins (subprimal thermocouple came loose and subprimal temperature was not recorded) table.**

10/7-8/2010 Week 2 Temperature Log
(Sirloins)

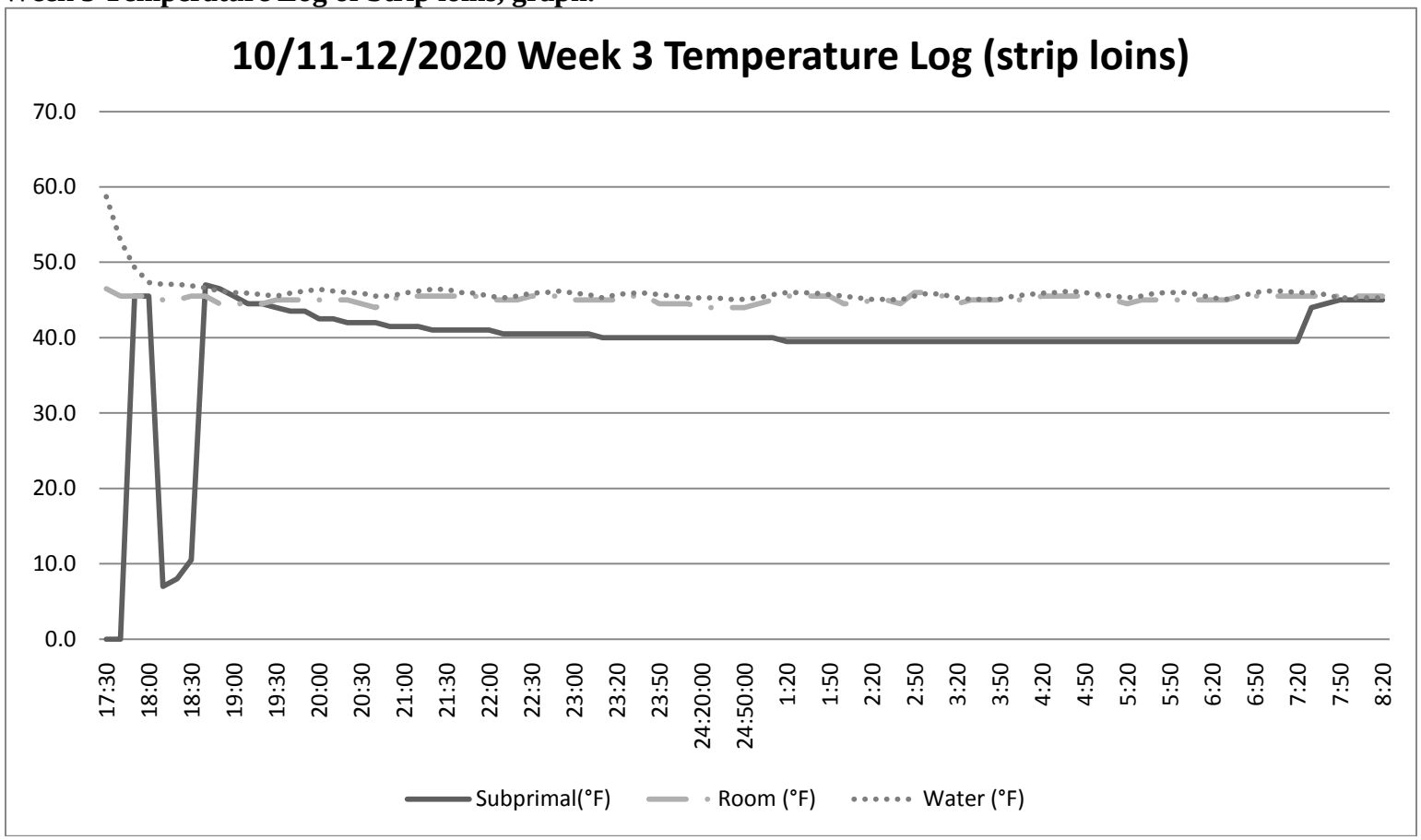
| Rec. No. | Time | Water (°F) | Room (°F) |
|---|---|---|---|
| 1 | 8:00 | 51.0 | 45.0 |
| 2 | 8:10 | 51.0 | 46.0 |
| 3 | 8:20 | 51.0 | 46.0 |
| 4 | 8:30 | 49.0 | 46.0 |
| 5 | 8:40 | 49.5 | 46.0 |
| 6 | 8:50 | 49.5 | 45.5 |
| 7 | 9:00 | 49.5 | 45.5 |
| 8 | 9:10 | 49.5 | 45.5 |
| 9 | 9:20 | 49.0 | 45.5 |
| 10 | 9:30 | 48.5 | 45.5 |
| 11 | 9:40 | 48.5 | 45.5 |
| 12 | 9:50 | 48.5 | 45.0 |
| 13 | 10:00 | 48.5 | 44.5 |
| 14 | 10:10 | 48.0 | 44.5 |
| 15 | 10:20 | 48.0 | 45.0 |
| 16 | 10:30 | 48.0 | 45.0 |
| 17 | 10:40 | 48.0 | 45.0 |
| 18 | 10:50 | 47.5 | 44.5 |
| 19 | 11:00 | 47.0 | 45.0 |
| 20 | 11:10 | 47.0 | 45.0 |
| 21 | 11:20 | 47.0 | 45.0 |
| 22 | 11:30 | 47.0 | 45.0 |
| 23 | 11:40 | 47.0 | 44.5 |
| 24 | 11:50 | 47.0 | 45.0 |
| 25 | 12:00 | 47.0 | 45.0 |
| 26 | 12:10 | 46.5 | 45.0 |
| 27 | 12:20 | 46.5 | 45.0 |
| 28 | 12:30 | 46.5 | 45.0 |
| 29 | 12:40 | 46.5 | 45.0 |
| 30 | 12:50 | 46.5 | 45.0 |
| 31 | 13:00 | 46.5 | 45.0 |
| 32 | 13:10 | 46.0 | 45.0 |
| 33 | 13:20 | 46.0 | 45.0 |
| 34 | 13:30 | 46.0 | 45.0 |
| 35 | 13:40 | 46.0 | 45.0 |
| 36 | 13:50 | 47.5 | 45.0 |
| 37 | 14:00 | 47.5 | 45.0 |
| 38 | 14:10 | 47.5 | 45.5 |
| 39 | 14:20 | 47.5 | 45.5 |
| 40 | 14:30 | 47.5 | 45.5 |
| 41 | 14:40 | 47.5 | 45.5 |
| 42 | 14:50 | 47.5 | 45.5 |

| | | | |
|---|---|---|---|
| 43 | 15:00 | 47.0 | 45.5 |
| 44 | 15:10 | 47.0 | 45.5 |
| 45 | 15:20 | 47.0 | 45.5 |
| 46 | 15:30 | 47.0 | 45.5 |
| 47 | 15:40 | 46.5 | 45.0 |
| 48 | 15:50 | 46.5 | 45.0 |
| 49 | 16:00 | 46.5 | 45.5 |
| 50 | 16:10 | 46.5 | 45.5 |
| 51 | 16:20 | 46.5 | 46.0 |
| 52 | 16:30 | 46.5 | 46.0 |
| 53 | 16:40 | 46.5 | 46.0 |
| 54 | 16:50 | 43.0 | 46.0 |
| 55 | 17:00 | 44.5 | 46.0 |
| 56 | 17:10 | 44.5 | 44.5 |
| 57 | 17:20 | 45.0 | 44.5 |
| 58 | 17:30 | 45.0 | 44.5 |
| 59 | 17:40 | 44.5 | 44.5 |
| 60 | 17:50 | 44.5 | 44.5 |
| 61 | 18:00 | 44.5 | 44.5 |
| 62 | 18:10 | 44.5 | 44.5 |
| 63 | 18:20 | 44.5 | 44.5 |
| 64 | 18:30 | 44.5 | 44.5 |
| 65 | 18:40 | 44.5 | 44.5 |
| 66 | 18:50 | 44.5 | 44.5 |
| 67 | 19:00 | 44.5 | 44.0 |
| 68 | 19:10 | 44.0 | 43.5 |
| 69 | 19:20 | 44.0 | 43.5 |
| 70 | 19:30 | 44.0 | 43.5 |
| 71 | 19:40 | 44.0 | 44.0 |
| 72 | 19:50 | 44.0 | 44.0 |
| 73 | 20:00 | 44.0 | 44.0 |
| 74 | 20:10 | 45.5 | 46.0 |
| 75 | 20:20 | 45.0 | 45.5 |
| 76 | 20:30 | 44.5 | 45.0 |
| 77 | 20:40 | 44.5 | 44.5 |
| 78 | 20:50 | 44.5 | 44.5 |
| 79 | 21:00 | 44.5 | 44.5 |
| 80 | 21:10 | 44.0 | 44.5 |
| 81 | 21:20 | 45.0 | 45.5 |
| 82 | 21:30 | 45.0 | 45.5 |
| 83 | 21:40 | 44.5 | 45.0 |
| 84 | 21:50 | 44.0 | 44.5 |
| 85 | 22:00 | 44.0 | 44.5 |
| 86 | 22:10 | 44.0 | 44.5 |
| 87 | 22:20 | 44.0 | 44.5 |
| 88 | 22:30 | 45.0 | 46.0 |
| 89 | 22:40 | 44.5 | 45.5 |
| 90 | 22:50 | 44.5 | 45.0 |

| | | | |
|---|---|---|---|
| 91 | 23:00 | 44.5 | 44.5 |
| 92 | 23:10 | 44.5 | 44.5 |
| 93 | 23:20 | 44.5 | 45.0 |
| 94 | 23:20 | 44.5 | 45.5 |
| 95 | 23:30 | 44.5 | 45.5 |
| 96 | 23:40 | 44.0 | 45.0 |
| 97 | 23:50 | 44.0 | 44.5 |
| 98 | 24:00 | 44.0 | 44.5 |
| 99 | 24:10 | 44.5 | 44.5 |
| 100 | 24:20 | 44.5 | 44.5 |
| 101 | 24:30 | 44.0 | 44.5 |
| 102 | 24:40 | 45.0 | 45.5 |
| 103 | 24:50 | 45.0 | 45.5 |
| 104 | 1:00 | 45.0 | 45.0 |
| 105 | 1:10 | 44.5 | 45.0 |
| 106 | 1:20 | 44.0 | 44.5 |
| 107 | 1:30 | 45.0 | 45.5 |
| 108 | 1:40 | 45.0 | 45.5 |
| 109 | 1:50 | 45.0 | 45.5 |
| 110 | 2:00 | 44.0 | 44.5 |
| 111 | 2:10 | 44.0 | 44.0 |
| 112 | 2:20 | 44.0 | 44.0 |
| 113 | 2:30 | 44.0 | 44.5 |
| 114 | 2:40 | 44.0 | 45.0 |
| 115 | 2:50 | 44.5 | 45.0 |
| 116 | 3:00 | 44.5 | 45.0 |
| 117 | 3:10 | 44.5 | 45.0 |
| 118 | 3:20 | 44.5 | 44.5 |
| 119 | 3:30 | 44.0 | 44.0 |
| 120 | 3:40 | 44.0 | 44.0 |
| 121 | 3:50 | 44.5 | 44.5 |
| 122 | 4:00 | 44.5 | 45.0 |
| 123 | 4:10 | 44.5 | 45.0 |
| 124 | 4:20 | 44.5 | 45.0 |
| 125 | 4:30 | 44.0 | 44.5 |
| 126 | 4:40 | 44.0 | 44.5 |
| 127 | 4:50 | 44.0 | 44.5 |
| 128 | 5:00 | 44.5 | 45.0 |
| 129 | 5:10 | 44.5 | 45.0 |
| 130 | 5:20 | 44.5 | 45.0 |
| 131 | 5:30 | 44.0 | 44.5 |
| 132 | 5:40 | 44.0 | 44.5 |
| 133 | 5:50 | 44.5 | 45.0 |
| 134 | 6:00 | 45.0 | 45.0 |
| 135 | 6:10 | 44.0 | 45.0 |
| 136 | 6:20 | 44.0 | 44.5 |
| 137 | 6:30 | 44.0 | 44.5 |
| 138 | 6:40 | 44.5 | 45.0 |

| | | | |
|---|---|---|---|
| 139 | 6:50 | 45.0 | 45.0 |
| 140 | 7:00 | 44.5 | 44.5 |
| 141 | 7:10 | 44.0 | 44.5 |
| 142 | 7:20 | 44.5 | 44.5 |
| 143 | 7:30 | 44.5 | 45.0 |
| 144 | 7:40 | 44.5 | 45.0 |
| 145 | 7:50 | 44.5 | 45.0 |
| 146 | 8:00 | 44.5 | 45.0 |
| 147 | 8:10 | 45.0 | 45.0 |
| 148 | 8:20 | 45.0 | 45.0 |

