Effects of thawing method on palatability and thawing characteristics of beef loins

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Abstract

The objective of this study was to investigate the effects of various thawing methods on beef palatability. USDA Choice paired beef strip loins (*n* = 15) were obtained from a Midwest commercial processing facility for palatability evaluation. Moreover, 6 USDA Low Choice strip loins for thawing characteristic data collection were collected. At day 11 of aging, the paired strip loins were portioned into 6 blocks, and fabricated into 2.5 cm steaks. Each block was then assigned one of six thawing methods, with each loin containing each thawing method. Thaw methods included the four USDA approved thawing methods: thawing in the refrigerator(2-3° C; 882 m), cold water (2-3° C; 637.5 m), microwave (50% power, 7 m), and cooking from frozen, as well as two methods commonly used by consumers: thawing in hot water (40° C; 10.3 m), and on the counter (19±1° C; 264 m). Within each block, steaks were assigned to one of four tests: consumer panel, trained panel, Warner-Bratzler shear force, and lab assay. Steaks were aged a total of 21d prior to freezing. Loins designated for thawing characteristic data collection were fabricated into 2.5 cm steaks at 11 d of aging, assigned a random thawing treatment. Temperature probes were inserted, vacuum packaged, and frozen. End-point thawing temperature was targeted at 0°C for all steaks. For thawing characteristic steaks, temperature probes were connected to data loggers immediately upon removal from the freezer, Thaw rate, time, and temperature at times prior to thawing were all recorded from –6.67° C to 0° C. Data were analyzed as a completely randomized block design.

Results from consumer panels indicate no differences ($P > 0.05$) among all thawing methods for consumer's ratings for tenderness, juiciness, flavor, and overall liking. Similarly, there were no differences ($P > 0.05$) among thawing methods for percentage of steaks rated acceptable for tenderness, juiciness, flavor, and overall liking. Moreover, there were no

differences ($P > 0.05$) in consumer perception of quality. In terms of myofibrillar tenderness in trained sensory panels, thawing in the refrigerator and cold water were more tender ($P < 0.05$) than cooking from frozen, while thawing in the refrigerator and cold water were rated higher for overall tenderness by trained sensory panelists than thawing in the microwave and cooking from frozen. Moreover, cooking steaks from frozen was rated higher ($P < 0.05$) for beef flavor intensity for all thawing methods. Lastly, there were no differences ($P > 0.05$) for initial juiciness, sustained juiciness, connective tissue, Warner- Bratzler Shear Force, and slice shear force.

In terms of objective quality measurements, thawing steaks in the microwave had lower ($P < 0.05$) a^* and b^* values than all other thawing methods, while cooking from frozen steaks had lower a^* and b^* values than thawing on the counter. Additionally, steaks thawing in the microwave had the highest ($P < 0.05$) cook loss, followed by cooking from frozen, with all other methods being similar. Similarly, steaks thawed in the microwave and in hot water had a higher ($P < 0.05$) thawing loss than thawing on the counter, in cold water, and in the refrigerator. Also, steaks thawed in the microwave had the highest ($P < 0.05$) total moisture loss, followed by hot water and cooking from frozen, then thawing in cold water, on the countertop, and in the refrigerator. Lastly, steaks cooked from frozen had a higher ($P < 0.05$) expressible moisture than thawing steaks on the counter, in colder water, or in the refrigerator.

These results indicate thawing method had minimal differences on overall palatability, and objective quality measures. Although, increases in thawing loss should be considered when thawing large quantities of meat for potential overall economic loss. Therefore, consumers and food service establishments should use their preferred thaw method, taking food safety and time into consideration.

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Dedication

This thesis is dedicated to my parents- Ed and Kim. Thank you for instilling in me a passion for agriculture and providing me with every opportunity to develop as a young person, and chase my dreams- no matter how far away I am. I certainly would not be where I am today without you both.

Chapter 1- Literature Review

Overview of thawing methods

In 2013, the USDA-FSIS defined three safe methods of thawing meat products, as well as defining cooking food from frozen as a safe method. Thawing in the refrigerator (**REF**) is the most time-consuming method, taking upwards of twenty-four hours to thaw completely (USDA-FSIS, 2013). Thawing in cold water (**CW**) is a more time-effective method, requiring meat to be sealed in sealed packaging without leaks, in order to prevent contamination from bacteria within the environment. The product must be placed in cold water (<40º C), with the water being replaced every thirty minutes until the product is thawed (USDA-FSIS, 2013). Within this method, the USDA-FSIS suggests meat be cooked immediately if completely thawed. Thawing in the microwave (**MIC**) is the fastest of the approved thawing methods. Meat must be cooked immediately after thawing it in the microwave due to the potential of external portions of the product reaching the temperature danger zone and beginning the cooking process during thawing (USDA-FSIS, 2013). Lastly, thawing as the cooking method (**COOK**) is also defined as safe by the USDA. However, cook times when cooking meat from the frozen state is increased, and should be taken into account when utilizing this thawing method. (Obuz and Dikeman, 2003; USDA-FSIS, 2013).

Moreover, the USDA defines thawing on counter (**CT**) and thawing in hot water (**HW**) as unsafe methods of thawing and risk the occurrence of foodborne illness. However, these thawing methods are still commonly utilized by consumers to thaw meat (Benli, 2015) CT thawing method is generally understood to be approximately ambient temperature, between 15° C and 30° C. These thawing methods increase the risk of meat entering the “temperature danger zone” (4 - 60° C) during the thawing process and greatly reduces the safety of meat products through the risk of bacterial growth (USDA-FSIS, 2013). Nonetheless, both thawing methods are commonly utilized by consumers, although the impact on quality is not thoroughly understood.

Freezing

Freezing is a long-standing necessity in the meat industry that allows for increased shelf life and flexibility of use of meat products. The effects of freezing on quality are widely researched, including the understanding of ice crystal formation and subsequent damage, changes in shear force and moisture losses, and consumer and trained panel findings amongst fresh vs. frozen samples. However, there are varying results on the overarching effects of freezing, freezing rate, and ice crystal size on the physiochemical and palatability traits of meat. Nonetheless, it is commonly understood that meat is subject to damage during the freezing process and is further evidenced through the thawing process.

The primary benefit of freezing is the extension of shelf life of beef. It is known that when beef is held over a long period of time at refrigeration temperatures that microbial growth of spoilage bacteria can occur in a matter of weeks (Pennacchio et al., 2011; Colle et al., 2015). The process of freezing meat products stops microbial growth and slows the deterioration of quality attributes that occur due to extended aging times (Lagerstedt et al., 2008; Colle et al., 2016). This extension of shelf-life assists in the management of the cold chain and allows for the export of meat products overseas (Leygonie et al., 2012; Ren et al., 2022). Exports in the beef industry accounted for over eleven million dollars in 2022, and freezing is essential for exporting beef to Asian countries, which account for over seventy percent of pounds of export (Ren et al., 2022; USDA, 2023). However, there are both public perception concerns and economic factors that are disadvantages of freezing. The increase in purge loss of frozen beef results in a total economic loss, as well as a deterioration of color and reduced juiciness of previously frozen beef

(Leygonie et al., 2012; Li et al., 2022). Moreover, while there is no evidence determining that consumers prefer fresh over frozen beef, it is commonly assumed that consumer prefer fresh over frozen beef product (Pietrasik and Janz, 2009).

Ice crystal formation is the primary cause of damage during the freezing process. The size and location of the ice crystals have the most significant effect on the overall quality changes caused by freezing (Rahelić et al., 1985a). The expanding of ice crystals during the freezing process puts pressure on the muscle fibers, causing fissures in muscle fibers and disrupting the structure of muscle as a whole (Rahelić et al., 1985a; Qian et al., 2022). When frozen meat is thawed, the water that was once contained within the fiber is now released, and can be seen as increased purge (Rahelić et al., 1985b; Huff-Lonergan and Loneragan, 2005; Qian et al., 2022). The location and size of crystals determines the level of damage to the muscle fiber. Freezing at lower temperatures (< -78° C) causes ice crystals to form intracellularly, while higher freezing temperatures (i.e. -10 ° C, -33° C) result in intercellular ice crystals. When ice crystals form both intracellularly and intercellularly, damage to muscle fibers increases compared to intercellularly or intracellularly formed ice crystals individually (Rahelić et al., 1985a; Kiani and Sun, 2011). Freezing rate is closely related to temperature, where a faster freezing rate would result in smaller, more uniform ice crystals, minimizing damage to muscle fibers (Aidani et al., 2014; Qian et al., 2022). Lower temperatures, thus faster freezing rates, increase the nucleation phase of ice crystal formation, in which new crystals are formed, rather than the crystal growth phase (Kiani and Sun, 2011). Faster freezing methods include processes such as immersion freezing, or cryogenic freezing, as well as novel methods such as high pressure assisted freezing, and electrostatic freezing (Leygonie et al., 2012; Li et al., 2022; Qian et al., 2022). Furthermore samples frozen at a slower rate have been shown to have lower a^* values in comparison to faster frozen product, coupled with a higher protein concentration within thaw exudate (Qian et al., 2022). The increase in protein concentration in thaw exudate indicates more severe damage to muscle fibers, causing an expulsion of muscle fiber contents into the extracellular space, subsequently released as purge.

While there is evidence that the damage caused to muscle fibers due to the freezing process occurs at varying levels pending freezing processes, the detectable quality differences by trained and consumer panelists, as well as instrumental measurements of quality are clouded. It is apparent that purge and cook loss increases when comparing frozen samples to fresh samples (Wheeler et al., 1990; Lagerstedt et al., 2008; Kim et al., 2015; Kim et al., 2017). Moreover, several studies show that shear force values decrease in frozen samples (Lagerstedt et al., 2008; Kim et al., 2017), however, Wheeler (1990) saw no difference in shear force values of steaks aged similarly. These variations could be explained by the utilization of different aging times amongst the studies, as well as varying freezing procedures. Moreover, consumer sensory panelists cannot detect a difference between fresh and frozen samples of the sample quality grade and aging period (Lagerstedt et al., 2008; Kim et al., 2017). However, trained panelists have found increased beef flavor and juiciness in fresh samples (Wheeler et al., 1990; Lagerstedt et al., 2008). Therefore, there is a notable loss of moisture through the freezing and thawing process, detectable by trained panelists, however undetectable to consumer panelists.

When freezing rate and temperature are evaluated for applied measures of quality, there is no evidence that faster freezing methods such as immersion freezing or cryogenic freezing have any impact on applied measurements of quality, such as shear force or thaw loss (Eastridge and Bowker, 2011; Hergenreder et al., 2013; Kim et al., 2015). Moreover, the trained panelist evaluations indicated no differences in tenderness, juiciness, connective tissue, and off-flavor amongst samples. Therefore, while faster freezing rates certainly have an effect on size crystal size and location, there is no evidence that determines an increase in both applied measurements of quality and panelist evaluation.

Freeze Thaw Cycles effect on beef quality

While freezing is obviously a necessity for export trade and long-term preservation, the process of storing and transporting meat products can lead to temperature fluctuations and abuse. These fluctuations could result in multiple freeze/thawing cycles to occur over the storage and transportation of meat products, which in turn could cause a change in the quality and physiochemical properties of meat.

There is an apparent change in quality characteristics over multiple freeze-thawing cycles. pH values decline significantly, while lipid oxidation increases from a fresh sample, through multiple freeze-thawing cycles (Rahman et al., 2015; Cheng et al., 2019). Moreover, *L**, *a**, and *b** values all decrease from a single freeze-thawing cycle to multiple freeze-thaw cycles (Jeong et al., 2011; Cheng et al., 2019). However, there was no difference in metmyoglobin reducing activity among fresh product, and freeze-thaw cycles. Thawing loss and cook loss increases significantly between each freeze-thawing cycle up to four cycles, where there is no significant difference after four cycles (Cheng et al., 2019). This follows a similar pattern to that of water holding capacity, which decreases linearly from fresh through seven freeze-thaw cycles. Moreover, there is a significant increase in the damage to muscle fibers over multiple thawing cycles (Fig. 2) , where there was a significant increase in the diameter of holes in muscle fibers as additional cycles were completed (Cheng et al., 2019). This further evidence the damage caused by ice crystal formation, and the severity of damage caused by repeated freeze-thaw cycles.

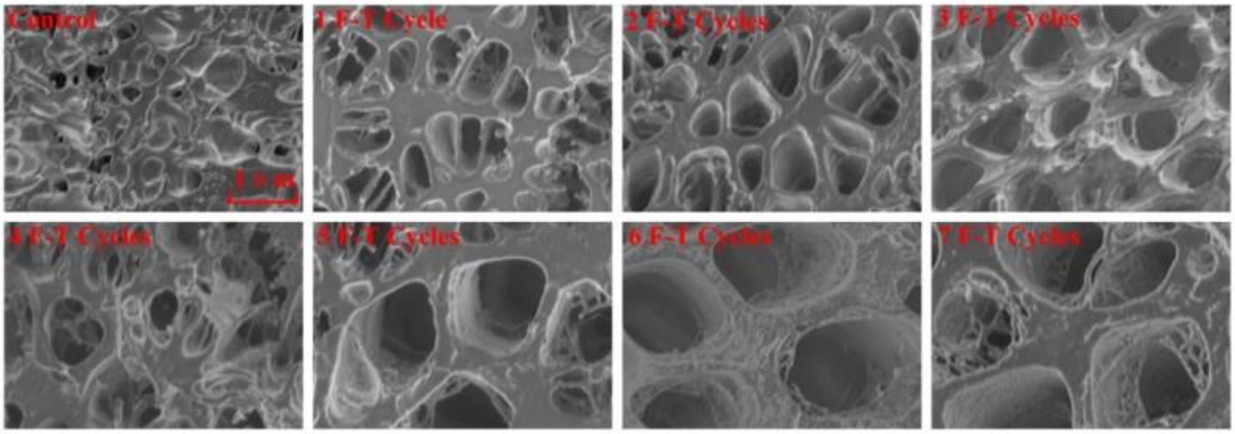

Figure 1. *Cross-section of beef samples subject to multiple freeze-thaw cycles, where control is a fresh sample*

Effect of thawing method on quality attributes

While freezing is a common practice within the industry, and the effects of freezing have been widely researched, thawing has not had the same level of interest. Research evaluating thawing methods effect on quality reaches as far back as to Childs and Paul (1937), however there is little modern research evaluating all commonly utilized thawing methods for palatability characteristics.

There are limited differences in trained panelist evaluation amongst all thawing methods. Kim et al. (2013) reported no difference between REF, CT, MIC, and steaks thawed in tap water (9° C) for flavor, texture, taste, and overall quality, similar to Zahir (2021), which indicated no sensory differences amongst the REF, CT and MIC (Zahir, 2021). In a similar study, REF and CT samples were similar in terms of tenderness and juiciness liking (Bogdanowicz et al., 2018). However, Yau (2000) showed that REF had higher juiciness, tenderness, overall quality ratings when compared to MIC (Yau and Huang, 2000). These differences could be attributed to the cut and cook method utilized in each study, whereas Yau and Huang (2000) utilized sous-vide stew meat, Kim et al. (2013) utilized grilled strip steaks, and Zahir (2021) utilized oven cooked strip steaks. Moreover, COOK steaks were not found to be different from steaks REF in juiciness, connective tissue, or overall tenderness, although COOK were less tender in terms of myofibrillar tenderness than REF (Obuz and Dikeman, 2003), while another study observed COOK samples have higher connective tissue ratings, and lower initial and final juiciness ratings when compared to REF patties (Bigner-George and Berry, 2000). However, Bigner-George and Berry (2000) utilized ground product, rather than the strip steaks utilized in Obuz and Dikeman (2003). Nonetheless, there is little clarity surrounding the four USDA thawing methods, and commonly used consumer methods in terms of trained panelist evaluation. Moreover, there is no current research amongst thawing methods for consumer panel evaluation.

When analyzing other instrumental measurements of quality, there are limited differences amongst thawing methods. MIC steaks have been evidenced to have higher lipid oxidation, followed by CT steaks, with REF having the least lipid oxidation (Zahir, 2021). Moreover, texture profile analysis showed that MIC steaks had higher hardness and chewiness values, with lower juiciness and fiber looseness values in comparison to REF (Yau and Huang, 2000). Moreover, pH was not different amongst REF and CT (Bogdanowicz et al., 2018).

Effects of thawing on purge and water loss

Moisture loss is a known negative attribute of freezing beef of beef, primarily caused by muscle fiber damage caused by ice crystals. (Wheeler et al., 1990; Lagerstedt et al., 2008; Kim et al., 2015; Kim et al., 2017; Li et al., 2022). The subsequent thawing process results in exudate, or thaw loss, that contains water, water soluble sarcoplasmic proteins, myoglobin, and other enzymes and proteins released from the damaged muscle fibers (Xing et al., 2020). However, the understanding of the effects of thawing method on thaw loss, cook loss, and other moisture and juiciness related assays lacks complete research comparing most common thawing methods.

MIC samples result in the highest thaw loss, followed by CT, then by REF samples (Zahir, 2021), while Bogdanowicz et al. (2018) found CT samples has a lower thaw loss compared to REF. However, these studies were performed in different countries (Iraq, Poland), therefore vastly different cattle types, as well as utilizing different muscles (longissimus dorsi, semitendinosus), and in Zahir (2021) unspecified aging time. Additionally, COOK steaks have a higher cook loss than REF steaks (Obuz and Dikeman, 2003). Moreover, MIC samples have a higher cook loss than CT, followed by steaks REF (Zahir, 2021), while Rahman et al. (2015) found HW steaks had a lower cook loss than REF, however the cooking method, cattle type and measurement procedure varied amongst all studies. This supports raw water holding capacity findings, whereas REF steaks have the highest water holding capacity, followed by steaks CT, and steaks MIC having the lowest water holding capacity (Zahir, 2021). Though, Kim et al. (2013) demonstrates MIC and CT steaks having a higher cooked water holding capacity than REF and CW steaks. This relationship could indicate that MIC and CT steaks purge moisture prior to cooking, whereas REF and CW steaks retain moisture throughout thawing and storage, and have a higher level of moisture to purge in the cooked state. This is further demonstrated by REF steaks have a higher pressed juice percentage (**PJP**) than MIC steaks (Yau and Huang, 2000). Moreover, Rahman et al. (2015) found REF steaks have a lower pressed juice percentage compared to HW. However, REF and MIC steaks are documented to have higher moisture content than CW (Kim et al., 2013).

There is a vast amount of conflicting research on how the speed of thawing affects thaw loss of meat. Gonzalez-Sanguinetti et al. (1985) indicated that a decrease in thawing time resulted in an increase in exudate due to the rapid release of purge into extracellular space, and lack of time to be reabsorbed, therefore released as purge. Alternatively, slow thawing would allow water to migrate into the dehydrated intercellular space and be reabsorbed, rather than being released as purge. This is supported through studies indicating that REF and CW methods yield lower thaw losses in comparison to MIC thawing methods (Zahir, 2021). However, Eastridge and Bowker (2011), Hergenreder et al. (2013), and Bogdanowicz et al. (2018) indicated that thawing at a slower rate resulted in a higher thaw loss, and higher total moisture loss, than faster thawing rates. The method for recording thaw loss varies minimally across studies, however, the muscle, aging time, breed type of the cattle sourced, and thickness and size of sample all vary widely among studies. However, there are a variety of methodological nuances differentiating the method of thawing samples. In Hergenreder et al. (2013), the slow thawing method occurred over several weeks' time, rather than hours as reported in Zahir (2021), Kim et al. (2013), and Yau and Huang (2000). Additionally, HW steaks in Eastridge and Bowker (2011) were dipped in cold water and temperature brough down to 1° to 2° C prior to packages opened and thaw loss recorded, which varied from procedures used for other thawing methods within the same study, and thawing procedures used in Yau and Huang (2000), Kim et al. (2013), Zahir (2021), and Bogdanowicz et al. (2018). Moreover, while thawing methods are similar in Bogdanowicz et al. (2018), product was collected from uncastrated males, rather than steers, and aged only four days prior to freezing.

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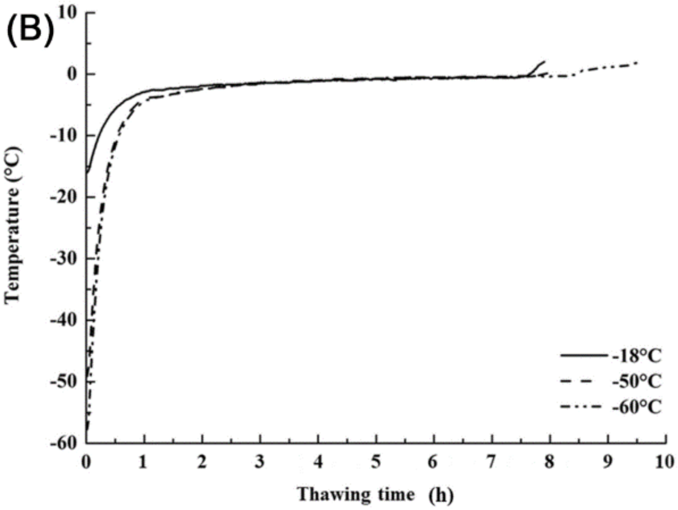
Thawing Time

Thawing rates and times have rarely been researched as the primary research focus of any study. However, there are a variety of recorded thawing times and rates recorded within freezing and thawing studies.

When it comes to defining thawing curves of samples, there is no research defining thawing curves outside of samples thawed around refrigeration temperatures. Lee et al. (2021) defined a thaw curve (Fig. 1) for minced pork pieces frozen at various temperatures, thawed at 2° C, finding no differences amongst thawing times regardless of storage temperature, which were approximately 7 h. This matches results found in Choi et al. (2018), whereas lamb strips (3 x 10 x 3 cm) thawed at the same temperature followed a similar curve (Fig. 2), and had no difference in thawing time based on freezing temperatures, however total thawing time was longer. This could be attributed to the difference in sample size between studies. Moreover, Li et al. (2022) stated that they found similar thawing times to that of Lee et al. (2021), however no thaw curve was illustrated.