**Week 3 Temperature Log of Strip loins, graph.**



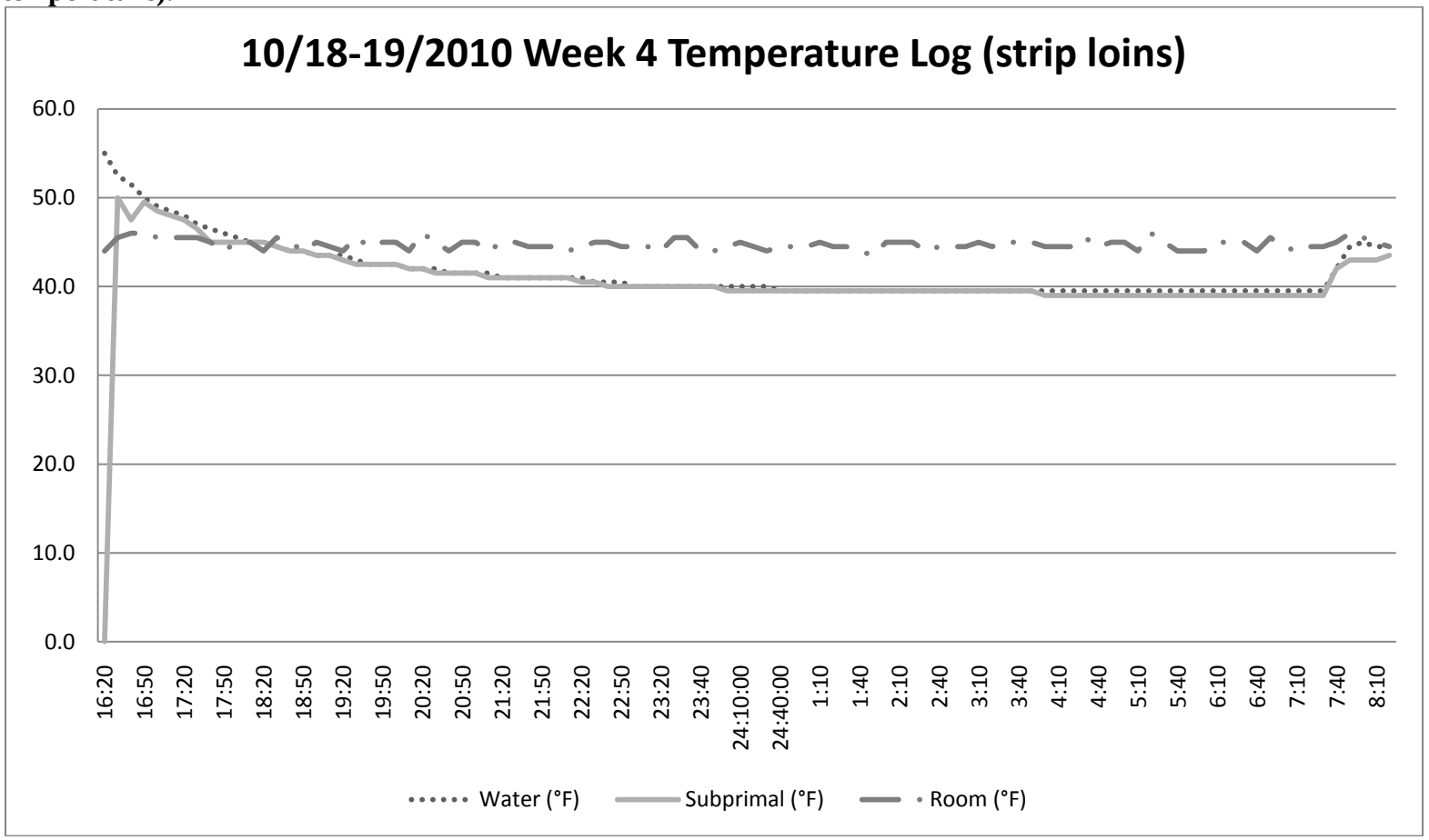
**Week 3 Temperature Log of Strip loins, table.**

10/11-12/2010 Week 3 Temperature Log (strip loins)

| Rec. No. | Time | Subprimal(°F) | Room (°F) | Water (°F) |
|---|---|---|---|---|
| 10 | 17:30 | - | 46.5 | 58.7 |
| 11 | 17:40 | - | 45.5 | 52.9 |
| 12 | 17:50 | 45.5 | 45.5 | 49.3 |
| 13 | 18:00 | 45.5 | 45.5 | 47.3 |
| 14 | 18:10 | 7.0 | 45.0 | 47.1 |
| 15 | 18:20 | 8.0 | 45.0 | 47.1 |
| 16 | 18:30 | 10.5 | 45.5 | 46.9 |
| 17 | 18:40 | 47.0 | 45.5 | 46.6 |
| 18 | 18:50 | 46.5 | 44.5 | 46.2 |
| 19 | 19:00 | 45.5 | 44.5 | 46.0 |
| 20 | 19:10 | 44.5 | 44.5 | 45.9 |
| 21 | 19:20 | 44.5 | 44.5 | 45.7 |
| 22 | 19:30 | 44.0 | 45.0 | 45.5 |
| 23 | 19:40 | 43.5 | 45.0 | 45.9 |
| 24 | 19:50 | 43.5 | 45.0 | 46.2 |
| 25 | 20:00 | 42.5 | 45.0 | 46.4 |
| 26 | 20:10 | 42.5 | 45.0 | 46.2 |
| 27 | 20:20 | 42.0 | 45.0 | 46.0 |
| 28 | 20:30 | 42.0 | 44.5 | 45.9 |
| 29 | 20:40 | 42.0 | 44.0 | 45.5 |
| 30 | 20:50 | 41.5 | 45.0 | 45.5 |
| 31 | 21:00 | 41.5 | 45.5 | 45.9 |
| 32 | 21:10 | 41.5 | 45.5 | 46.2 |
| 33 | 21:20 | 41.0 | 45.5 | 46.4 |
| 34 | 21:30 | 41.0 | 45.5 | 46.4 |
| 35 | 21:40 | 41.0 | 45.5 | 46.0 |
| 36 | 21:50 | 41.0 | 45.5 | 45.9 |
| 37 | 22:00 | 41.0 | 45.0 | 45.5 |
| 38 | 22:10 | 40.5 | 45.0 | 45.3 |
| 39 | 22:20 | 40.5 | 45.0 | 45.5 |
| 40 | 22:30 | 40.5 | 45.5 | 45.9 |
| 41 | 22:40 | 40.5 | 45.5 | 46.0 |
| 42 | 22:50 | 40.5 | 45.5 | 46.2 |
| 43 | 23:00 | 40.5 | 45.0 | 45.9 |
| 44 | 23:10 | 40.5 | 45.0 | 45.7 |
| 45 | 23:20 | 40.0 | 45.0 | 45.3 |
| 46 | 23:20 | 40.0 | 45.0 | 45.7 |
| 47 | 23:30 | 40.0 | 45.5 | 45.9 |
| 48 | 23:40 | 40.0 | 45.5 | 45.9 |
| 49 | 23:50 | 40.0 | 44.5 | 45.7 |
| 50 | 24:00 | 40.0 | 44.5 | 45.5 |
| 51 | 24:10 | 40.0 | 44.5 | 45.3 |
| 52 | 24:20 | 40.0 | 44.0 | 45.3 |
| 53 | 24:30 | 40.0 | 44.0 | 45.3 |

| | | | | |
|---|---|---|---|---|
| 54 | 24:40 | 40.0 | 44.0 | 45.1 |
| 55 | 24:50 | 40.0 | 44.0 | 45.1 |
| 56 | 1:00 | 40.0 | 44.5 | 45.3 |
| 57 | 1:10 | 40.0 | 45.0 | 45.7 |
| 58 | 1:20 | 39.5 | 45.5 | 46.0 |
| 59 | 1:30 | 39.5 | 45.5 | 46.0 |
| 60 | 1:40 | 39.5 | 45.5 | 45.9 |
| 61 | 1:50 | 39.5 | 45.5 | 45.7 |
| 62 | 2:00 | 39.5 | 44.5 | 45.5 |
| 63 | 2:10 | 39.5 | 44.5 | 45.3 |
| 64 | 2:20 | 39.5 | 45.0 | 45.1 |
| 65 | 2:30 | 39.5 | 45.0 | 45.1 |
| 66 | 2:40 | 39.5 | 44.5 | 45.0 |
| 67 | 2:50 | 39.5 | 46.0 | 45.5 |
| 68 | 3:00 | 39.5 | 46.0 | 45.9 |
| 69 | 3:10 | 39.5 | 45.5 | 45.7 |
| 70 | 3:20 | 39.5 | 44.5 | 45.3 |
| 71 | 3:30 | 39.5 | 45.0 | 45.1 |
| 72 | 3:40 | 39.5 | 45.0 | 45.1 |
| 73 | 3:50 | 39.5 | 45.0 | 45.1 |
| 74 | 4:00 | 39.5 | 45.0 | 45.5 |
| 75 | 4:10 | 39.5 | 45.0 | 45.7 |
| 76 | 4:20 | 39.5 | 45.5 | 45.9 |
| 77 | 4:30 | 39.5 | 45.5 | 46.0 |
| 78 | 4:40 | 39.5 | 45.5 | 46.2 |
| 79 | 4:50 | 39.5 | 45.5 | 46.0 |
| 80 | 5:00 | 39.5 | 45.5 | 45.7 |
| 81 | 5:10 | 39.5 | 45.0 | 45.5 |
| 82 | 5:20 | 39.5 | 44.5 | 45.3 |
| 83 | 5:30 | 39.5 | 45.0 | 45.5 |
| 84 | 5:40 | 39.5 | 45.0 | 45.9 |
| 85 | 5:50 | 39.5 | 45.0 | 46.0 |
| 86 | 6:00 | 39.5 | 45.0 | 46.0 |
| 87 | 6:10 | 39.5 | 45.0 | 45.7 |
| 88 | 6:20 | 39.5 | 45.0 | 45.3 |
| 89 | 6:30 | 39.5 | 45.0 | 45.1 |
| 90 | 6:40 | 39.5 | 45.5 | 45.5 |
| 91 | 6:50 | 39.5 | 45.5 | 46.0 |
| 92 | 7:00 | 39.5 | 45.5 | 46.2 |
| 93 | 7:10 | 39.5 | 45.5 | 46.2 |
| 94 | 7:20 | 39.5 | 45.5 | 46.0 |
| 95 | 7:30 | 44.0 | 45.5 | 46.0 |
| 96 | 7:40 | 44.5 | 45.5 | 45.7 |
| 97 | 7:50 | 45.0 | 45.5 | 45.3 |
| 98 | 8:00 | 45.0 | 45.5 | 45.3 |
| 99 | 8:10 | 45.0 | 45.5 | 45.3 |
| 100 | 8:20 | 45.0 | 45.5 | 45.3 |