Figure 2. *Thaw curve for minced pork at refrigeration temperatures*



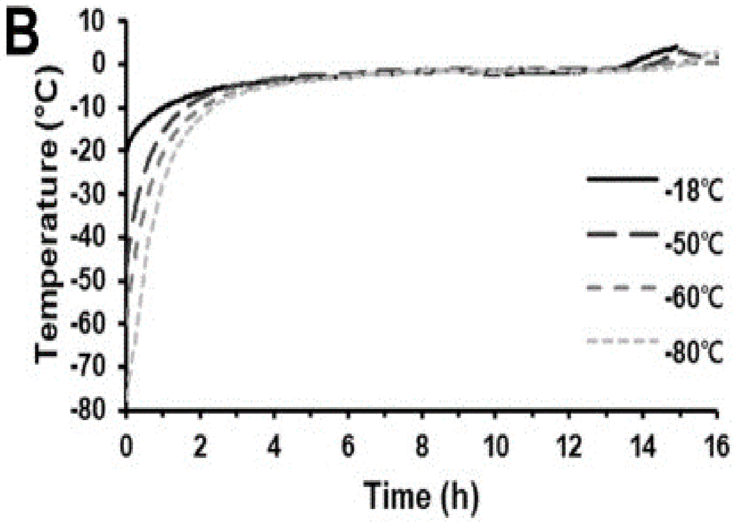


Figure 3. *Thaw curve for lamb strips at refrigeration temperatures*

Moreover, predictive models for the thawing times of various sizes of meat blocks and varying thawing temperatures have been developed. Creed and James (1981) developed the following equation in order to predict total thawing time, whereas Y is the total thawing time, D is the thickness of the frozen sample, T is the thawing temperature, and H is the heat transfer coefficient.

$$Y = \frac{D^{(2.043 \times T^{-0.012})}}{3.947 + 0.43T} + \frac{123.724T^{-0.831} \times D^{(0.928\ T^{0.059})}}{H}$$

Figure 4. *Thawing time predictive equation,*

Palatability defined

Palatability as a whole is the entire eating experience of a consumer. Beef palatability specifically is commonly divided into three primary factors: flavor, tenderness, and juiciness (Bratzler, 1971; Smith and Carpenter, 1974; Miller et al., 1995; O'Quinn, 2016). Moreover, consumers willingness to pay for beef is impacted by palatability characteristics- specifically tenderness (Platter et al., 2005), whereas an increase in perceived palatability characteristics indicated a higher willingness to pay. Additionally, consumer repurchasing intent is 65% driven by quality (Egan et al., 2001), which can primarily be contributed to overall palatability. Therefore, the understanding of beef palatability and components that affect it is widely researched and understood.

Throughout history, tenderness and flavor have been the more prevalent factors affecting beef palatability in comparison to juiciness. In earlier studies, tenderness contributed 71%, followed by flavor at 20%, and juiciness at 9% for consumers, with food service following similar trends, listing tenderness first, followed by flavor (Egan et al., 2001). Similarly, Platter et al. (2003) found tenderness to be the most important factor to 51.6% of consumers, followed by flavor at 37.6%, and juiciness at 10.8%. More recently, flavor has overtaken as the primary factor affecting beef palatability, with 50-59% of consumers rating flavor as the most important aspect (Vierck et al., 2018; Drey et al., 2019; Farmer et al., 2022). This could indicate that flavor is the palatability trait most found unacceptable by consumers, rather than unacceptable tenderness or juiciness. Moreover, tenderness, flavor and juiciness work cohesively to create a positive eating experience. When one of these aspects are unacceptable, the likelihood of the sample also being rated unacceptable was 7.2, 12.5, and 6.5 times more likely, respectively (O'Quinn et al., 2018). Therefore, the failure of tenderness, flavor or juiciness can have a significant impact on overall palatability.

There are remaining factors that can affect beef palatability such as cooked color, aroma, and texture. Cooked color has the largest visual impact on consumer eating satisfaction, as degree of doneness preference and the visual perception of degree of doneness can impact perceived quality (Prill, 2019). Moreover, when analyzing texture utilizing a texture profile analysis, hardness and adhesiveness account for 51% of the variation in tenderness (Caine et al., 2003). However, there is no consumer data to indicate whether texture has an impact on palatability for consumers.

Warner-Bratzler Shear Force

Warner-Bratzler Shear Force (**WBSF**) is an objective tenderness measure (Shackelford et al., 1991; American Meat Science Association, 2016). Tenderness measurements can be affected by a vast number of factors, including degree of doneness, quality grade, and muscle type (McKeith et al., 1985; Belew et al., 2003; Guelker et al., 2013; Nyquist et al., 2018; Drey et al., 2019). Whereas medium rare steaks are more tender than very-rare, medium, well done and very well done steaks, and a medium degree of doneness is more tender than very well done and rare, and rare being the least tender when compared to all other degree of doneness (Drey et al., 2019). Moreover, Prime steaks have lower shear force values than all other quality grades, and Top and Low Choice steaks have lower shear force values than select (Drey et al., 2019). Moreover, muscles of locomotion from the round and chuck, such as the *semimembranosus* or *triceps brachii* have higher shear force values than muscles from the loin and rib such as the *psoas major* and *longissimus lumborum* (Belew et al., 2003). However, when thawing method is evaluated, no differences were found when comparing REF to steaks CT, HW, and COOK (Eastridge and Bowker, 2011; Obuz et al., 2014; Bogdanowicz et al., 2018). Moreover, there is no research comparing the four USDA approved thawing methods, and those commonly used by consumers for WBSF.

Raw Fat and Moisture

There is a tremendous amount of research involving fat and moistures percentages of beef. Fat content knowingly increases as marbling and quality grade increases (Savell and Cross, 1988; O'Quinn et al., 2012; Hunt et al., 2014; Lucherk et al., 2016; Drey et al., 2019; Farmer et al., 2022). Prime has the highest marbling content in the *longissimus lumborum* (13-14%), followed by Top Choice (8-9%), Low Choice (4-6%), Select, (2-3%), and Standard (1%) (O'Quinn et al., 2012; Hunt et al., 2014; Legako et al., 2015; Nyquist et al., 2018; Drey et al., 2019; Farmer et al., 2022). Additionally, fat content varies amongst different muscles of the same quality grade (Hunt et al., 2014; Legako et al., 2015; Nyquist et al., 2018) Moreover, moisture has an inverse relationship with fat content, with moisture decreasing as fat percentage increases (O'Quinn et al., 2012; Hunt et al., 2014; Legako et al., 2015; Nyquist et al., 2018; Drey et al., 2019; Farmer et al., 2022). Prime *longissimus lumborum* steaks have moisture content of approximately 57-64%, followed by Top Choice (63-67%), Low Choice (~ 70%), Select (71-72%) and Standard (71-73%) (O'Quinn, 2012; Hunt et al., 2014; Legako et al., 2015; Nyquist et al., 2018; Drey et al., 2019).

While fat content is primarily influenced by marbling content, moisture can be influenced by a variety of factors. The ability of fresh meat to retain moisture is incredibly important for both quality and yield of meat (Huff-Lonergan and Lonergan, 2005). The bulk of water in meat is held within the myofibrils, between the myofibrils and sarcolemma, or between cells or muscle bundles, with up to 85% of the water held within the myofibrils (Huff-Lonergan and Loneragan, 2005). Intrinsic factors such as the final pH, calpain and calpastatin activity can have a significant effect on meats ability to retain moisture (Huff-Lonergan and Lonergan, 2005). Moreover, post-processing handling of meat products can affect the ability of meat to retain moisture, such as being previously frozen, and enhancement (Kim et al., 2015; Kim et al., 2017; Drey et al., 2019)

Pressed Juice Percentage

PJP is an instrumental measurement of juiciness. Juiciness of samples can be altered by a variety of factors, including quality grade, degree of doneness, enhancement, and muscle (Lucherk et al., 2017; Drey et al., 2019). Applied PJP measurements have a stronger correlation with consumer juiciness ratings in comparison to other juiciness measurements such ass expressible moisture, drip loss and Carver-press (Lucherk et al., 2017). Moreover, PJP values increase with degree of doneness, with rare steaks having the highest PJP, followed by medium, and well done. Moreso, the quality grade has a lesser affect on PJP, with Prime having greater PJP values than Standard, with no differences amongst any other quality grade (Lucherk et al., 2017).

Cooked Color

Myoglobin is the primary protein responsible for meat color, existing in three primary forms: oxymyoglobin, deoxymyoglobin, and metmyoglobin. Fresh meat color is well understood, however cooked color is less widely researched, especially in the evaluation of cooked color of whole muscles. Nonetheless, during the cooking process, all three forms of myoglobin are denatured, which is responsible for dull brown cooked meat color (Hunt et al., 1999; American Meat Science Association, 2012).

Degree of doneness has the primary effect of cooked meat color. According to Prill et al. (2019b) not only does degree of doneness have an effect on L^*, a^*, and b^* values, but time post-cutting and quality grade also have an impact on final cooked color. Moreover, the state of myoglobin of the raw product also impacts final cooked color, as deoxymyoglobin browns at a higher temperature than oxymyoglobin and metmyoglobin (Hunt et al., 1999). The denaturation temperature of myoglobin can alter the final cooked color at a given end point temperature through the redox status of the myoglobin (Hunt et al., 1999; American Meat Science Association, 2012). Changes in the denaturation temperature causes defects such as premature browning and persistent pinking (American Meat Science Association, 2012).

While not widely researched, there is evidence that cooked color can be altered by thawing method. Eastridge (2011) indicated that HW steaks resulted in a higher a* value than REF, while L* and b* values remain unaffected by thawing method. Moreover, within ground product, L* values are increased in COOK in comparison to REF, while b* values have the inverse relationship (Bigner-George and Berry, 2000). Moreover, Obuz (2003), there were no significant differences in *L**, and *a** values amongst COOK and REF steaks, but resulted in COOK samples having lower *b** values in comparison to REF.

Novel thawing methods

Various novel thawing methods have been developed and tested to attempt and negate the quality loss that occurs during freezing and thawing. The primary objective of most novel thawing techniques is to vastly reduce thawing times without sacrificing the quality of products (Makita, 1992; He et al., 2013; Uyar et al., 2015; Guo et al., 2021). Novel thawing methods include ultrasound assisted thawing, ohmic, or electrostatic thawing, high-pressure thawing and radio-frequency thawing.

Ohmic, or high voltage electrostatic thawing, is one of the most widely researched novel thawing methods. This method involved applying an electric field to meat products to generate heat and decreases total thawing time (Fu and Hsieh, 1999; He et al., 2013; Duygu and Umit, 2015). Difference between ohmic and electrostatic thawing methods revolve around the voltage level used. Primarily, ohmic thawing uses a low voltage (< 1 kV), while electrostatic thawing utilizes higher voltage (> 1 kV) (Fu and Hsieh, 1999; Duygu and Umit, 2015). Research thus far indicates that there is little quality influence based on electrostatic field thawing, with no differences in thaw loss at any voltage (4kV, 6kV, 8kV, 10kV), and an increase in cook loss at 8 kV in comparison to control and all other voltages (He et al., 2013). However, the lack of quality improvements and the complexity and cost of ohmic/electrostatic thawing methods have prevented the method from being utilized to scale throughout the meat industry.

Ultrasound assisted thawing utilizes similar method as to that of electrostatic thawing, utilizing the idea that part of the energy released by the ultrasound is converted into heat within the frozen meat, increasing the efficiency of thawing (Guo et al., 2021). While thawing and cooking losses were reduced in meat products thawed using ultrasound assisted thawing, similar issues present itself for ultrasound assisted thawing as do for electrostatic thawing (Guo et al., 2021). The complexity and costs of widely utilizing ultrasound assisted thawing across the industry for minimal quality or efficiency improvements, as well as the lack of uniformity of meat products creating difficulty to use ultrasound assisted thawing in a continuous manner.

High pressure assisted thawing involves using high pressure to alter the freezing point of water in order to rapidly thaw meat products (Makita, 1992; Zhao et al., 1998). Processing and storage under high pressure can change the structure of polypeptide chains, the state of enzymes, and denaturation of proteins (Makita, 1992). It is understood that high pressure thawing tremendously reduces the thaw times of meat products, from ground beef chubs thawing over 12 hours, to less than 0.5 hour, however conversely increases the cook loss of beef thawed under high pressure forces of 280 MPa, but not at 210 MPa (Zhao et al., 1998). Moreover, there are known negative quality impacts of storing meat under high-pressure, including decrease tenderness and consumer acceptability (Frenzel, 2015). However, the process of high pressure treatments requires a large input cost in terms of equipment as a hydrostatic pressure unit is required in order to create the high pressure environment (Zhao et al., 1998) resulting in a lack of application in the beef industry.

Radio frequency assisted thawing is another novel method utilized to decrease thawing times of meat while maintaining quality levels and reducing damage to meat. This method involves using radio-frequency waves to penetrate and distribute energy to evenly heat, and therefore thaw meat products (Uyar et al., 2015). Radio frequency thawing is evidenced to have no negative impact on textural properties of meat, while greatly reducing drip loss in comparison to REF thawed samples (Bedane et al., 2018). However, this system is primarily researched in a batch setting rather than continuous processes that better suit commercial processing (Bedane et al., 2017), creating challenges for practical applications in the meat industry.

Conclusion

Freezing has increased in popularity, and therefore so has our understanding of the effects of freezing on both quality and physiochemical characteristics. However, there is a lack of clarity and understanding of the role thawing has in the quality of frozen/thawed products. There is conflicting research whether faster thawing methods such as microwave or hot water thawing, or slow thawing methods, such as cold water or refrigeration, cause more a higher level of moisture loss through thaw and cook loss. Therefore, it is the intention of this research to evaluate whether the four USDA approved thawing methods, and two methods commonly utilized by consumers has an impact on palatability traits of beef strip steaks.

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Chapter 2- The Effects of Thawing Methods on Quality Attributes and Thawing Time of Beef Strip Steaks

Introduction

Freezing, and therefore the subsequent thawing, of meat products has been a common preservation practice across the meat industry for decades, specifically due to the need to extend the shelf life of beef. More recently, the necessity of freezing meat has increased due to the increased demand for exported frozen beef to Asian countries (Ren et al., 2022; USDA, 2023). Therefore, there has been a vast amount of research investigating the quality and physiochemical changes that occur during the freezing process (Rahelić et al., 1985a; Rahelić et al., 1985b; Wheeler et al., 1990; Lagerstedt et al., 2008; Leygonie et al., 2012; Kim et al., 2015; Qian et al., 2022; Beyer, 2023), while the thawing process has not received the same level of attention.

It is understood that the majority of damage occurs at a cellular level during the freezing process(Rahelić et al., 1985a; Rahelić et al., 1985b; Qian et al., 2022). The cause of damage is primarily attributed to ice crystal growth between muscle fiber, damaging cell membranes (Rahelić et al., 1985b; Qian et al., 2022). This process causes the purge of frozen samples to be greater than those of fresh, never frozen beef (Wheeler et al., 1990; Lagerstedt et al., 2008; Beyer, 2023). Moreover, the damage to muscle fibers caused by ice crystal formation has been shown to cause an increase in tenderness of frozen samples, while decreases the juiciness of frozen steaks (Beyer, 2023). Therefore, while there is an economic loss through the damage caused by ice crystals and resulting purge loss of frozen steaks, there are both negative and positive quality characteristics that occur due to freezing.

Thawing is a necessary process of freezing meat in order to be usable for consumers and food service. The USDA defines four methods of thawing as safe: thawing in refrigeration, thawing in cold water, microwaving, and cooking from a frozen state (USDA-FSIS, 2013). These methods are determined as safe due to the low likelihood that meat products enter the "temperature danger zone" (40°F-140°F) during the thawing process, or, in the case of microwave thawing, are recommended to be cooked directly after thawing to prevent the temperature remaining in the temperature danger zone (USDA-FSIS, 2013). However, consumers commonly use alternative methods, such as thawing on the counter, and thawing in hot water to thaw meat (Benli, 2015). While there is a vast amount of literature exploring the changes caused by freezing, the same attention has not been paid to understanding how thawing processes can affect the quality of beef. There is limited literature exploring thawing methods for palatability and applied measurements of quality. Published studies have typically compared a particular thawing method to thawing in the refrigerator rather than a complete analysis of the USDA approved methods and common consumer thawing methods. Moreover, there are conflicting theories as to whether faster thawing methods, such as thawing in the microwave or in hot water, increase or decrease the thawing loss of samples. Eastridge and Bowker (2011); Hergenreder et al. (2013) and Bogdanowicz et al. (2018) all found that quicker thawed samples resulted in a lower thaw loss, while Zahir (2021) and Gonzalez-Sanguinetti et al. (1985) suggested that slower thawing methods result in reduced thaw loss. Therefore, conflicting literature leaves room for further understanding of thawing methods effect on moisture loss. Additionally, there is no literature outlining and comparing the rate, time, and thawing curves of different thawing methods. Nonetheless, there is a lack of a complete analysis of various thawing methods on palatability characteristics.

Therefore, the objective of the current study was to evaluate palatability traits of beef strip loin steaks thawed utilizing the four USDA recommended thawing methods: refrigeration, microwave, thawing in cold water, and cooking from frozen; as well as two methods commonly utilized by consumers: thawing on the counter, and thawing in hot water, as well as evaluate thawing characteristics of each method.

Materials and Methods

The approval for all protocols utilizing human subjects for sensory evaluation was completed by the Kansas State University Institutional Review Board (IRB #7440.8, October 2022).

Sample Selection

Paired USDA Low Choice beef strip loins (IMPS # 180) were collected from a midwestern beef processing facility (*n* = 15 pairs; North American Meat Institute, 2014). In addition, 6 USDA Low Choice strip loins were collected for thawing curve development. The carcass characteristics were collected by the Kansas State University research group for the 15 paired loins (marbling score, lean maturity, skeletal maturity, ribeye area, preliminary fat thickness, adjusted fat thickness, hot carcass weight, kidney pelvic and heart fat; Appendix A). The subprimals were vacuum-packaged and transported under refrigeration (< 40° F) to the Kansas State University Meat Laboratory.

On postmortem day 11, loins were fabricated in 2.5-cm thick steaks. The paired loins were cut into six sections of 4 steaks each, with 3 sections per individual loin. Sections were randomly assigned to one of four USDA recommended thawing treatments: thawing in the refrigerator (**REF**), thawing in cold water (**CW**), thawing as cook method (**COOK**), thaw in the microwave (**MIC**); and two methods commonly utilized by consumers: thawing on the counter

(**CT**), and thawing in hot water (**HW**). Each steak within the section was assigned to either: consumer sensory panel, trained sensory panel, lab assay, or Warner-Bratzler Shear Force (**WBSF**). Steaks designated for WBSF were also utilized to calculate pressed juice percentage (**PJP),** slice shear force, cooked color, thaw loss, and cook loss. Steaks designated for consumer sensory panels were also utilized to collect water-holding capacity data. All steaks were assigned a random four-digit number and vacuum-packaged. Steaks were then aged an additional 10 days, for a total of 21 days of aging. then frozen in a commercial freezer (-20º C) until thawing and analysis.

Loins designated for thaw curve testing were fabricated into 2.5-cm steaks on day 11 of aging. Steaks were randomly assigned a thawing method and a four-digit number. Temperature probes (Q-Series Type K, American Fork, UT.) were inserted, and steaks were vacuum-packaged and frozen (-20ºC) until thawing and analysis.

Thawing Procedures

For each thawing method, the internal temperature was targeted at 0ºC (±1º C). A pilot study utilizing each thawing method was conducted prior to steak thawing for determination of the approximate amount of time steaks would need with each method for complete thawing. Steaks designated REF were held at 2-3° C in a refrigerator (Turbo Air, M3R47-2-N, Long Beach, CA) throughout thawing. Steaks designated for thawing in CW were placed in individual plastic containers of 2-3ºC water for 24 h. The steaks in containers of water were placed in a refrigerator (Turbo Air, M3R47-2-N, Long Beach, CA) to maintain temperature throughout the thawing process. Steaks designated for COOK were immediately cooked upon removal from the freezer, while still in a frozen state. Thawing power level and time for MIC were determined by a pilot study, with the target being steaks thawed completely, while the center of the steak still cool, with minimal browning. The resulting procedure was microwaving steaks for 210s at 50% power in a retail microwave (Amana, Over-The-Range Microwave, Benton Harbor, MI.), rotated, and then microwaved for an additional 180 s at 50% power. If steaks were not completely thawed, they were microwaved for 30 to 60 s at 50% power to complete thawing. The goal of this was to create a similar result to that of a defrost setting on a retail microwave. Steaks designated for CT were thawed on plastic trays at 17-20º C for approximately 5 h, or until internal temperature reached 0ºC. Steaks designated for thawing in hot water were thawed in 40ºC water for 20 minutes (±2 minutes) until internal temperature reached at least 0ºC. A sous vide machine (Anova Precision Cooker, San Francisco, CA.) was utilized to maintain consistent water temperature throughout the thawing process

Thawing Curves

Temperature probes (Q-Series Type K, American Fork, UT.) were inserted into thawing curves steaks prior to packaging and freezing. The probes were connected to temperature data loggers (Therma Data® 4 Channel Data Logger; American Fork, UT.) immediately upon removal from the freezer and thawed according to their defined method. REF and CW data loggers were set to record temperatures every 30 min, and probes were removed after 24 h, or when internal temperature reached 0°C. CT data loggers were set to record temperature every 10 min and removed after 5 h, or when internal temperature reached 0°C. HW data loggers were set to record temperature every 30 s and removed when internal temperature reached 0°C. Thawing as cook method and microwave methods were not included in thawing curve data collection due to the inability to safely insert probes and measure temperatures within these cooking methods.

Consumer sensory panels

Untrained consumer panelists (*n* = 120) from the Manhattan, KS area were recruited and compensated for their participation. 5 panel sessions took place at Kansas State University in a large lecture-style room with 24 panelists each under fluorescent lighting. The panels lasted approximately 1 hr.

Each consumer was provided with a tablet (Lenovo TB-8505F, Morrisville, NC) to fill out a digital survey (Qualtrics Software, Provo, UT.). Surveys consisted of a demographic survey, purchasing motivator survey, and 6 sample evaluation surveys. The demographic survey consisted of questions related to gender, age, household size, income level, ethnicity, education level and palatability preferences. Also, consumers utilized one-hundred-point scale sliders in response to the importance of various product and animal characteristics when purchasing beef, such as animal welfare, antibiotic use, etc. with zero representing extremely unimportant and one hundred representing extremely important. One-hundred-point sliders were utilized to rate juiciness, tenderness, flavor liking, and overall liking, where 0 represented extremely dry, extremely tough, dislike extremely; 50 represented neither juicy nor dry / tough nor tender / like nor disklike; and 100 represented extremely juicy, extremely tender, and like extremely. Moreover, consumers answered a question determining if the sample was acceptable for juiciness, tenderness, flavor, and overall (yes/no). Lastly, consumers rated the sample on their perception of the quality of the sample, as unsatisfactory, everyday quality, better than everyday quality, or premium quality.