**Week 4 Temperature Log of Strip loins, graph (subprimal thermocouple recorded water temperature instead of surface temperature).**



**Week 4 Temperature Log of Strip loins, table (subprimal thermocouple recorded water temperature instead of surface temperature).**

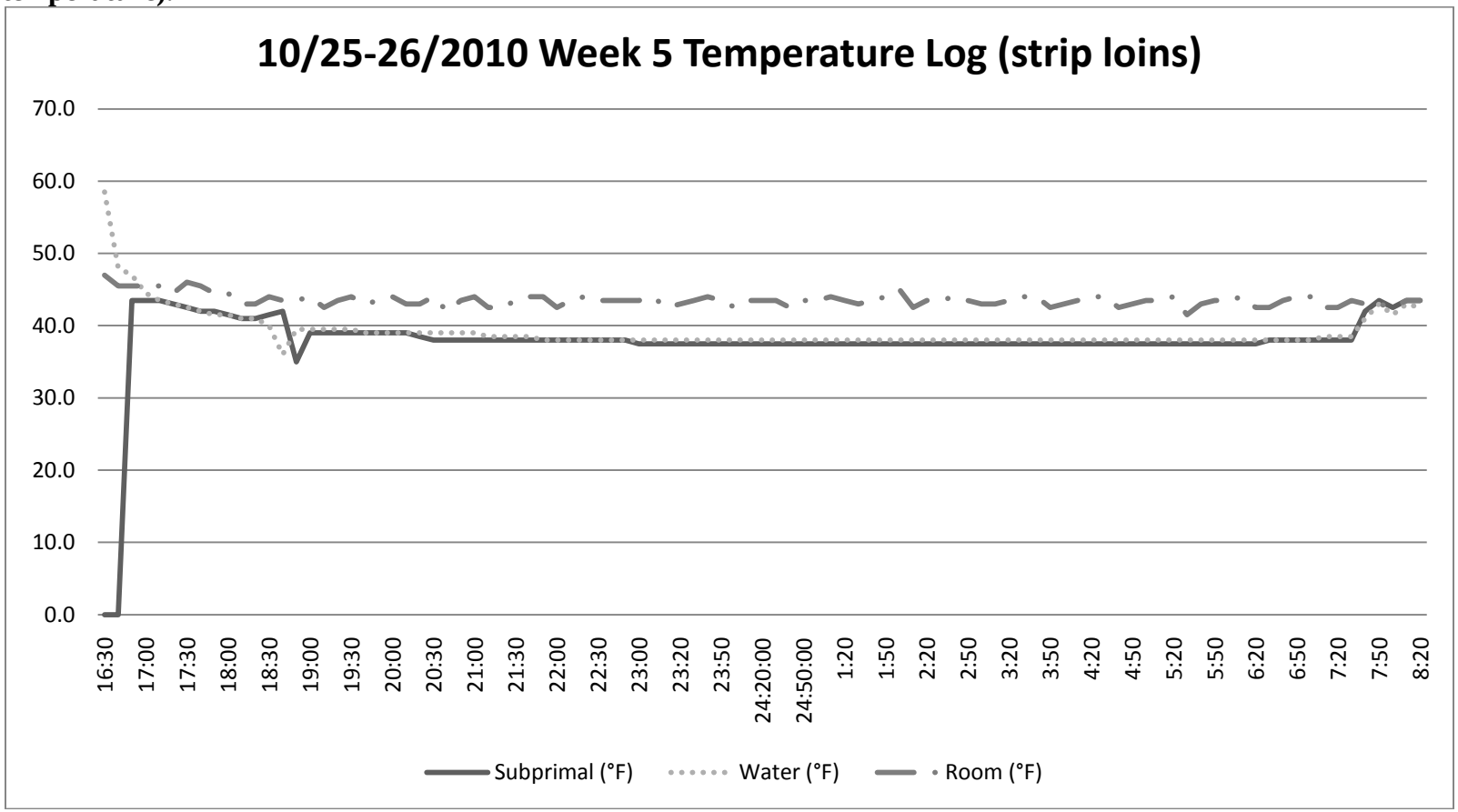
10/18-19/2010 Week 4 Temperature Log (strip loins)

| Rec. No. | Time | Water (°F) | Subprimal (°F) | Room (°F) |
|---|---|---|---|---|
| 1 | 16:20 | 55.0 | - | 44.0 |
| 2 | 16:30 | 52.5 | 50.0 | 45.5 |
| 3 | 16:40 | 51.5 | 47.5 | 46.0 |
| 4 | 16:50 | 50.0 | 49.5 | 46.0 |
| 5 | 17:00 | 49.0 | 48.5 | 45.5 |
| 6 | 17:10 | 48.5 | 48.0 | 45.5 |
| 7 | 17:20 | 48.0 | 47.5 | 45.5 |
| 8 | 17:30 | 47.0 | 46.5 | 45.5 |
| 9 | 17:40 | 46.5 | 45.0 | 45.0 |
| 10 | 17:50 | 46.0 | 45.0 | 44.0 |
| 11 | 18:00 | 45.5 | 45.0 | 45.0 |
| 12 | 18:10 | 45.0 | 45.0 | 45.0 |
| 13 | 18:20 | 45.0 | 45.0 | 44.0 |
| 14 | 18:30 | 44.5 | 44.5 | 45.5 |
| 15 | 18:40 | 44.0 | 44.0 | 45.0 |
| 16 | 18:50 | 44.0 | 44.0 | 44.0 |
| 17 | 19:00 | 43.5 | 43.5 | 45.0 |
| 18 | 19:10 | 43.5 | 43.5 | 44.5 |
| 19 | 19:20 | 43.5 | 43.0 | 44.0 |
| 20 | 19:30 | 43.0 | 42.5 | 45.5 |
| 21 | 19:40 | 42.5 | 42.5 | 44.5 |
| 22 | 19:50 | 42.5 | 42.5 | 45.0 |
| 23 | 20:00 | 42.5 | 42.5 | 45.0 |
| 24 | 20:10 | 42.0 | 42.0 | 44.0 |
| 25 | 20:20 | 42.0 | 42.0 | 46.0 |
| 26 | 20:30 | 42.0 | 41.5 | 45.0 |
| 27 | 20:40 | 41.5 | 41.5 | 44.0 |
| 28 | 20:50 | 41.5 | 41.5 | 45.0 |
| 29 | 21:00 | 41.5 | 41.5 | 45.0 |
| 30 | 21:10 | 41.5 | 41.0 | 44.0 |
| 31 | 21:20 | 41.0 | 41.0 | 45.0 |
| 32 | 21:30 | 41.0 | 41.0 | 45.0 |
| 33 | 21:40 | 41.0 | 41.0 | 44.5 |
| 34 | 21:50 | 41.0 | 41.0 | 44.5 |
| 35 | 22:00 | 41.0 | 41.0 | 44.5 |
| 36 | 22:10 | 41.0 | 41.0 | 44.0 |
| 37 | 22:20 | 41.0 | 40.5 | 44.5 |
| 38 | 22:30 | 40.5 | 40.5 | 45.0 |
| 39 | 22:40 | 40.5 | 40.0 | 45.0 |
| 40 | 22:50 | 40.5 | 40.0 | 44.5 |
| 41 | 23:00 | 40.0 | 40.0 | 44.5 |
| 42 | 23:10 | 40.0 | 40.0 | 44.5 |
| 43 | 23:20 | 40.0 | 40.0 | 44.0 |

| | | | | |
|---|---|---|---|---|
| 44 | 23:20 | 40.0 | 40.0 | 45.5 |
| 45 | 23:30 | 40.0 | 40.0 | 45.5 |
| 46 | 23:40 | 40.0 | 40.0 | 44.0 |
| 47 | 23:50 | 40.0 | 40.0 | 44.0 |
| 48 | 24:00 | 40.0 | 39.5 | 44.5 |
| 49 | 24:10 | 40.0 | 39.5 | 45.0 |
| 50 | 24:20 | 40.0 | 39.5 | 44.5 |
| 51 | 24:30 | 40.0 | 39.5 | 44.0 |
| 52 | 24:40 | 39.5 | 39.5 | 44.5 |
| 53 | 24:50 | 39.5 | 39.5 | 44.5 |
| 54 | 1:00 | 39.5 | 39.5 | 44.5 |
| 55 | 1:10 | 39.5 | 39.5 | 45.0 |
| 56 | 1:20 | 39.5 | 39.5 | 44.5 |
| 57 | 1:30 | 39.5 | 39.5 | 44.5 |
| 58 | 1:40 | 39.5 | 39.5 | 44.0 |
| 59 | 1:50 | 39.5 | 39.5 | 43.5 |
| 60 | 2:00 | 39.5 | 39.5 | 45.0 |
| 61 | 2:10 | 39.5 | 39.5 | 45.0 |
| 62 | 2:20 | 39.5 | 39.5 | 45.0 |
| 63 | 2:30 | 39.5 | 39.5 | 44.0 |
| 64 | 2:40 | 39.5 | 39.5 | 44.5 |
| 65 | 2:50 | 39.5 | 39.5 | 44.5 |
| 66 | 3:00 | 39.5 | 39.5 | 44.5 |
| 67 | 3:10 | 39.5 | 39.5 | 45.0 |
| 68 | 3:20 | 39.5 | 39.5 | 44.5 |
| 69 | 3:30 | 39.5 | 39.5 | 45.0 |
| 70 | 3:40 | 39.5 | 39.5 | 45.0 |
| 71 | 3:50 | 39.5 | 39.5 | 45.0 |
| 72 | 4:00 | 39.5 | 39.0 | 44.5 |
| 73 | 4:10 | 39.5 | 39.0 | 44.5 |
| 74 | 4:20 | 39.5 | 39.0 | 44.5 |
| 75 | 4:30 | 39.5 | 39.0 | 45.5 |
| 76 | 4:40 | 39.5 | 39.0 | 44.5 |
| 77 | 4:50 | 39.5 | 39.0 | 45.0 |
| 78 | 5:00 | 39.5 | 39.0 | 45.0 |
| 79 | 5:10 | 39.5 | 39.0 | 44.0 |
| 80 | 5:20 | 39.5 | 39.0 | 46.0 |
| 81 | 5:30 | 39.5 | 39.0 | 45.0 |
| 82 | 5:40 | 39.5 | 39.0 | 44.0 |
| 83 | 5:50 | 39.5 | 39.0 | 44.0 |
| 84 | 6:00 | 39.5 | 39.0 | 44.0 |
| 85 | 6:10 | 39.5 | 39.0 | 45.0 |
| 86 | 6:20 | 39.5 | 39.0 | 45.0 |
| 87 | 6:30 | 39.5 | 39.0 | 45.0 |
| 88 | 6:40 | 39.5 | 39.0 | 44.0 |
| 89 | 6:50 | 39.5 | 39.0 | 45.5 |
| 90 | 7:00 | 39.5 | 39.0 | 44.5 |
| 91 | 7:10 | 39.5 | 39.0 | 44.0 |

| | | | | |
|---|---|---|---|---|
| 92 | 7:20 | 39.5 | 39.0 | 44.5 |
| 93 | 7:30 | 39.5 | 39.0 | 44.5 |
| 94 | 7:40 | 42.0 | 42.0 | 45.0 |
| 95 | 7:50 | 44.5 | 43.0 | 46.0 |
| 96 | 8:00 | 45.0 | 43.0 | 45.5 |
| 97 | 8:10 | 44.5 | 43.0 | 45.0 |
| 98 | 8:20 | 44.5 | 43.5 | 44.5 |

**Week 5 Temperature Log of Strip loins, graph (subprimal thermocouple recorded water temperature instead of surface temperature).**



**Week 5 Temperature Log of Strip loins, table (subprimal thermocouple recorded water temperature instead of surface temperature).**