Consumers were provided with a napkin, fork, water cup, expectorant cup, apple juice and unsalted crackers. The apple juice and unsalted crackers were consumed as a palate cleanser between samples. Prior to beginning, consumers were verbally given instructions in regard to the tablet, ballot, testing procedures and the utilization of palate cleansers.

Steaks were thawed according to individual treatment prior to cooking. Samples were cooked to a medium degree of doneness (71ºC) on a Cuisinart Griddler Deluxe clam-shell style grill (Stamford, Connecticut, USA). Peak temperatures were verified and recorded using a thermometer (Thermopen mk4, Salt Lake City, UT). For COOK steaks, temperature probes were inserted during the cooking process immediately upon being thawed. The *longissimus* was cut into pieces (2.5-cm thick × 1-cm × 1-cm cuboids) and two pieces were served immediately to consumers. Consumers were fed six samples, one of each treatment, from the same carcass in a random order. 1 piece (2.5-cm thick × 1-cm × 1-cm) was removed and utilized for cooked water holding capacity assay.

Trained sensory panels

Panelists from Kansas State University were trained according to the American Meat Science Association (**AMSA**) Sensory Guidelines (AMSA, 2015). Panelists were trained in a total of four 30 min training sessions within one week prior to panels using anchors and methods described by Lucherk et al. (2016) and Vierck et al. (2019). A total of 15 trained panel sessions with each panel consisting of eight trained panelists were performed. Steaks were thawed according to their specific thawing method and cooked as described for consumer evaluation. Each panelist was served six samples, 1 of each treatment, from the same carcass in a random order.

Panelists were provided with a napkin, fork, water cup, expectorant cup, gala apple slices and unsalted crackers. Moreover, panelists were provided with a tablet (Lenovo TB-8505F, Morrisville, NC) to fill out a digital survey (Qualtrics Software, Provo, UT.). The survey consisted of 7 questions, evaluated on 100-point line scales for initial juiciness, sustained juiciness, myofibrillar tenderness, connective tissue amount, overall tenderness, beef flavor intensity, and off-flavor intensity. Verbal anchors were at 0, representing extremely dry, extremely tough, none, and extremely bland, 50 as the midpoint representing neither dry nor juicy, and neither tough nor tender, and 100 representing extremely juicy, extremely tender, extremely abundant, and extremely intense. Moreover, if no off flavor was detected, a box labeled “not applicable” was available to select. Lastly, panelists were given a “warm-up” sample prior to beginning to prevent panelist drift.

Thawing and cooking loss

Steaks designated for shear force were thawed according to their individual treatment protocol. To calculate thaw loss for HW, CW, REF, and CT steaks, weights were taken while still in the package, raw steak removed from the package, patted dry with a paper towel and weighed. The packaging and tag were dried and weighed, and total thawing loss was calculated. For MIC steaks, a frozen steak was weighed with no packaging and blotted dry with a paper towel post-thawing in microwave and reweighed, and thawing loss calculated. COOK steaks did not have thaw loss data. Steaks were cooked as described for consumer panels, and peak temperatures recorded. To calculate cooking loss, the raw steak weight from thawing loss calculations was used, and a cooked weight taken after peak temperature was recorded. Total loss was calculated as the moisture lost from thawing and cooking, divided by the raw steak weight.

Slice Shear Force

Slice Shear Force (**SSF**) was determined using steaks identified for Warner-Bratzler Shear Force similar to the procedure utilized in Shackelford et al. (1999). Immediately following the peak temp recording, a cut was made 2-cm from the lateral end of the *longissimus lumborum*, followed by a second cut 5-cm from the first cut in order to determine muscle fiber orientation. A 1-cm x 5-cm piece was sliced at a forty-five-degree angle parallel to the muscle fibers with a double-bladed knife. The warm sample was then sheared using the SSF machine (Model GR-152; Tallgrass Solutions, Manhattan, KS). The slice was sheared perpendicular to the muscle fiber in the approximate middle of the slice, and the peak force recorded.

Pressed Juice Percentage

Pressed juice percentage was determined using similar methods as in Lucherk et al. (2017). A 1-cm slice was taken immediately medial to the slice shear force sample and cut parallel to the muscle fiber in three 1-cm wide pieces. Each piece was then placed on a pre-weighed sheet of filter paper (Fisher brand Filter Paper P8, 12.5 cm, Pittsburg, PA), a weighed filter paper set on top, weighed, and compressed (Instron Model 5569, Canton MA) at 8.0 kg was calculated as in Lucherk et al. (2017) The three samples were averaged for each steak to result in the final PJP value.

Instrumental cooked color

Cooked instrumental color (*L**, *a**, *b**) was obtained from steaks designated for WBSF following the AMSA Color Guidelines (King et al., 2023). Immediately following the removal of the 1-cm x 5-cm piece utilized for SSF, a timer was set for 3 min to allow for cooked color to bloom. The cut surface immediately lateral to where the piece for slice shearing was cut was utilized for cooked color measurements. Three scans were taken of each piece using a Hunter Lab Miniscan spectrophotometer (Illuminant A, 2.54-cm aperture, 10° observer; Hunter Associates Laboratory, Reston, VA) and averaged for final *L**, *a** and *b** values.

Warner Bratzler Shear Force

After SSF and PJP, the remainder of samples were refrigerated (2-4ºC) overnight prior to WBSF measurement. The AMSA Sensory Guideline (AMSA, 2015) protocol was utilized. Six cores (1.27 cm diameter) were removed and sheared utilizing an Instron (Instron Model 5569, Canton MA) perpendicular to the muscle fiber with a crosshead speed of 250mm/minute and a load cell of 100 kg. The peak force was recorded for each core. The values for each of the six samples were averaged and used for statistical analysis.

Fat and moisture analysis

Samples designated for lab assay were thawed according to individual treatment protocol, except for COOK steaks, in which no lab data was collected. Steaks were cut into approximately 1-cm cubes, submerged in liquid nitrogen, and homogenized using a four-blade blender (Model 33BL 79, Waring Products, New Hartford, CT) and placed in sterile sample bags and stored in a -80º C freezer until analysis. Moisture percentage was determined by the oven drying method as outlined in the Official Methods of Analysis (AOAC, 1995). Fat content was determined by a modified Folch method (Folch et al., 1957). In short, duplicate 5 g samples were weighed, and added to 50 ml centrifuge tubes. Water, choloroform, and methanol were added, and the mixture shaken for 4 min, then centrifuged for 10 min at 5000 rpm. The resulting supernatant was removed, and a 4 ml samples of the chloroform layer was removed and added to pre-weighed glass tubes. Heating stones and nitrogen gas were utilized to evaporate samples, and fat was calculated utilizing the weight of dried sample in the glass tube as a percentage of the original sample.

Lipid oxidation

Lipid oxidation was determined using the thiobarbituric reactive substances assay (**TBARS**) as outlined by Dahmer et al. (2022). Approximately 0.3 g of powdered sample was combined with 1.4 ml of thiobarbituric acid/trichloroacetic acid (**TBA/TCA**) and 0.1 ml butylated hydroxytoluene (**BHT**), homogenized, then centrifuged (D2400 Homogenizer, Benchmark Scientific, Edison, NJ.). Supernatant was pipetted out of the tube, covered with aluminum foil, and incubated at 70° C for 30 min. The samples were cooled for 5 min in an ice bath. Lastly, 0.2 ml of MDA concentration standards and supernatant from each sample were transferred to a 96 well plate and read in the spectrophotometer at 532 nm. A standard curve was developed, and MDA concentration was calculated and expressed at µM malonaldehyde.

Water holding capacity

Steaks designated for consumer panels were utilized for cooked water holding capacity analysis. The water holding capacity protocol was based on a protocol from that of Lucherk et al. (2017) and altered slightly. One cube (2.5 cm x 1 cm x 1 cm) was taken from the cooked consumer steak, weighed, and placed in a 15 ml centrifuge tube with homogenization beads. The tube was then centrifuged at 900 x g for 10 min. at 4°C, and the meat cube removed from the tube and reweighed. Expressible moisture and water holding capacity were calculated as described by Pietrasik and Janz (2009).

Statistical analysis

The PROC GLIMMIX procedure of SAS (SAS Institute Inc., Cary, MC) was used for statistical analysis, with the Kenward-Roger adjustment for denominator degrees of freedom. Data were analyzed as a completely randomized block design, with carcass serving as the blocking factor. Steak was utilized as an experimental unit and peak temperature served as a covariate for all cooked analyses. An ɑ of 0.05 was considered significant for the comparison of all treatments.

Results

Consumer demographic and purchasing motivators

The demographic information of the 120 consumer panelists that participated in the consumer panels is shown in Table 2.1. Panelists were predominantly female (58.5%) and married (67.5%) rather than male (41.5%) and single (32.5%). Moreover, panelists were predominately below thirty years of age (63.3%) and Caucasian (86.6%), and primarily had at least some college education (78.3%). The household income of participants was relatively bimodal, where 33.3% of participants had an annual income of less than $25,000, and 40% of participants with a household income of greater than $100,000. When asked which palatability factor was most important when consuming beef, flavor was the most common response (56.7%), followed by tenderness (33.3) then juiciness (10.0). However, when asked what trait they experienced the most variability with, tenderness was the most common response (52.5%), followed by juiciness (24.2%) then flavor (23.3%), Moreover, the most common degree of doneness preference was medium-rare (43.3%), followed by medium (25.0), while most consumers consumed beef between 1-3 times per week (43.3%) and 4-5 times per week (35.0%).

Consumers were presented with 17 beef traits in and asked to rate the importance of each trait in terms of purchasing motivation. Results of this are shown in Table 2.1 "Price" was rated more (P <0.05) important than all traits other than "size, weight and thickness", "color", "USDA Grade", and "marbling" of which were not different (P > 0.05). Moreover "size, weight and thickness", "color", "USDA Grade" "marbling" were also rated higher (P < 0.05) than all traits except for "nutrient content" and "price". Additionally, "brand of product" and "natural or organic claims" were rated the least ($P < 0.05$) important of all traits other than "animal fed a grass-based diet," "packaging," and "animal fed a grain-fed diet".

Consumer sensory evaluation

There were no differences ($P > 0.05$) among all thawing methods for any consumer palatability traits in the current study, reported in Table 2.3. However, while there were no differences among thawing methods, all mean sample ratings were greater than 56 for all palatability traits, indicating that consumers liked the samples or considered the traits on the positive end of the scale. Consumers were asked to rate samples as acceptable or unacceptable, and resulting data is reported in Table 2.4. Moreover, all thawing methods were similar ($P > 0.05$) for percentage of samples rated as acceptable, while all samples were rated as 80.0% or more acceptable for juiciness, tenderness, flavor, and overall acceptability. Lastly, means for perceived quality level of various thawing methods are presented in Table 2.5. All thawing methods were similar ($P > 0.05$) for all levels of perceived quality and were most commonly seen as everyday quality.