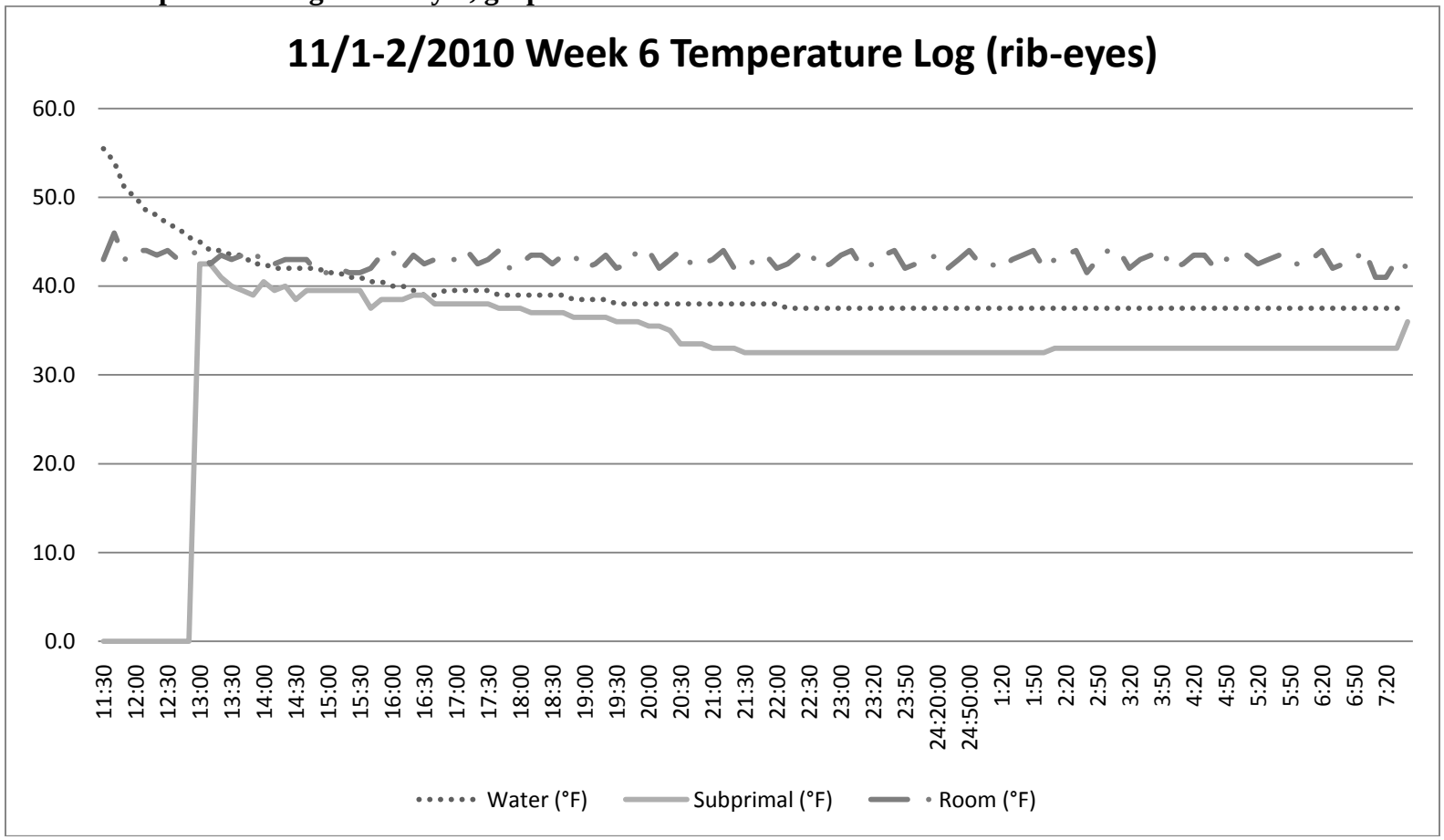
10/25-26/2010 Week 5 Temperature Log (strip loins)

| Rec. No. | Time | Subprimal (°F) | Water (°F) | Room (°F) |
|---|---|---|---|---|
| 1 | 16:30 | - | 58.5 | 47.0 |
| 2 | 16:40 | - | 48.0 | 45.5 |
| 3 | 16:50 | 43.5 | 47.0 | 45.5 |
| 4 | 17:00 | 43.5 | 44.5 | 45.5 |
| 5 | 17:10 | 43.5 | 43.5 | 45.5 |
| 6 | 17:20 | 43.0 | 43.0 | 44.5 |
| 7 | 17:30 | 42.5 | 42.5 | 46.0 |
| 8 | 17:40 | 42.0 | 42.0 | 45.5 |
| 9 | 17:50 | 42.0 | 41.5 | 44.5 |
| 10 | 18:00 | 41.5 | 41.5 | 44.5 |
| 11 | 18:10 | 41.0 | 41.0 | 43.0 |
| 12 | 18:20 | 41.0 | 41.0 | 43.0 |
| 13 | 18:30 | 41.5 | 40.0 | 44.0 |
| 14 | 18:40 | 42.0 | 36.0 | 43.5 |
| 15 | 18:50 | 35.0 | 39.5 | 43.5 |
| 16 | 19:00 | 39.0 | 39.5 | 44.0 |
| 17 | 19:10 | 39.0 | 39.5 | 42.5 |
| 18 | 19:20 | 39.0 | 39.5 | 43.5 |
| 19 | 19:30 | 39.0 | 39.5 | 44.0 |
| 20 | 19:40 | 39.0 | 39.0 | 43.0 |
| 21 | 19:50 | 39.0 | 39.0 | 43.5 |
| 22 | 20:00 | 39.0 | 39.0 | 44.0 |
| 23 | 20:10 | 39.0 | 39.0 | 43.0 |
| 24 | 20:20 | 38.5 | 39.0 | 43.0 |
| 25 | 20:30 | 38.0 | 39.0 | 44.0 |
| 26 | 20:40 | 38.0 | 39.0 | 42.0 |
| 27 | 20:50 | 38.0 | 39.0 | 43.5 |
| 28 | 21:00 | 38.0 | 39.0 | 44.0 |
| 29 | 21:10 | 38.0 | 38.5 | 42.5 |
| 30 | 21:20 | 38.0 | 38.5 | 42.5 |
| 31 | 21:30 | 38.0 | 38.5 | 43.5 |
| 32 | 21:40 | 38.0 | 38.5 | 44.0 |
| 33 | 21:50 | 38.0 | 38.0 | 44.0 |
| 34 | 22:00 | 38.0 | 38.0 | 42.5 |
| 35 | 22:10 | 38.0 | 38.0 | 43.5 |
| 36 | 22:20 | 38.0 | 38.0 | 44.0 |
| 37 | 22:30 | 38.0 | 38.0 | 43.5 |
| 38 | 22:40 | 38.0 | 38.0 | 43.5 |
| 39 | 22:50 | 38.0 | 38.0 | 43.5 |
| 40 | 23:00 | 37.5 | 38.0 | 43.5 |
| 41 | 23:10 | 37.5 | 38.0 | 44.0 |
| 42 | 23:20 | 37.5 | 38.0 | 42.5 |
| 43 | 23:20 | 37.5 | 38.0 | 43.0 |

| | | | | |
|---|---|---|---|---|
| 44 | 23:30 | 37.5 | 38.0 | 43.5 |
| 45 | 23:40 | 37.5 | 38.0 | 44.0 |
| 46 | 23:50 | 37.5 | 38.0 | 43.5 |
| 47 | 24:00 | 37.5 | 38.0 | 42.5 |
| 48 | 24:10 | 37.5 | 38.0 | 43.5 |
| 49 | 24:20 | 37.5 | 38.0 | 43.5 |
| 50 | 24:30 | 37.5 | 38.0 | 43.5 |
| 51 | 24:40 | 37.5 | 38.0 | 42.5 |
| 52 | 24:50 | 37.5 | 38.0 | 43.5 |
| 53 | 1:00 | 37.5 | 38.0 | 43.5 |
| 54 | 1:10 | 37.5 | 38.0 | 44.0 |
| 55 | 1:20 | 37.5 | 38.0 | 43.5 |
| 56 | 1:30 | 37.5 | 38.0 | 43.0 |
| 57 | 1:40 | 37.5 | 38.0 | 43.5 |
| 58 | 1:50 | 37.5 | 38.0 | 44.0 |
| 59 | 2:00 | 37.5 | 38.0 | 45.0 |
| 60 | 2:10 | 37.5 | 38.0 | 42.5 |
| 61 | 2:20 | 37.5 | 38.0 | 43.5 |
| 62 | 2:30 | 37.5 | 38.0 | 43.5 |
| 63 | 2:40 | 37.5 | 38.0 | 44.0 |
| 64 | 2:50 | 37.5 | 38.0 | 43.5 |
| 65 | 3:00 | 37.5 | 38.0 | 43.0 |
| 66 | 3:10 | 37.5 | 38.0 | 43.0 |
| 67 | 3:20 | 37.5 | 38.0 | 43.5 |
| 68 | 3:30 | 37.5 | 38.0 | 44.0 |
| 69 | 3:40 | 37.5 | 38.0 | 44.0 |
| 70 | 3:50 | 37.5 | 38.0 | 42.5 |
| 71 | 4:00 | 37.5 | 38.0 | 43.0 |
| 72 | 4:10 | 37.5 | 38.0 | 43.5 |
| 73 | 4:20 | 37.5 | 38.0 | 44.0 |
| 74 | 4:30 | 37.5 | 38.0 | 44.0 |
| 75 | 4:40 | 37.5 | 38.0 | 42.5 |
| 76 | 4:50 | 37.5 | 38.0 | 43.0 |
| 77 | 5:00 | 37.5 | 38.0 | 43.5 |
| 78 | 5:10 | 37.5 | 38.0 | 43.5 |
| 79 | 5:20 | 37.5 | 38.0 | 44.0 |
| 80 | 5:30 | 37.5 | 38.0 | 41.5 |
| 81 | 5:40 | 37.5 | 38.0 | 43.0 |
| 82 | 5:50 | 37.5 | 38.0 | 43.5 |
| 83 | 6:00 | 37.5 | 38.0 | 43.5 |
| 84 | 6:10 | 37.5 | 38.0 | 44.0 |
| 85 | 6:20 | 37.5 | 38.0 | 42.5 |
| 86 | 6:30 | 38.0 | 38.0 | 42.5 |
| 87 | 6:40 | 38.0 | 38.0 | 43.5 |
| 88 | 6:50 | 38.0 | 38.0 | 44.0 |
| 89 | 7:00 | 38.0 | 38.0 | 44.0 |
| 90 | 7:10 | 38.0 | 38.5 | 42.5 |
| 91 | 7:20 | 38.0 | 38.5 | 42.5 |

| | | | | |
|---|---|---|---|---|
| 92 | 7:30 | 38.0 | 38.5 | 43.5 |
| 93 | 7:40 | 42.0 | 41.0 | 43.0 |
| 94 | 7:50 | 43.5 | 43.0 | 43.0 |
| 95 | 8:00 | 42.5 | 41.5 | 42.5 |
| 96 | 8:10 | 43.5 | 43.0 | 43.5 |
| 97 | 8:20 | 43.5 | 42.5 | 43.5 |