Trained panelist evaluation

As a whole, thawing method has a minimal impact on trained panelist evaluation. Trained panelist least squares mean for palatability characteristics are presented in Table 2.6. All thawing methods were similar ($P > 0.05$) in terms of initial juiciness, sustained juiciness, and connective tissue. In terms of myofibrillar tenderness, CW and REF were rated higher ($P < 0.05$) than COOK steaks, while CT, HW, and MIC steaks were similar ($P > 0.05$) to all thawing methods. Similarly, CW and REF steaks were rated higher ($P < 0.05$) for overall tenderness than COOK and MIC steaks while CT and HW were similar ($P > 0.05$) to all treatments. Additionally, COOK samples were rated higher ($P < 0.05$) than all treatments for flavor intensity.

Instrumental Quality Measurements

Results for instrumental quality measurements are shown in Table 2.7. All thawing methods were similar ($P > 0.05$) for cooked L^* values, however CT steaks had higher ($P < 0.05$) a^* and b^* values that COOK, and MIC steaks, while CW, HW, and REF steaks have higher ($P < 0.05$) a^* and b^* than MIC steaks. Moreover, Warner-Bratzler shear force and slice shear force for all thawing methods were similar ($P > 0.05$). Moreover, MIC had the highest ($P < 0.05$) cook loss, followed by COOK, followed by all other treatments (MIC > COOK > CT = HW = CW = REF). When comparing MIC to other treatments, cook loss was reduced by 4.0 % for REF, 4.8% for CW, 4.4% for CT, 5.0% for HW, and 1.3% for COOK. In terms of thaw loss, MIC and HW were similar ($P > 0.05$) but rated higher ($P < 0.05$) than CT, CW and REF (MIC = HW > CT = CW = REF). Thaw loss increased from as low as 0.8% for REF, to 3.7% for HW and 4.2% for MIC. For total moisture loss, MIC, HW and COOK were not different ($P > 0.05$) but had a higher ($P < 0.05$) total moisture loss than CW, CT, and REF (MIC = HW = COOK > CT = CW = REF). When comparing total loss to MIC (23.5%), moisture loss was lower by 7.5% for REF, 8.1% for CW, 7.4% for CT, 5.4% for HW, and 5.2% for COOK. However, there was no PJP differences ($P > 0.05$) among all treatments. Moreover, CW, REF and HW steaks had a higher ($P < 0.05$) percent moisture than COOK while CT was similar to all treatments. There were no differences ($P > 0.05$) in lipid oxidation amongst all treatments. Additionally, COOK had higher ($P < 0.05$) cooked expressible moisture than CT, CW, and REF, while MIC and HW were similar to all treatments. Similarly, CT, CW and REF had a higher ($P < 0.05$) cooked water holding capacity than COOK, while MIC and HW were similar to all treatments.

Thawing Rate, Time and Temperature

Thawing rate, time and temperature data is presented in Table 2.8. HW had the highest ($P < 0.05$) thawing rate, followed by CT, and REF and CW, which were not different (HW < CT < REF = CW). Similarly, HW had the least ($P < 0.05$) minutes to thawed, followed by CT, then CW, then REF (HW < CT < CW < REF). Moreover, temperatures at times prior to thawing, CW was at a lower ($P < 0.05$) temperature than REF from thirteen hours to six hours prior to thawing but were the same ($P > 0.05$) temperature from five hours until thawed. Additionally, CT samples remained at a lower ($P < 0.05$) temperature than CW or REF from five hours to two hours prior to being thawed and remained at a lower ($P < 0.05$) temperature than REF at one and a half hours prior to thawing. REF, CT and CW were similar ($P > 0.05$) in temperature from one hour to the time of thawing. HW was at a lower ($P < 0.05$) temperature than CT at ten minutes prior to being thawed.

Discussion

Consumer preferences

Consumer purchasing motivators give context to consumer’s priorities when purchasing and consuming beef. Previous published literature has determined color, price and size are consistently rated the highest for importance when purchasing beef (Lucherk et al., 2016; Vierck et al., 2018; Olson et al., 2019; Farmer et al., 2022). This is similar to the current study, with price, size, color, USDA Grade, and marbling rated the most important. Moreover, brand of product, natural or organic claims, animal diet, and packaging have been consistently the least important purchasing motivators (Lucherk et al., 2016; Vierck et al., 2018; Olson et al., 2019; Farmer et al., 2022), similar to the results of the current study.

The most important palatability trait to consumers when consuming beef steaks in recent research, including the current study, has been consistently flavor, followed by tenderness, then juiciness (Drey et al., 2019; Beyer et al., 2021; Hernandez et al., 2023). However, consumers in the current study found the most variation in tenderness. Table 2.9 compiled standard error measures of twenty studies evaluating juiciness, tenderness, flavor, and overall liking by consumer panelists. They used standard error to evaluate the variability within each palatability trait, with a higher standard error indicating more variability within the trait. They found tenderness had the highest, or equal to the highest variability within 65% of studies, followed by overall liking (15%), juiciness (10%) and flavor liking (10%). Therefore, it is apparent that consumers view flavor as the most important aspect of beef palatability, while the current study, and compiled consumer data from previous works, indicate consumers experience the most variability in tenderness.

Effect of thaw method on palatability

There is limited research evaluating the effects of thawing method on overall palatability. The current study found limited differences among thawing methods for tenderness, juiciness, flavor, overall liking, the percentage of samples rated acceptable, and perceived level of quality. Similar results were reported by Kim et al. (2013), who found few differences in trained sensory evaluation of appearance, flavor, texture, taste, and overall quality for steaks thawed in the refrigerator (4 ± 1° C; 164.9 h), countertop (25° C; 5 h), cool water (15° C; 1.5 h) and microwave (1440 s). Also, Bogdanowicz et al. (2018) found no palatability differences among steaks thawed in the refrigerator (4° C) and on the counter (20° C), which is also in agreement with the current study. In a separate study, Zahir (2021) found no differences in palatability among steaks thawed in the refrigerator (5 ± 1° C; 22 h), countertop (25° C; 2.5 h), and microwave (300 s) for flavor, tenderness, juiciness, and overall acceptability. This differs slightly from the current study, in which thawing in the refrigerator was rated higher for overall tenderness than thawing in the microwave. However, in Zahir (2021), total microwaved time was 23.1% less than the current study (390 s). An increase in power level has been shown to shorten total microwave thawing time, as well negatively impacted tenderness (Kim et al., 2011). Therefore, the likely increase in power level of in Zahir (2021), as well as a limited number of replications (*N* =5) in their study, are the potential causes of lack of tenderness differences found in Zahir (2021).

In an older study, Obuz and Dikeman (2003) evaluated thawing steaks in the refrigerator (4° C) and cooking from frozen for palatability traits. They found no differences for connective tissue, juiciness, flavor intensity, and overall tenderness, while finding refrigerator thawed steaks were more myofibrillary tender than steaks cooked from frozen, similar to results of the current study. However, Obuz and Dikeman (2003) did not find an increase in flavor intensity of cooked from frozen samples as found in the current study. Obuz and Dikeman (2003) utilized an electric-belt grill set at a surface temperature of 93°C, whereas the current study utilized clamshell-style griddle set at a surface temperature of 177° C. Other studies have reported as cooking surface temperature increases, beef flavor attributes such at beef identification, and brown/roasted flavors increase (Wall, 2017). Therefore, the discrepancy between beef flavor results in the current study and Obuz and Dikeman (2003) may be a result of the variation in surface temperature of cooking methods.

Across multiple studies, including the current study, there are limited palatability differences when thawing steaks in the refrigerator, in cold water, in hot water, and on the counter. Moreover, there are negative tenderness attributes detected by trained panelists of steaks thawed in the microwave and cooked straight from frozen, although those tenderness differences are not detected by consumer panelists. Therefore, when evaluating the effects of thawing method on palatability, it can be concluded that thawing method has a minimal impact on overall palatability of beef steaks.

Effects of thawing on instrumental quality measures

There is limited published research on the effects of thawing on cooked color. Obuz and Dikeman (2003) found steaks thawed in the refrigerator (4° C) had no L^* and a^* value differences, and higher b^* values than steaks cooked directly from frozen. This differs from the current study, which found no instrumental color differences between COOK and REF. However, Obuz and Dikeman (2003) allowed color to bloom for 3 h at 4° C prior to taking color measurements, rather than the 3 min utilized in the current study. The shorter bloom time used in the current work was intended to represent the short amount of time between when a consumer first cuts the steak and the time they would consume it. Cooked color has been shown to bloom and change over a short period of time, specifically in minutes (Prill et al., 2019b), however it is largely unknown how cooked color changes over several hours. However, the work by Obuz and Dikeman (2003) indicated that observed differences in redness (a^*) and lightness (L^*) may be stabilized through longer post-cooking blooming periods.

Prill et al. (2019b) defined expected L^*, a^*, and b^* values for strip loins steaks cooked to various degrees of doneness at various bloom times. At a medium degrees of doneness, and 3 min. post cutting, Prill et al. (2019b) found L^*, a^*, and b^* values to be approximately 52, 19, and 20 respectively. In the current study, CW, REF, CT, COOK, and HW steaks were similar to those values. However, MIC steaks had a lower mean a^* value of 16.4, which is more closely in line with the a^* value associated with a well-done degree of doneness published in Prill et al. (2019b). Moreover, Prill et al. (2019a) established that the preferred degree of doneness and actual perceived degree of doneness by consumers impact the overall palatability of samples. Therefore, the decreased a* and *b** of MIC samples, could cause samples to appear at a higher degree of doneness at a similar temperature, and should be considered by consumers and food-service establishments who use MIC as their thawing method.

Objective tenderness measurements of thawing methods have been previously evaluated by numerous authors who have all reported similar results. Obuz and Dikeman (2003) found steaks cooked directly from the frozen state and steaks thawed in the refrigerator (4° C) did not differ in WBSF. Moreover, Eastridge and Bowker (2011) found no WBSF differences in steaks thawed in the refrigerator (3-4° C; 18 – 20 h), thawed in room temperature circulating water bath (20° C; 20 ± 5 min), and thawed in a circulating hot water bath (39° C; 11 ± 5 min). Additionally, Bogdanowicz et al. (2018) found no WBSF differences among thawing in the refrigerator (4° C) and on the counter (20° C). All these results align with those in the current study, where no differences occurred among WBSF or SSF. This further aligns with the consumer panelist data, where consumers found no tenderness differences among all treatment methods. However, trained panelists found COOK and MIC lower in overall tenderness than CW and REF.

Differences in lipid oxidation were evaluated by Zahir (2021) for steaks thawed in the refrigerator (5 ± 1° C; 22 h), countertop (25° C; 2.5 h), and microwave (300 s). They found steaks thawed in the microwave to have the highest thiobarbituric acid concentration, followed by thawed on the countertop, then steaks thawed in the refrigerator (microwave > countertop > refrigerator). This contradicts the current study, where no differences in lipid oxidation were found. However, a different measure of malondialdehyde (MDA) / kg of muscle was utilized by Zahir (2021), lacking an addition of an antioxidant. It has been shown that a lack of an antioxidant in thiobarbituric acid assays can result in overestimated MDA concentrations (Garcia et al., 2005). Furthermore, the longer microwave time in the current study indicates that steaks were thawed at a lower power level than utilized in Zahir (2021). It has been shown that microwaving meat as a thawing method result in uneven thawing, and that unevenness increases as the microwave power level increases (James et al., 2017). This unevenness has a likelihood of portions of the steaks reaching and remaining at high temperatures, while other portions remain frozen. The shorter time, higher power method utilized in Zahir (2021) could have resulted in portion of the steak beginning browning during thawing, which would result in increased lipid oxidation. The current study utilized a low power level to avoid the cooking process beginning in the microwave, and a rest time after prior to being cooked for temperature to equilibrate throughout the steak. Therefore, the likelihood of the final MDA concentrations in Zahir (2021) being overestimate due to method, as well as a variation in power level and microwave time amongst studies, likely explain the differences in results from the current study.

Effects of thawing on moisture loss

There is a wide variety of conflicting literature on the effect of thawing method of moisture loss of steaks, specifically thawing loss. Some authors have reported thawing using an increased temperature, such as thawing in the microwave or hot water, rather than in cold water or the refrigerator, increased thawing loss (Gonzalez-Sanguinetti et al., 1985; Zahir, 2021); supporting the results of the current study, in which HW and MIC had a higher thawing loss than CT, CW, and REF. In another study, Hergenreder et al. (2013) found conflicting results, in which a more extended thawing time resulted in a higher thawing loss. However, in this study, the slow thawing method utilized included thawing at 0°C over a 14 d period, while the “fast thawing method was held in < 12° C water bath for 21 h (Hergenreder et al., 2013).

Thawing at a temperature as low as 0°C has been show to result in repeated formation and thawing of ice crystals (Small et al., 2011). Repeated thawing and freezing of meat is known to cause further damage to muscle fibers thus negatively impacting thawing loss of meat (Cheng et al., 2019). Therefore, the slow thawing method utilized within Hergenreder et al. (2013) may have further damaged muscle fibers and caused an increase in overall thawing loss, thus contributing to their results.

Outside of the aforementioned studies, there is variation surrounding thawing loss results across multiple studies. Eastridge and Bowker (2011) found that thawing in the refrigerator resulted in the highest thawing loss, followed by thawing in hot water, then room temperature water (refrigerator > hot water > room temperature water), although the steaks thawed in hot water and room temperature water were placed in an ice-slush bath (1-2° C) immediately upon thawing. Additionally, Kim et al. (2013) found thawing steaks in the microwave to have the lowest thawing loss, with steaks thawed on the counter had the highest thawing loss, with no differences among thawing in the refrigerator, and in cold water. Although, Kim et al. (2013) utilized beef frozen 2 days post-harvest, and packaged in 5 x 7 cm cubes rather than entire steaks.

Thawing loss changes are primarily a concern in total economic loss of beef steaks, via weight lost during the thawing process as purge. In the current study, thawing loss consistently increased as thawing rate increased, with REF, CW and CT having the lowest thawing loss; 0.8%, 0.9%, and 1.2% respectively, while HW and MIC thaw loss is significantly higher at 3.7% and 4.2%. Therefore, while there is variation among published literature in how thawing method impacts thawing loss, the current work provides the most context for how thawing method affects thawing loss, utilizing the most complete array of thawing methods, and therefore temperatures and rates

When evaluating the cook loss among different thawing method, Obuz and Dikeman (2003) found samples thawed in the refrigerator (4° C) had a lower cooking loss (27.03%) than steaks cooked directly from the frozen state (32.96%), supporting results from the current study. Although, the current study had far lower total cooking loss, were REF had a cook loss of 15.4% and COOK having a cooking loss of 18.1%, although could be attributed to being cooked via griddle rather than electric belt. Moreover, Zahir (2021) found steaks thawed in the microwave had the highest cooking loss at 39.3%, followed by samples thawed on the counter (34.5%) which were higher than steaks thawed in the refrigerator (27.9%). This supports the current studies results of MIC having a higher cook loss than CT or REF, while the current study found CT and REF to be similar for cook loss, although overall cook loss was much lower in the current study. Moreover, countertop thawed steaks in Zahir (2021) were thawed for 50% less time than the current study, while target internal temperature for thawing was 10° C. Furthermore, cooking loss was performed by cooking a 10 g sample, wrapped in foil, in a water bath, to an internal temperature of 75° C. The increase in cooking temperature likely caused the increase in cook loss in Zahir (2021), as well as the minimal differences in cooking loss results.

Published literature evaluating objective juiciness measures for thawing methods outside of thaw and cook loss is sparse. Zahir (2021) evaluated water holding capacity for various thawing methods. Samples thawed in the refrigerator had the highest water holding capacity, followed by countertop, then microwave. The current study found no differences among CT, MIC and REF. However, the current study performed a cooked water holding capacity assay, while Zahir (2021) utilized raw samples.

Lucherk et al. (2017) evaluated a PJP, carver press, and a variety of other objective juiciness measure for their accuracy in predicting consumer juiciness ratings. It was found that PJP, along with cook loss, and protein percentages relate to consumer juiciness ratings most closely Lucherk et al. (2017). In the current study, there were no differences in PJP values among all treatments. Furthermore, there were no consumer juiciness differences rated among all treatments. The lack of differences in both consumer and objective measurements of juiciness, along with the alignment of PJP as a predictor of consumer juiciness ratings further evidences the lack of juiciness difference among the thawing methods.

Across all quality measurements, moisture loss, particularly thawing and cooking loss, are widely the most affected by thawing method. It is evident that previously published literature has found conflicting results within these attributes. However, the current study painted the most complete picture of the effects of thawing method on beef quality, indicating that fast thawing methods, such as thawing in the microwave and in hot water, negatively impact the thawing, cooking, and total moisture loss of beef steaks.

Thawing characteristics

Published literature evaluating thawing rates, times, and thawing curves of various thawing methods are limited. The difference in time to thaw, and thawing rate among samples can be affected by both the temperature and environment that meat is placed in. Samples thawed in water have been shown to thaw faster due to the higher heater transfer ability of water in comparison to air (Li et al., 2020). In the current study, REF and CW samples were thawed at the same temperature, while either on a tray, or submerged in water. The total thawing time for REF was 1.4x greater than CW, further evidencing the increase in heat transfer by water. Additionally, multiple studies have evidenced higher thawing temperatures indicated a reduction total thawing time, and thus increased the rate of thawing (Yau and Huang, 2000; Eastridge and Bowker, 2011; Kim et al., 2013). This aligns with results in the current studies, where when thawed in the same environment (CW and HW thawed in water; REF and CT thawed on a tray) the increased temperature resulted in increased thawing rates and decreased total thawing time. HW steaks thawed over 61x faster than CW steaks in terms of thawing time, while CT steaks thawed over 3x faster than REF steaks.

The thawing curves of REF and CW followed a similar pattern, where temperatures rose at a decreasing rate, plateauing between -2° and -1°C. The temperature of CT also rose at a decreasing rate, but plateaued for a far shorter period than CW and REF. This plateau in temperature rise for REF, CW, and CT between -2° and -1° C is likely caused by the phase change occurring at that temperature, as the freezing point of meat is -2.2° C (USDA, 2013). The melting of ice crystals back into the liquid state has been evidenced to occur in layers over time, causing the lag in temperature rise in that range (Kiani and Sun, 2011). Therefore, the temperature during REF, CW, and CT likely increased rapidly at the beginning of thawing to near the freezing point, then remained at that temperature during ice crystal melting, followed by a more rapid temperature increase post ice crystal melting.

Conclusion

As a whole, thawing method has minimal impact on the overall quality of beef steaks. Consumers and trained panelists alike detected minimal differences in palatability among all thawing methods tested. Nonetheless, a notable thaw loss increase in steaks thawed in the hot water and microwave have a negative economic impact and reduced fresh meat yield. While there is other published literature evaluating thawing methods, few utilize more than three thawing methods, nor complete as complete of array of both objective and subjective tests to determine the effect of thawing on beef quality. Still, thawing steaks in hot water and on the counter are not considered safe methods of thawing by the USDA, with concerns for potential bacterial growth. Therefore, consumers and food service establishments should utilize their preferred method when thawing beef steaks, while taking safety, time, and quality into consideration.

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Table 2.1. Demographic characteristics of consumers (N = 144) who participated in consumer sensory panels

Characteristic	Response	Percentage of consumers
Gender	Male	41.5
	Female	58.5
Household size	1 person	25.8
	2 people	34.2
	3 people	12.5
	4 people	15.0
	5 people	4.2
	6 people	2.5
	Greater than 6 people	5.8
Marital Status	Married	67.5
	Single	32.5
Age	Under 20	25.2
	20-29	37.8
	30-39	1.7
	40-49	5.0
	50-59	10.1
	Over 60	20.2
Ethnic Origin	African American	2.5
	Asian	2.5
	Caucasian/White	86.6
	Mixed Race	3.4
	Native-American	1.7
	Latino	3.4
	Other	0.0
Household Income Level	Under $25,000	33.3
	$25,000-$34,999	3.3
	$35,000-$49,999	7.5
	$50,000-$74,999	6.7
	$75,000-$99,999	9.2
	$100,000-$149,999	20.8
	$150,000-$199,999	9.2
	Greater than $199,999	10.0
Education Level	Non-high school graduate	2.5
	High school graduate	19.2
	Some college/technical school	42.5
	College graduate	17.5
	Post-college graduate	18.3
Most important palatability trait when consuming beef	Tenderness	33.3
	Juiciness	10.0
	Flavor	56.7
Trait experienced the most variability when consuming beef	Tenderness	52.5
	Juiciness	24.2
	Flavor	23.3
Preferred degree of doneness when consuming beef	Very rare	1.7
	Rare	10.0
	Medium rare	47.5
	Medium	25.0
	Medium well	13.3
	Well done	2.5
	Very well done	0.0
Weekly beef consumption	1 to 3 times	43.3
	4 to 6 times	35.0
	7 to 9 times	12.5
	10 or more times	9.2

Table 2.2. Fresh beef steak purchasing motivators of consumers (N = 144) who participated in consumer sensory panels

Characteristic	Importance of each trait[1]
Price	73.7[a]
Size, weight and thickness	69.7[ab]
Color	69.3[ab]
USDA Grade	68.9[ab]

Marbling	68.8^{ab}
Nutrient Content	65.8^{bc}
Familiarity with cut	61.1^{cd}
Eating satisfaction claims	54.3^{de}
Animal Welfare	53.7^{ef}
Fresh never Frozen	49.7^{efg}
Antibiotic use in animal	48.9^{efgh}
Growth hormone used in animal	46.7^{fghi}
Animal fed a grain-based diet	42.7^{ghij}
Packaging	42.1^{hij}
Animal fed a grass-based diet	41.5^{ij}
Brand of product	38.5^{j}
Natural or organic claims	38.2^{j}
SEM[2]	2.5
P-value	< 0.01

[abcdefghij] Least square means lacking a common superscript differ ($P < 0.05$).

[1] Purchasing motivators: 0 = extremely unimportant, 100 = extremely important.

[2] SEM (largest) of the least squares means.