**Week 6 Temperature Log of Rib-eyes, graph.**



**Week 6 Temperature Log of Rib-eyes, table.**

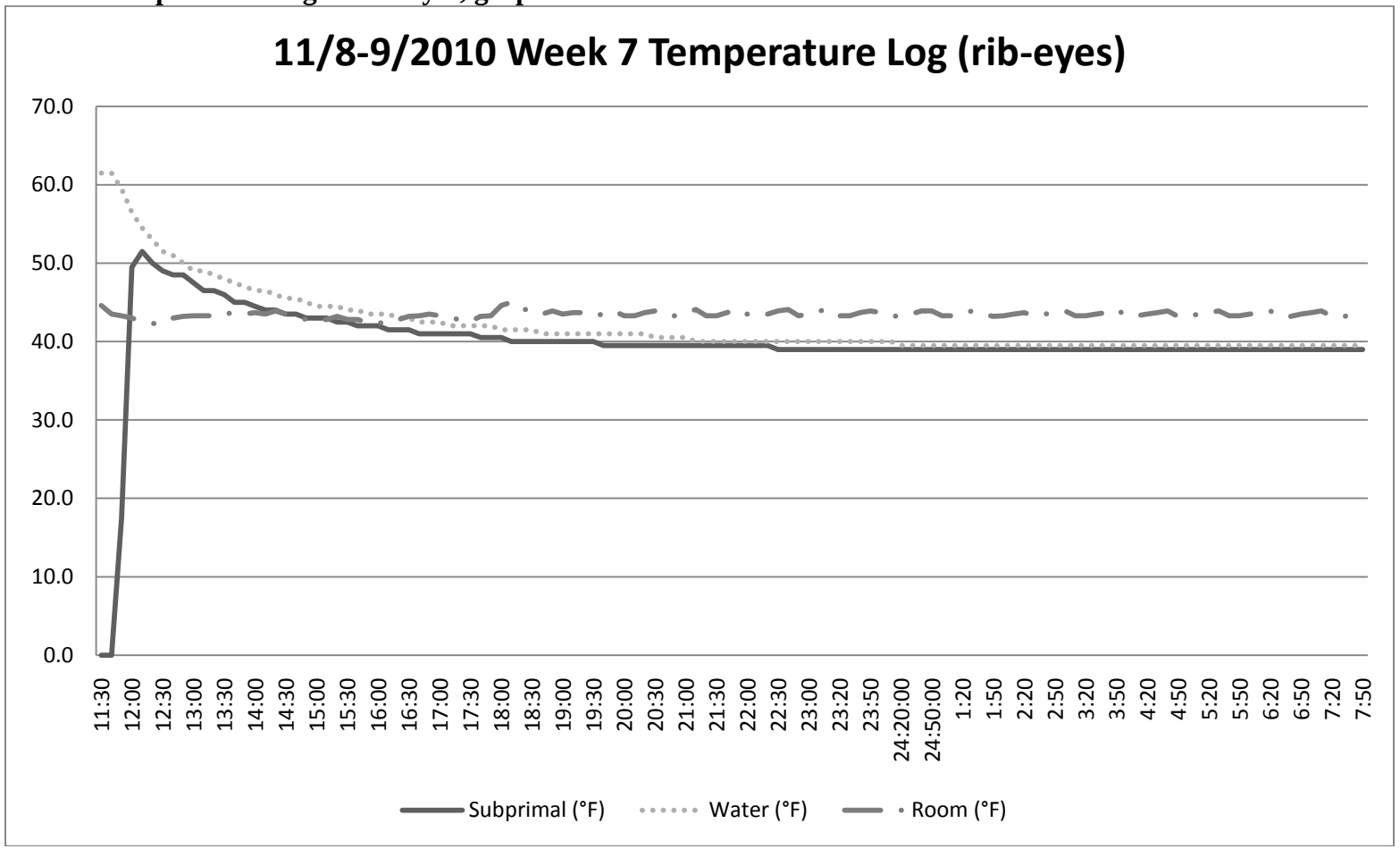
11/1-2/2010 Week 6 Temperature Log (rib-eyes)

| Rec. No. | Time | Water (°F) | Subprimal (°F) | Room (°F) |
|---|---|---|---|---|
| 1 | 11:30 | 55.5 | - | 43.0 |
| 2 | 11:40 | 54.0 | - | 46.0 |
| 3 | 11:50 | 51.0 | - | 43.0 |
| 4 | 12:00 | 50.0 | - | 44.0 |
| 5 | 12:10 | 48.5 | - | 44.0 |
| 6 | 12:20 | 48.0 | - | 43.5 |
| 7 | 12:30 | 47.0 | - | 44.0 |
| 8 | 12:40 | 46.5 | - | 43.0 |
| 9 | 12:50 | 45.5 | - | 43.5 |
| 10 | 13:00 | 45.0 | 42.5 | 44.0 |
| 11 | 13:10 | 44.0 | 42.5 | 42.5 |
| 12 | 13:20 | 44.0 | 41.0 | 43.5 |
| 13 | 13:30 | 43.5 | 40.0 | 43.0 |
| 14 | 13:40 | 43.5 | 39.5 | 43.5 |
| 15 | 13:50 | 42.5 | 39.0 | 44.0 |
| 16 | 14:00 | 42.5 | 40.5 | 42.5 |
| 17 | 14:10 | 42.0 | 39.5 | 42.5 |
| 18 | 14:20 | 42.0 | 40.0 | 43.0 |
| 19 | 14:30 | 42.0 | 38.5 | 43.0 |
| 20 | 14:40 | 42.0 | 39.5 | 43.0 |
| 21 | 14:50 | 42.0 | 39.5 | 41.5 |
| 22 | 15:00 | 41.5 | 39.5 | 41.5 |
| 23 | 15:10 | 41.5 | 39.5 | 42.0 |
| 24 | 15:20 | 41.0 | 39.5 | 41.5 |
| 25 | 15:30 | 41.0 | 39.5 | 41.5 |
| 26 | 15:40 | 40.5 | 37.5 | 42.0 |
| 27 | 15:50 | 40.5 | 38.5 | 43.5 |
| 28 | 16:00 | 40.0 | 38.5 | 44.0 |
| 29 | 16:10 | 40.0 | 38.5 | 42.0 |
| 30 | 16:20 | 39.5 | 39.0 | 43.5 |
| 31 | 16:30 | 39.0 | 39.0 | 42.5 |
| 32 | 16:40 | 39.0 | 38.0 | 43.0 |
| 33 | 16:50 | 39.5 | 38.0 | 43.0 |
| 34 | 17:00 | 39.5 | 38.0 | 43.0 |
| 35 | 17:10 | 39.5 | 38.0 | 44.0 |
| 36 | 17:20 | 39.5 | 38.0 | 42.5 |
| 37 | 17:30 | 39.5 | 38.0 | 43.0 |
| 38 | 17:40 | 39.0 | 37.5 | 44.0 |
| 39 | 17:50 | 39.0 | 37.5 | 42.0 |
| 40 | 18:00 | 39.0 | 37.5 | 42.5 |
| 41 | 18:10 | 39.0 | 37.0 | 43.5 |
| 42 | 18:20 | 39.0 | 37.0 | 43.5 |
| 43 | 18:30 | 39.0 | 37.0 | 42.5 |
| 44 | 18:40 | 39.0 | 37.0 | 43.5 |

| | | | | |
|---|---|---|---|---|
| 45 | 18:50 | 38.5 | 36.5 | 43.5 |
| 46 | 19:00 | 38.5 | 36.5 | 42.0 |
| 47 | 19:10 | 38.5 | 36.5 | 42.5 |
| 48 | 19:20 | 38.5 | 36.5 | 43.5 |
| 49 | 19:30 | 38.0 | 36.0 | 42.0 |
| 50 | 19:40 | 38.0 | 36.0 | 42.5 |
| 51 | 19:50 | 38.0 | 36.0 | 44.0 |
| 52 | 20:00 | 38.0 | 35.5 | 44.0 |
| 53 | 20:10 | 38.0 | 35.5 | 42.0 |
| 54 | 20:20 | 38.0 | 35.0 | 43.0 |
| 55 | 20:30 | 38.0 | 33.5 | 44.0 |
| 56 | 20:40 | 38.0 | 33.5 | 42.5 |
| 57 | 20:50 | 38.0 | 33.5 | 42.5 |
| 58 | 21:00 | 38.0 | 33.0 | 43.0 |
| 59 | 21:10 | 38.0 | 33.0 | 44.0 |
| 60 | 21:20 | 38.0 | 33.0 | 42.0 |
| 61 | 21:30 | 38.0 | 32.5 | 42.0 |
| 62 | 21:40 | 38.0 | 32.5 | 43.0 |
| 63 | 21:50 | 38.0 | 32.5 | 43.5 |
| 64 | 22:00 | 38.0 | 32.5 | 42.0 |
| 65 | 22:10 | 37.5 | 32.5 | 42.5 |
| 66 | 22:20 | 37.5 | 32.5 | 43.5 |
| 67 | 22:30 | 37.5 | 32.5 | 44.0 |
| 68 | 22:40 | 37.5 | 32.5 | 42.0 |
| 69 | 22:50 | 37.5 | 32.5 | 42.5 |
| 70 | 23:00 | 37.5 | 32.5 | 43.5 |
| 71 | 23:10 | 37.5 | 32.5 | 44.0 |
| 72 | 23:20 | 37.5 | 32.5 | 42.0 |
| 73 | 23:20 | 37.5 | 32.5 | 42.5 |
| 74 | 23:30 | 37.5 | 32.5 | 43.5 |
| 75 | 23:40 | 37.5 | 32.5 | 44.0 |
| 76 | 23:50 | 37.5 | 32.5 | 42.0 |
| 77 | 24:00 | 37.5 | 32.5 | 42.5 |
| 78 | 24:10 | 37.5 | 32.5 | 43.0 |
| 79 | 24:20 | 37.5 | 32.5 | 43.5 |
| 80 | 24:30 | 37.5 | 32.5 | 42.0 |
| 81 | 24:40 | 37.5 | 32.5 | 43.0 |
| 82 | 24:50 | 37.5 | 32.5 | 44.0 |
| 83 | 1:00 | 37.5 | 32.5 | 42.5 |
| 84 | 1:10 | 37.5 | 32.5 | 42.5 |
| 85 | 1:20 | 37.5 | 32.5 | 42.0 |
| 86 | 1:30 | 37.5 | 32.5 | 43.0 |
| 87 | 1:40 | 37.5 | 32.5 | 43.5 |
| 88 | 1:50 | 37.5 | 32.5 | 44.0 |
| 89 | 2:00 | 37.5 | 32.5 | 42.0 |
| 90 | 2:10 | 37.5 | 33.0 | 43.0 |
| 91 | 2:20 | 37.5 | 33.0 | 43.5 |
| 92 | 2:30 | 37.5 | 33.0 | 44.0 |

| | | | | |
|---|---|---|---|---|
| 93 | 2:40 | 37.5 | 33.0 | 41.5 |
| 94 | 2:50 | 37.5 | 33.0 | 43.0 |
| 95 | 3:00 | 37.5 | 33.0 | 44.0 |
| 96 | 3:10 | 37.5 | 33.0 | 44.0 |
| 97 | 3:20 | 37.5 | 33.0 | 42.0 |
| 98 | 3:30 | 37.5 | 33.0 | 43.0 |
| 99 | 3:40 | 37.5 | 33.0 | 43.5 |
| 100 | 3:50 | 37.5 | 33.0 | 44.0 |
| 101 | 4:00 | 37.5 | 33.0 | 42.0 |
| 102 | 4:10 | 37.5 | 33.0 | 42.5 |
| 103 | 4:20 | 37.5 | 33.0 | 43.5 |
| 104 | 4:30 | 37.5 | 33.0 | 43.5 |
| 105 | 4:40 | 37.5 | 33.0 | 42.0 |
| 106 | 4:50 | 37.5 | 33.0 | 43.0 |
| 107 | 5:00 | 37.5 | 33.0 | 43.5 |
| 108 | 5:10 | 37.5 | 33.0 | 43.5 |
| 109 | 5:20 | 37.5 | 33.0 | 42.5 |
| 110 | 5:30 | 37.5 | 33.0 | 43.0 |
| 111 | 5:40 | 37.5 | 33.0 | 43.5 |
| 112 | 5:50 | 37.5 | 33.0 | 42.5 |
| 113 | 6:00 | 37.5 | 33.0 | 42.5 |
| 114 | 6:10 | 37.5 | 33.0 | 43.0 |
| 115 | 6:20 | 37.5 | 33.0 | 44.0 |
| 116 | 6:30 | 37.5 | 33.0 | 42.0 |
| 117 | 6:40 | 37.5 | 33.0 | 42.5 |
| 118 | 6:50 | 37.5 | 33.0 | 43.0 |
| 119 | 7:00 | 37.5 | 33.0 | 44.0 |
| 120 | 7:10 | 37.5 | 33.0 | 41.0 |
| 121 | 7:20 | 37.5 | 33.0 | 41.0 |
| 122 | 7:30 | 37.5 | 33.0 | 43.0 |
| 123 | 7:40 | 37.5 | 36.0 | 42.0 |

**Week 7 Temperature Log of Rib-eyes, graph.**



**Week 7 Temperature Log of Rib-eyes, table.**

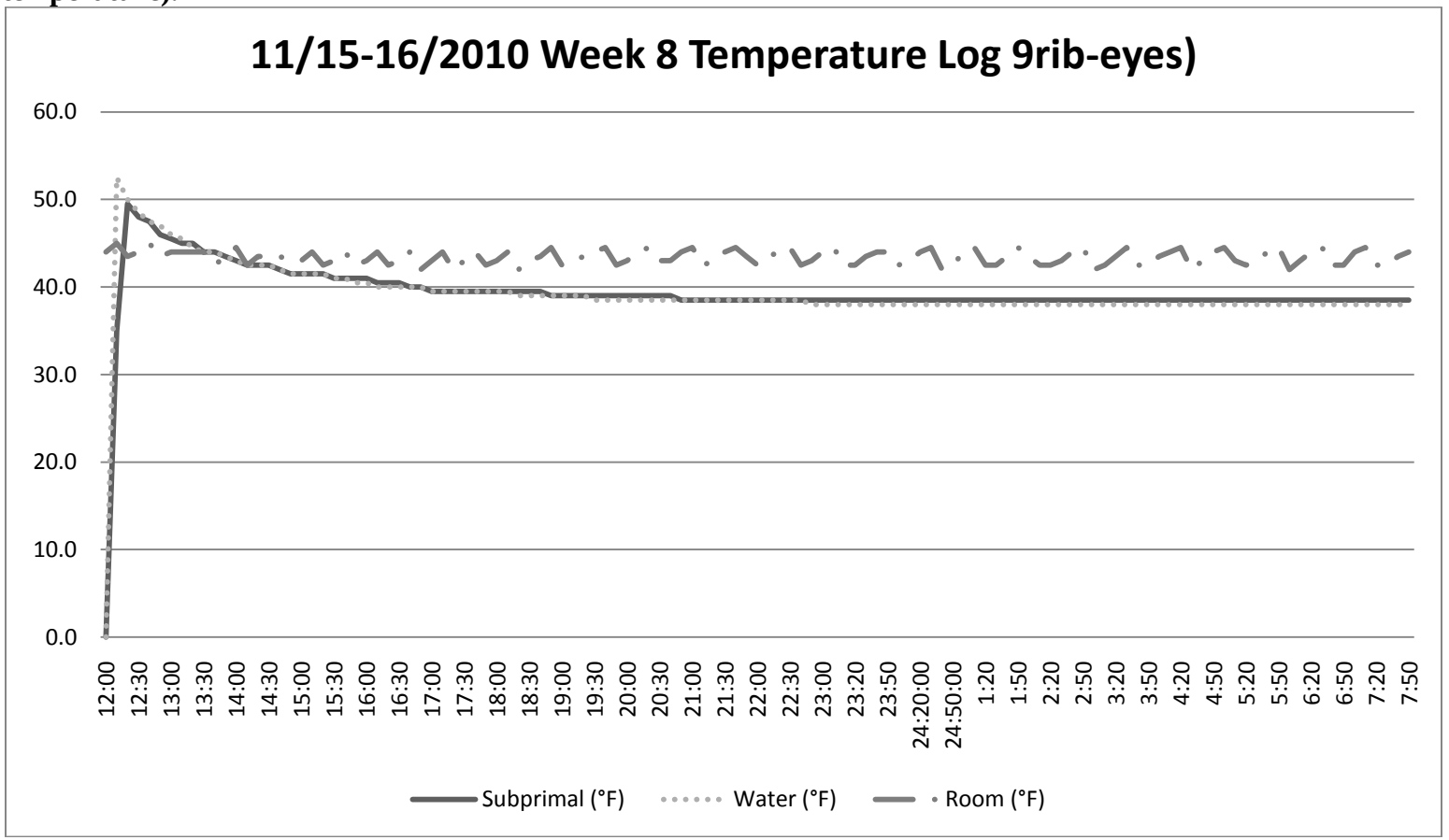
11/8-9/2010 Week 7 Temperature Log (rib-eyes)

| Rec. No. | Time | Subprimal (°F) | Water (°F) | Room (°F) |
|---|---|---|---|---|
| 22 | 11:30 | - | 61.5 | 44.6 |
| 23 | 11:40 | - | 61.5 | 43.5 |
| 24 | 11:50 | 17.5 | 59.5 | 43.3 |
| 25 | 12:00 | 49.5 | 56.5 | 43.0 |
| 26 | 12:10 | 51.5 | 54.5 | 42.6 |
| 27 | 12:20 | 50.0 | 53.0 | 42.3 |
| 28 | 12:30 | 49.0 | 51.5 | 42.3 |
| 29 | 12:40 | 48.5 | 51.0 | 43.0 |
| 30 | 12:50 | 48.5 | 50.0 | 43.2 |
| 31 | 13:00 | 47.5 | 49.0 | 43.3 |
| 32 | 13:10 | 46.5 | 49.0 | 43.3 |
| 33 | 13:20 | 46.5 | 48.5 | 43.3 |
| 34 | 13:30 | 46.0 | 48.0 | 43.7 |
| 35 | 13:40 | 45.0 | 47.5 | 43.5 |
| 36 | 13:50 | 45.0 | 47.0 | 43.5 |
| 37 | 14:00 | 44.5 | 46.5 | 43.7 |
| 38 | 14:10 | 44.0 | 46.5 | 43.5 |
| 39 | 14:20 | 44.0 | 46.0 | 43.9 |
| 40 | 14:30 | 43.5 | 45.5 | 43.5 |
| 41 | 14:40 | 43.5 | 45.5 | 43.2 |
| 42 | 14:50 | 43.0 | 45.0 | 42.8 |
| 43 | 15:00 | 43.0 | 44.5 | 42.8 |
| 44 | 15:10 | 43.0 | 44.5 | 42.8 |
| 45 | 15:20 | 42.5 | 44.5 | 43.2 |
| 46 | 15:30 | 42.5 | 44.0 | 42.8 |
| 47 | 15:40 | 42.0 | 44.0 | 42.8 |
| 48 | 15:50 | 42.0 | 43.5 | 42.4 |
| 49 | 16:00 | 42.0 | 43.5 | 42.4 |
| 50 | 16:10 | 41.5 | 43.5 | 42.3 |
| 51 | 16:20 | 41.5 | 43.0 | 42.8 |
| 52 | 16:30 | 41.5 | 43.0 | 43.2 |
| 53 | 16:40 | 41.0 | 42.5 | 43.3 |
| 54 | 16:50 | 41.0 | 42.5 | 43.5 |
| 55 | 17:00 | 41.0 | 42.5 | 43.3 |
| 56 | 17:10 | 41.0 | 42.0 | 43.0 |
| 57 | 17:20 | 41.0 | 42.0 | 42.8 |
| 58 | 17:30 | 41.0 | 42.0 | 42.6 |
| 59 | 17:40 | 40.5 | 42.0 | 43.2 |
| 60 | 17:50 | 40.5 | 42.0 | 43.3 |
| 61 | 18:00 | 40.5 | 41.5 | 44.6 |
| 62 | 18:10 | 40.0 | 41.5 | 45.0 |
| 63 | 18:20 | 40.0 | 41.5 | 44.1 |
| 64 | 18:30 | 40.0 | 41.5 | 44.1 |
| 65 | 18:40 | 40.0 | 41.0 | 43.5 |

| | | | | |
|---|---|---|---|---|
| 66 | 18:50 | 40.0 | 41.0 | 43.9 |
| 67 | 19:00 | 40.0 | 41.0 | 43.5 |
| 68 | 19:10 | 40.0 | 41.0 | 43.7 |
| 69 | 19:20 | 40.0 | 41.0 | 43.7 |
| 70 | 19:30 | 40.0 | 41.0 | 43.3 |
| 71 | 19:40 | 39.5 | 41.0 | 43.5 |
| 72 | 19:50 | 39.5 | 41.0 | 43.9 |
| 73 | 20:00 | 39.5 | 41.0 | 43.3 |
| 74 | 20:10 | 39.5 | 41.0 | 43.3 |
| 75 | 20:20 | 39.5 | 41.0 | 43.7 |
| 76 | 20:30 | 39.5 | 40.5 | 43.9 |
| 77 | 20:40 | 39.5 | 40.5 | 43.3 |
| 78 | 20:50 | 39.5 | 40.5 | 43.3 |
| 79 | 21:00 | 39.5 | 40.5 | 43.7 |
| 80 | 21:10 | 39.5 | 40.0 | 44.1 |
| 81 | 21:20 | 39.5 | 40.0 | 43.3 |
| 82 | 21:30 | 39.5 | 40.0 | 43.3 |
| 83 | 21:40 | 39.5 | 40.0 | 43.7 |
| 84 | 21:50 | 39.5 | 40.0 | 44.1 |
| 85 | 22:00 | 39.5 | 40.0 | 43.5 |
| 86 | 22:10 | 39.5 | 40.0 | 43.3 |
| 87 | 22:20 | 39.5 | 40.0 | 43.5 |
| 88 | 22:30 | 39.0 | 40.0 | 43.9 |
| 89 | 22:40 | 39.0 | 40.0 | 44.1 |
| 90 | 22:50 | 39.0 | 40.0 | 43.3 |
| 91 | 23:00 | 39.0 | 40.0 | 43.5 |
| 92 | 23:10 | 39.0 | 40.0 | 43.9 |
| 93 | 23:20 | 39.0 | 40.0 | 44.1 |
| 94 | 23:20 | 39.0 | 40.0 | 43.3 |
| 95 | 23:30 | 39.0 | 40.0 | 43.3 |
| 96 | 23:40 | 39.0 | 40.0 | 43.7 |
| 97 | 23:50 | 39.0 | 40.0 | 43.9 |
| 98 | 24:00 | 39.0 | 40.0 | 43.7 |
| 99 | 24:10 | 39.0 | 40.0 | 43.2 |
| 100 | 24:20 | 39.0 | 39.5 | 43.3 |
| 101 | 24:30 | 39.0 | 39.5 | 43.5 |
| 102 | 24:40 | 39.0 | 39.5 | 43.9 |
| 103 | 24:50 | 39.0 | 39.5 | 43.9 |
| 104 | 1:00 | 39.0 | 39.5 | 43.3 |
| 105 | 1:10 | 39.0 | 39.5 | 43.3 |
| 106 | 1:20 | 39.0 | 39.5 | 43.7 |
| 107 | 1:30 | 39.0 | 39.5 | 43.9 |
| 108 | 1:40 | 39.0 | 39.5 | 43.5 |
| 109 | 1:50 | 39.0 | 39.5 | 43.2 |
| 110 | 2:00 | 39.0 | 39.5 | 43.3 |
| 111 | 2:10 | 39.0 | 39.5 | 43.5 |
| 112 | 2:20 | 39.0 | 39.5 | 43.7 |
| 113 | 2:30 | 39.0 | 39.5 | 43.3 |

| | | | | |
|---|---|---|---|---|
| 114 | 2:40 | 39.0 | 39.5 | 43.5 |
| 115 | 2:50 | 39.0 | 39.5 | 43.7 |
| 116 | 3:00 | 39.0 | 39.5 | 43.9 |
| 117 | 3:10 | 39.0 | 39.5 | 43.3 |
| 118 | 3:20 | 39.0 | 39.5 | 43.3 |
| 119 | 3:30 | 39.0 | 39.5 | 43.5 |
| 120 | 3:40 | 39.0 | 39.5 | 43.7 |
| 121 | 3:50 | 39.0 | 39.5 | 44.1 |
| 122 | 4:00 | 39.0 | 39.5 | 43.3 |
| 123 | 4:10 | 39.0 | 39.5 | 43.3 |
| 124 | 4:20 | 39.0 | 39.5 | 43.5 |
| 125 | 4:30 | 39.0 | 39.5 | 43.7 |
| 126 | 4:40 | 39.0 | 39.5 | 43.9 |
| 127 | 4:50 | 39.0 | 39.5 | 43.2 |
| 128 | 5:00 | 39.0 | 39.5 | 43.2 |
| 129 | 5:10 | 39.0 | 39.5 | 43.5 |
| 130 | 5:20 | 39.0 | 39.5 | 43.7 |
| 131 | 5:30 | 39.0 | 39.5 | 43.9 |
| 132 | 5:40 | 39.0 | 39.5 | 43.3 |
| 133 | 5:50 | 39.0 | 39.5 | 43.3 |
| 134 | 6:00 | 39.0 | 39.5 | 43.5 |
| 135 | 6:10 | 39.0 | 39.5 | 43.7 |
| 136 | 6:20 | 39.0 | 39.5 | 43.9 |
| 137 | 6:30 | 39.0 | 39.5 | 43.2 |
| 138 | 6:40 | 39.0 | 39.5 | 43.2 |
| 139 | 6:50 | 39.0 | 39.5 | 43.5 |
| 140 | 7:00 | 39.0 | 39.5 | 43.7 |
| 141 | 7:10 | 39.0 | 39.5 | 43.9 |
| 142 | 7:20 | 39.0 | 39.5 | 43.2 |
| 143 | 7:30 | 39.0 | 39.5 | 43.2 |
| 144 | 7:40 | 39.0 | 39.5 | 43.3 |
| 145 | 7:50 | 39.0 | 39.5 | 43.7 |

**Week 8 Temperature Log of Rib-eyes, graph (subprimal thermocouple recorded water temperature instead of surface temperature).**



**Week 8 Temperature Log of Rib-eyes, table (subprimal thermocouple recorded water temperature instead of surface temperature).**

11/15-16/2010 Week 8 Temperature Log (rib-eyes)

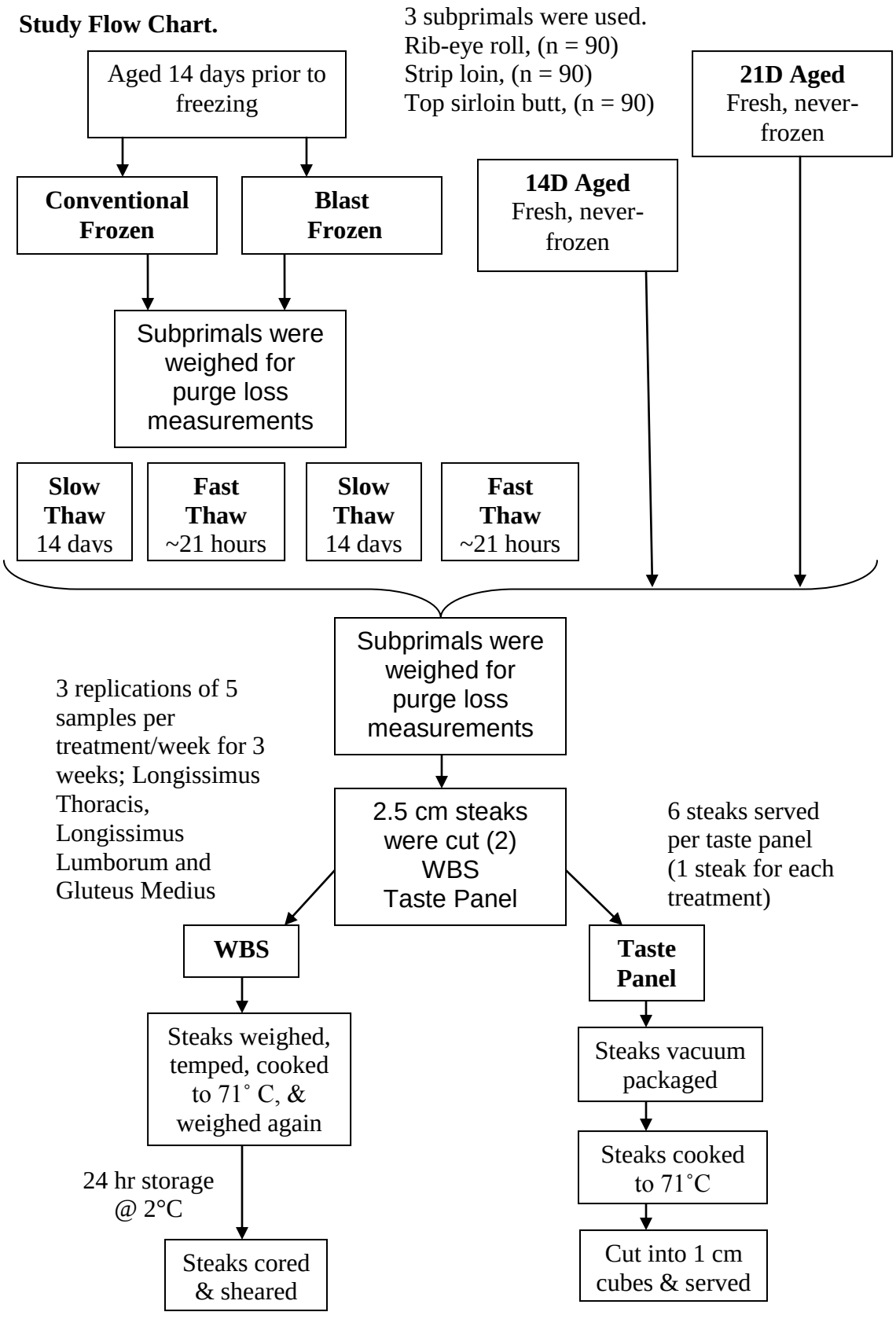
| Rec. No. | Time | Subprimal (°F) | Water (°F) | Room (°F) |
|---|---|---|---|---|
| 1 | 12:00 | - | - | 44.0 |
| 2 | 12:10 | 35.0 | 52.5 | 45.0 |
| 3 | 12:20 | 49.5 | 50.0 | 43.5 |
| 4 | 12:30 | 48.0 | 48.5 | 44.0 |
| 5 | 12:40 | 47.5 | 47.5 | 45.0 |
| 6 | 12:50 | 46.0 | 47.0 | 43.5 |
| 7 | 13:00 | 45.5 | 46.0 | 44.0 |
| 8 | 13:10 | 45.0 | 45.5 | 44.0 |
| 9 | 13:20 | 45.0 | 44.5 | 44.0 |
| 10 | 13:30 | 44.0 | 44.0 | 44.0 |
| 11 | 13:40 | 44.0 | 44.0 | 42.5 |
| 12 | 13:50 | 43.5 | 43.5 | 43.5 |
| 13 | 14:00 | 43.0 | 43.0 | 44.5 |
| 14 | 14:10 | 42.5 | 42.5 | 42.5 |
| 15 | 14:20 | 42.5 | 42.5 | 43.5 |
| 16 | 14:30 | 42.5 | 42.5 | 43.5 |
| 17 | 14:40 | 42.0 | 42.0 | 43.5 |
| 18 | 14:50 | 41.5 | 41.5 | 43.0 |
| 19 | 15:00 | 41.5 | 41.5 | 43.0 |
| 20 | 15:10 | 41.5 | 41.5 | 44.0 |
| 21 | 15:20 | 41.5 | 41.5 | 42.5 |
| 22 | 15:30 | 41.0 | 41.0 | 43.0 |
| 23 | 15:40 | 41.0 | 41.0 | 44.0 |
| 24 | 15:50 | 41.0 | 40.5 | 42.5 |
| 25 | 16:00 | 41.0 | 40.5 | 43.0 |
| 26 | 16:10 | 40.5 | 40.0 | 44.0 |
| 27 | 16:20 | 40.5 | 40.0 | 42.5 |
| 28 | 16:30 | 40.5 | 40.0 | 43.0 |
| 29 | 16:40 | 40.0 | 40.0 | 44.0 |
| 30 | 16:50 | 40.0 | 40.0 | 42.0 |
| 31 | 17:00 | 39.5 | 39.5 | 43.0 |
| 32 | 17:10 | 39.5 | 39.5 | 44.0 |
| 33 | 17:20 | 39.5 | 39.5 | 42.0 |
| 34 | 17:30 | 39.5 | 39.5 | 43.0 |
| 35 | 17:40 | 39.5 | 39.5 | 44.0 |
| 36 | 17:50 | 39.5 | 39.5 | 42.5 |
| 37 | 18:00 | 39.5 | 39.5 | 43.0 |
| 38 | 18:10 | 39.5 | 39.5 | 44.0 |
| 39 | 18:20 | 39.5 | 39.0 | 42.0 |
| 40 | 18:30 | 39.5 | 39.0 | 43.0 |
| 41 | 18:40 | 39.5 | 39.0 | 43.5 |
| 42 | 18:50 | 39.0 | 39.0 | 44.5 |
| 43 | 19:00 | 39.0 | 39.0 | 42.5 |

| | | | | |
|---|---|---|---|---|
| 44 | 19:10 | 39.0 | 39.0 | 43.0 |
| 45 | 19:20 | 39.0 | 39.0 | 43.5 |
| 46 | 19:30 | 39.0 | 38.5 | 44.0 |
| 47 | 19:40 | 39.0 | 38.5 | 44.5 |
| 48 | 19:50 | 39.0 | 38.5 | 42.5 |
| 49 | 20:00 | 39.0 | 38.5 | 43.0 |
| 50 | 20:10 | 39.0 | 38.5 | 44.0 |
| 51 | 20:20 | 39.0 | 38.5 | 44.5 |
| 52 | 20:30 | 39.0 | 38.5 | 43.0 |
| 53 | 20:40 | 39.0 | 38.5 | 43.0 |
| 54 | 20:50 | 38.5 | 38.5 | 44.0 |
| 55 | 21:00 | 38.5 | 38.5 | 44.5 |
| 56 | 21:10 | 38.5 | 38.5 | 42.5 |
| 57 | 21:20 | 38.5 | 38.5 | 43.0 |
| 58 | 21:30 | 38.5 | 38.5 | 44.0 |
| 59 | 21:40 | 38.5 | 38.5 | 44.5 |
| 60 | 21:50 | 38.5 | 38.5 | 43.5 |
| 61 | 22:00 | 38.5 | 38.5 | 42.5 |
| 62 | 22:10 | 38.5 | 38.5 | 43.5 |
| 63 | 22:20 | 38.5 | 38.5 | 44.0 |
| 64 | 22:30 | 38.5 | 38.5 | 44.5 |
| 65 | 22:40 | 38.5 | 38.5 | 42.5 |
| 66 | 22:50 | 38.5 | 38.0 | 43.0 |
| 67 | 23:00 | 38.5 | 38.0 | 44.0 |
| 68 | 23:10 | 38.5 | 38.0 | 44.5 |
| 69 | 23:20 | 38.5 | 38.0 | 42.5 |
| 70 | 23:20 | 38.5 | 38.0 | 42.5 |
| 71 | 23:30 | 38.5 | 38.0 | 43.5 |
| 72 | 23:40 | 38.5 | 38.0 | 44.0 |
| 73 | 23:50 | 38.5 | 38.0 | 44.0 |
| 74 | 24:00 | 38.5 | 38.0 | 42.5 |
| 75 | 24:10 | 38.5 | 38.0 | 43.0 |
| 76 | 24:20 | 38.5 | 38.0 | 44.0 |
| 77 | 24:30 | 38.5 | 38.0 | 44.5 |
| 78 | 24:40 | 38.5 | 38.0 | 42.0 |
| 79 | 24:50 | 38.5 | 38.0 | 42.5 |
| 80 | 1:00 | 38.5 | 38.0 | 44.0 |
| 81 | 1:10 | 38.5 | 38.0 | 44.5 |
| 82 | 1:20 | 38.5 | 38.0 | 42.5 |
| 83 | 1:30 | 38.5 | 38.0 | 42.5 |
| 84 | 1:40 | 38.5 | 38.0 | 43.5 |
| 85 | 1:50 | 38.5 | 38.0 | 44.5 |
| 86 | 2:00 | 38.5 | 38.0 | 43.5 |
| 87 | 2:10 | 38.5 | 38.0 | 42.5 |
| 88 | 2:20 | 38.5 | 38.0 | 42.5 |
| 89 | 2:30 | 38.5 | 38.0 | 43.0 |
| 90 | 2:40 | 38.5 | 38.0 | 44.0 |
| 91 | 2:50 | 38.5 | 38.0 | 44.5 |

| | | | | |
|---|---|---|---|---|
| 92 | 3:00 | 38.5 | 38.0 | 42.0 |
| 93 | 3:10 | 38.5 | 38.0 | 42.5 |
| 94 | 3:20 | 38.5 | 38.0 | 43.5 |
| 95 | 3:30 | 38.5 | 38.0 | 44.5 |
| 96 | 3:40 | 38.5 | 38.0 | 42.5 |
| 97 | 3:50 | 38.5 | 38.0 | 42.5 |
| 98 | 4:00 | 38.5 | 38.0 | 43.5 |
| 99 | 4:10 | 38.5 | 38.0 | 44.0 |
| 100 | 4:20 | 38.5 | 38.0 | 44.5 |
| 101 | 4:30 | 38.5 | 38.0 | 42.0 |
| 102 | 4:40 | 38.5 | 38.0 | 43.0 |
| 103 | 4:50 | 38.5 | 38.0 | 44.0 |
| 104 | 5:00 | 38.5 | 38.0 | 44.5 |
| 105 | 5:10 | 38.5 | 38.0 | 43.0 |
| 106 | 5:20 | 38.5 | 38.0 | 42.5 |
| 107 | 5:30 | 38.5 | 38.0 | 43.0 |
| 108 | 5:40 | 38.5 | 38.0 | 44.0 |
| 109 | 5:50 | 38.5 | 38.0 | 44.5 |
| 110 | 6:00 | 38.5 | 38.0 | 42.0 |
| 111 | 6:10 | 38.5 | 38.0 | 43.0 |
| 112 | 6:20 | 38.5 | 38.0 | 44.0 |
| 113 | 6:30 | 38.5 | 38.0 | 44.5 |
| 114 | 6:40 | 38.5 | 38.0 | 42.5 |
| 115 | 6:50 | 38.5 | 38.0 | 42.5 |
| 116 | 7:00 | 38.5 | 38.0 | 44.0 |
| 117 | 7:10 | 38.5 | 38.0 | 44.5 |
| 118 | 7:20 | 38.5 | 38.0 | 42.5 |
| 119 | 7:30 | 38.5 | 38.0 | 42.5 |
| 120 | 7:40 | 38.5 | 38.0 | 43.5 |
| 121 | 7:50 | 38.5 | 38.0 | 44.0 |

**Appendix 42**

**Study Flow Chart.**



## APPENDIX 43

**SENSORY PANEL CONSANT FORM**

### TASTE PANEL CONSENT FORM

**Title of Protocol: Characteristics of Beef Subprimals after Freezing and Thawing**

**INVITATION TO PARTICIPATE**

You are invited to participate in a taste panel assessing the acceptability of beef after different freezing and thawing methods.

**BASIS FOR SUBJECT SELECTION**

**Participants must be 19 years or older.**

**PURPOSE OF THE STUDY**

This study is being conducted to determine how different methods of freezing and thawing beef subprimals can change the characteristics of the steak.

**EXPLANATION OF PROCEDURES**

You will be required to be at the training sessions, and 80% of the taste panels. You will then be given a sample of steak from 5 treatments and asked to assess the differences, rating the sample on tenderness, juiciness and connective tissue.

**POTENTIAL RISKS AND DISCOMFORTS**

There will be no risks other than those normally associated with eating of meat products. The food will be prepared under sanitary conditions.

**POTENTIAL BENEFITS**

Your recognition of the importance of sensory panels, and your contribution to them, is one benefit. Society in general benefits from the production of meat products with improved consumer acceptance.

**ASSURANCE OF CONFIDENTIALITY**

Any information obtained in connection with this project and which could be identified with you will be kept confidential. Summary results and statistical data may be reported in scientific journals or presented at scientific meetings; however, individual panelist responses will be maintained in confidence.

**WITHDRAWAL FROM THE STUDY**

Participation in this study is voluntary. Your decision whether or not to participate will not affect your present or future relationship with the investigator or the University of Nebraska. If you decide to participate, you are free to withdraw your consent and to discontinue participation at any time without penalty.

**COMPENSATION FOR PARTICIPATION**

Individuals participating in the freezing/thawing taste panel will receive $7 for every training session and $10 for every taste panel session. The panelists will also receive a small treat after every session, once consent to participate in this study is given.

**OFFER TO ANSWER QUESTIONS**

If you have any questions, please do not hesitate to ask. If you think of questions later, please feel free to contact Chris Calkins, Ph.D. (402-472-6314). If you have any additional questions concerning the rights of research subjects, you may contact the University of Nebraska-Lincoln Institutional Review Board (IRB), telephone 402-472-6965.

YOU ARE VOLUNTARILY MAKING A DECISION WHETHER OR NOT TO PARTICIPATE IN THIS RESEARCH TODAY. YOUR SIGNATURE CERTIFIES THAT YOU HAVE DECIDED TO PARTICIPATE HAVING READ THE INFORMATION PRESENTED. YOUR SIGNATURE ALSO CERTIFIES THAT YOU HAVE HAD AN ADEQUATE OPPORTUNITY TO DISCUSS THIS STUDY WITH THE INVESTIGATOR AND YOU HAVE HAD ALL YOUR QUESTIONS ANSWERED TO YOU SATISFACTION. YOU WILL BE GIVEN A COPY OF THIS CONSENT FORM TO KEEP.

_____ _____

SIGNATURE OF SUBJECT DATE

IN MY JUDGEMENT THE SUBJECT IS VOLUNTARILY AND KNOWINGLY GIVING INFORMED CONSENT AND POSSESSES THE LEGAL CAPACITY TO GIVE INFORMED CONSENT TO PARTICIPATE IN THIS RESEARCH STUDY.

_____ _____

SIGNATURE OF INVESTIGATOR DATE

Chris Calkins, Ph.D.
402-472-6314 (Office)

## APPENDIX 44

## TRAINED SENSORY PANEL EVALUATION FORM

TRAINED SENSORY PANEL EVALUATION FORM

Trained Taste Panel
Form

Panelist #: _____

Please evaluate each sensory attributes of the sample by using the rating scale (1-8) and then identify the flavor associated with the sample.

Rating scales:

| **TENDERNESS** | **CONNECTIVE TISSUE** | **JUICINESS** | **OFF-FLAVOR INTENSITY** |
|---|---|---|---|
| 8 Extremely Tender | 8 No Connective Tissue | 8 Extremely Juicy | 4 Strong |
| 7 Very Tender | 7 Trace amount | 7 Very Juicy | 3 Moderate |
| 6 Moderately Tender | 6 Slight Amount | 6 Moderately Juicy | 2 Slight |
| 5 Slightly Tender | 5 Small Amount | 5 Slightly Juicy | 1 None |
| 4 Slightly Tough | 4 Modest Amount | 4 Slightly Dry | |
| 3 Moderately Tough | 3 Moderate Amount | 3 Moderately Dry | |
| 2 Very Tough | 2 Slightly Abundant | 2 Very Dry | |
| 1 Extremely Tough | 1 Abundant Amount | 1 Extremely Dry | |

| **Sample ID** | **Tenderness** | **Connective Tissue** | **Juiciness** | **Off-flavor Intensity** | **Comments** |
|---|---|---|---|---|---|
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |

## APPENDIX 45

## SENSORY PANEL TRAINING, DUO TRIO TEST

Duo trio test

Name:_____ Panel #:_____ Date:_____

Write the number of the sample that was the same as the reference sample in the space provided.

Test 1:_____

Test 2:_____

Test 3:_____

## APPENDIX 46

## SENSORY PANEL TRAINING, MATCHING TEST

Matching Test

Name:_____ Panel #:_____ Date:_____

Write the code number of the matching samples in the boxes with the same letter in them.

Box 1

| | |
|---|---|
| Match 1 | Match1 |
| Match 2 | Match 2 |
| Match 3 | Match 3 |

Box 2

| | |
|---|---|
| Match 1 | Match 1 |
| Match 2 | Match 2 |
| Match 3 | Match 3 |

Box 3

| | |
|---|---|
| Match 1 | Match 1 |
| Match 2 | Match 2 |
| Match 3 | Match 3 |

## APPENDIX 47

## SENSORY PANEL TRAINING, RANKING TEST

Ranking Test
Tenderness

Name:_____ Panel #:_____ Date:_____
Rank the following samples;

| Tenderness | Sample # |
|---|---|
| Most tender | |
| | |
| | |
| Least tender | |

| Tenderness | Sample # |
|---|---|
| Most tender | |
| | |
| | |
| Least tender | |

| Tenderness | Sample # |
|---|---|
| Most tender | |
| | |
| | |
| Least tender | |

Ranking Test
Connective Tissue

Name:_____ Panel #:_____ Date:_____

Rank the following samples;

| Connective Tissue | Sample # |
|---|---|
| Most connective tissue | |
| | |
| | |
| Least connective tissue | |

| Connective Tissue | Sample # |
|---|---|
| Most connective tissue | |
| | |
| | |
| Least connective tissue | |

| Connective Tissue | Sample # |
|---|---|
| Most connective tissue | |
| | |
| | |
| Least connective tissue | |

Ranking Test
Juiciness

Name:_____ Panel #:_____ Date:_____
Rank the following samples;

| Juiciness | Sample # |
|---|---|
| Most juicy | |
| | |
| | |
| Least juicy | |

| Juiciness | Sample # |
|---|---|
| Most juicy | |
| | |
| | |
| Least juicy | |

| Juiciness | Sample # |
|---|---|
| Most juicy | |
| | |
| | |
| Least juicy | |

# RECOMMENDATIONS FOR FUTURE RESEARCH

This research unveiled significant findings, some of which were expected and others that were not. The most significant finding from this research was that freezing and thawing had little meaningful effects on tenderness and sensory attributes. This suggests that subprimals can be frozen and thawed and consumers will not be able to tell the difference.

Another significant finding was that freezing rate of subprimals did not have an effect on purge loss. It was the thawing rate that had the significant effect on purge loss. The faster thawed subprimals had significantly less purge loss than the subprimals that were slow thawed. I would suggest doing another study like this one but to focus more on different thawing rates than freezing rates. I would modify the thawing processes that I used in my study and try to make them more like the industry would do. I would leave the subprimals packed in the boxes they were shipped for the slow thaw process. For the fast thaw process, I would use a smaller vat so the subprimals did not have as much room to move around in. Also, the subprimals needed to be placed in the fast thaw water bath for a longer period of time to be completely thawed. Finally, it would be good to add another thaw process using high air velocity in a cooler at about 0 - 2°C to thaw the meat rapidly as well.

There could also be issues with color due to the freezing process. This study did not research the color stability of steaks. If retailers wanted to freeze and thaw subprimals, I would also suggest doing a study that measures retail shelf life compared to fresh product. I would expect for the frozen/thawed steaks to have a shorter shelf life and

experience greater purge loss than fresh, never-frozen steaks. I would expect these results due to the damage that the cells experience in the freezing processes.