Table 2.3. Least squares means for consumer sensory evaluation of palatability characteristics[1] of frozen beef strip loin steaks thawed using various thaw methods

Trait	Countertop[2]	Cook from frozen[3]	Cold water[4]	Hot water[5]	Microwave[6]	Refrigerator[7]	*P* - value	SEM[8]
Juiciness	60.8	59.2	65.5	58.1	56.8	57.1	0.28	2.9
Tenderness	60.6	56.9	63.8	60.8	56.8	57.6	0.38	2.8
Flavor	61.8	62.7	62.3	60.5	56.1	62.2	0.19	2.1
Overall liking	62.6	60.8	65.9	61.6	57.0	62.7	0.18	2.4

[1] Sensory scores: 0 = extremely dry/tough/dislike extremely; 50 neither dry nor juicy/neither tough nor tender/neither like or dislike; 100 = extremely juicy/tender/like extremely.

[2] Thawed at 17-20 º C for approximately 5 h, or until internal temperature reached 0ºC

[3] Cooked immediately upon removal from the freezer while still in a frozen state

[4] Thawed in individual plastic containers of 2-3ºC water for 24 h

[5] Thawed in 40ºC water for 20 minutes (±2 minutes) utilizing a sous vide machine to maintain water temperature

[6] Microwaved in a retail microwave at 50% power for 180 s, rotated, and microwave for an additional 180s, microwaving for an additional 30-60 s if not completely thawed

[7] Thawed at 2-3° C in open air in a refrigerator

[8] SEM (largest) of the least square means.

Table 2.4. Least squares means for consumer sensory evaluation of percentage of samples rated as acceptable[1] of frozen beef strip loin steaks thawed using various thaw methods

Trait	Countertop[2]	Cook from frozen[3]	Cold water[4]	Hot water[5]	Microwave[6]	Refrigerator[7]	*P* - value	SEM[8]
Juiciness acceptability	82.6	81.8	92.0	80.9	79.1	80.0	0.17	4.2
Tenderness acceptability	82.2	79.9	87.9	91.6	80.6	81.5	0.12	3.9
Flavor acceptability	87.4	87.4	91.1	87.4	84.8	85.7	0.80	3.5
Overall acceptability	85.2	82.6	95.2	86.3	87.4	83.7	0.13	4.0

[1] Percentage of samples rated as acceptable (yes/no) by consumer sensory panelists.

[2] Thawed at 17-20 º C for approximately 5 h, or until internal temperature reached 0ºC

[3] Cooked immediately upon removal from the freezer while still in a frozen state

[4] Thawed in individual plastic containers of 2-3ºC water for 24 h

[5] Thawed in 40ºC water for 20 minutes (±2 minutes) utilizing a sous vide machine to maintain water temperature

[6] Microwaved in a retail microwave at 50% power for 180 s, rotated, and microwave for an additional 180s, microwaving for an additional 30-60 s if not completely thawed

[7] Thawed at 2-3° C in open air in a refrigerator

[8] SEM (largest) of the least square means.

Table 2.5. Least squares means for consumer sensory evaluation of perceived quality level[1] of frozen beef strip loin steaks thawed using various thaw methods

Trait	Countertop[2]	Cook from frozen[3]	Cold water[4]	Hot water[5]	Microwave[6]	Refrigerator[7]	P - value	SEM[8]
Premium quality	6.5	6.5	8.8	4.0	3.1	3.9	0.39	2.8
Better than everyday	29.0	25.7	28.7	25.3	21.5	27.9	0.79	4.5
Everyday quality	49.3	47.5	47.1	45.8	44.8	46.5	0.13	4.8
Unsatisfactory	13.7	16.2	6.5	10.5	8.1	14.7	0.20	3.8

[1] Percentage of samples classified at various quality levels by consumer sensory panelists

[2] Thawed at 17-20 º C for approximately 5 h, or until internal temperature reached 0ºC

[3] Cooked immediately upon removal from the freezer while still in a frozen state

[4] Thawed in individual plastic containers of 2-3ºC water for 24 h

[5] Thawed in 40ºC water for 20 minutes (±2 minutes) utilizing a sous vide machine to maintain water temperature

[6] Microwaved in a retail microwave at 50% power for 180 s, rotated, and microwave for an additional 180s, microwaving for an additional 30-60 s if not completely thawed

[7] Thawed at 2-3° C in open air in a refrigerator

[8] SEM (largest) of the least square means.

Table 2.6. Least squares means for trained sensory panel evaluation[1] of palatability characteristics of frozen beef strip loin steaks thawed using various thaw method

Trait	Countertop[2]	Cook from frozen[3]	Cold water[4]	Hot water[5]	Microwave[6]	Refrigerator[7]	P - value	SEM[8]
Initial juiciness	58.6	55.2	59.6	55.9	57.5	59.9	0.26	2.0
Sustained juiciness	51.9	48.2	53.1	49.2	51.1	53.8	0.20	2.2
Myofibrillar tenderness	64.6^{ab}	61.7^{b}	66.2^{a}	63.5^{ab}	63.3^{ab}	65.7^{a}	< 0.01	1.5
Connective tissue	4.1	5.4	4.1	4.9	5.0	4.2	0.48	0.7
Overall tenderness	63.1^{ab}	59.6^{b}	65.1^{a}	62.0^{ab}	60.5^{b}	64.5^{a}	0.02	1.8
Flavor intensity	36.5^{b}	41.0^{a}	35.8^{b}	37.8^{b}	37.5^{b}	37.2^{b}	< 0.01	0.8

^{ab}Least squares means in the same row without a common superscript differ ($P < 0.05$)

[1] Sensory scores: 0 = extremely dry/tough/none/extremely bland/no off-flavor; 50 neither dry nor juicy/neither tough nor tender; 100 = extremely juicy/tender/abundant/extremely intense.

[2] Thawed at 17-20 º C for approximately 5 h, or until internal temperature reached 0ºC

[3] Cooked immediately upon removal from the freezer while still in a frozen state

[4] Thawed in individual plastic containers of 2-3ºC water for 24 h

[5] Thawed in 40ºC water for 20 minutes (±2 minutes) utilizing a sous vide machine to maintain water temperature

[6] Microwaved in a retail microwave at 50% power for 180 s, rotated, and microwave for an additional 180s, microwaving for an additional 30-60 s if not completely thawed

[7] Thawed at 2-3° C in open air in a refrigerator

[8] SEM (largest) of the least square means of the same row

Table 2.7. Least squares means for Warner-Bratzler shear force (WBSF), slice shear force, cooking characteristics, and instrumental cooked color of frozen beef strip loin steaks thawed using for various thaw methods

	Countertop[1]	Cook from frozen[2]	Cold water[3]	Hot water[4]	Microwave[5]	Refrigerator[6]	P - value	SEM[7]
L^*	56.7	55.0	56.0	55.3	55.5	55.9	0.16	0.6
a^*	21.3^{a}	18.2^{bc}	20.4^{ab}	20.3^{ab}	16.4^{c}	20.5^{ab}	0.02	1.1
b^*	19.2^{a}	17.7^{bc}	18.9^{ab}	18.7^{ab}	16.9^{c}	18.9^{ab}	< 0.01	0.5
Slice shear force, kg	14.5	15.6	15.0	14.7	15.5	14.8	0.78	0.7
WBSF, kg	3.6	3.6	3.5	3.4	3.8	3.7	0.15	0.1
Cook loss, %[8]	15.0^{c}	18.1^{b}	14.6^{c}	14.4^{c}	19.4^{a}	15.4^{c}	< 0.01	0.5
Thaw loss, %[9]	1.2^{b}	.	0.9^{b}	3.7^{a}	4.2^{a}	0.8^{b}	< 0.01	0.4
Total loss, %[10]	16.1^{b}	18.3^{a}	15.4^{b}	18.1^{a}	19.4^{a}	16.0^{b}	< 0.01	0.8
PJP[11]	13.7	13.5	14.7	14.8	15.2	13.8	0.23	0.0
Moisture, %	69.3^{ab}	.	69.6^{a}	69.7^{a}	68.8^{b}	69.8^{a}	0.04	0.4
Fat, %	9.0^{a}	.	8.1^{ab}	8.1^{ab}	9.0^{a}	7.5^{b}	0.04	0.5
Malonaldehyde/kg[12]	0.2	.	0.2	0.2	0.2	0.2	0.61	0.0
Expressible moisture,%	7.9^{b}	10.1^{a}	7.9^{b}	8.9^{ab}	8.8^{ab}	8.3^{b}	0.03	0.5
WHC, %[13]	92.2^{a}	89.9^{b}	92.1^{a}	91.1^{ab}	91.2^{ab}	91.7^{a}	0.03	0.5

^{abc}Least squares means in the same row without a common superscript differ ($P < 0.05$).

[1] Thawed at 17-20 º C for approximately 5 h, or until internal temperature reached 0ºC

[2] Cooked immediately upon removal from the freezer while still in a frozen state

[3] Thawed in individual plastic containers of 2-3ºC water for 24 h

[4] Thawed in 40ºC water for 20 minutes (±2 minutes) utilizing a sous vide machine to maintain water temperature

[5] Microwaved in a retail microwave at 50% power for 180 s, rotated, and microwave for an additional 180s, microwaving for an additional 30-60 s if not completely thawed

[6] Thawed at 2-3° C in open air in a refrigerator

[7] SEM (largest) of the least square means.

[8] Cook loss percentage = [(raw weight – cooked weight) / raw weight] x 100

[9] Thaw loss percentage =[(steak in package – raw steak weight – dried package weight) / raw steak weight] x 100

[10] Total loss = [(steak in package – dried package weight – cooked weight) / raw steak weight] x 100

[11] Pressed Juice Percentage

[12] mg of Malonaldehyde/kg of meat

[13] Water holding capacity

Table 2.8. Least squares means for thaw rate, time, and temperatures (°C) at times prior to thawed of strip loin steaks thawed using various methods

Time prior to thawed[1]	Hot water	Countertop	Cold water	Refrigerator	*P* - value	SEM[2]
Thaw Rate[3]	0.811^{a}	0.028^{b}	0.010^{c}	0.007^{c}	< 0.01	0.09
Thaw Time[4]	10.3^{a}	264.0^{b}	637.5^{c}	882.0^{d}	< 0.01	10.7
0:00	0.3	0.2	0.0	0.1	0.21	0.10
0:05	-3.9	.	.	.		0.83
0:10	-3.6^{a}	-0.4^{b}	.	.	< 0.01	0.42
0:30	.	-1.0	-0.8	-0.9	0.31	0.12
1:00	.	-1.3	-1.2	-1.1	0.47	0.11
1:30	.	-1.6^{a}	-1.4^{ab}	-1.2^{b}	0.29	0.10
2:00	.	-1.9^{a}	-1.5^{b}	-1.2^{b}	< 0.01	0.12
2:30	.	-2.5^{a}	-1.6^{b}	-1.3^{b}	< 0.01	0.17
3:00	.	-3.3^{a}	-1.6^{b}	-1.3^{b}	< 0.01	0.25
3:30	.	-4.0^{a}	-1.7^{b}	-1.4^{b}	< 0.01	0.33
4:00	.	-5.3^{a}	-1.8^{b}	-1.4^{b}	< 0.01	0.36
5:00	.	-8.4^{a}	-2.1^{b}	-1.6^{b}	< 0.01	1.07
6:00	.	.	-2.4^{a}	-1.7^{b}	0.01	0.17
7:00	.	.	-2.5^{a}	-1.8^{b}	< 0.01	0.17
8:00	.	.	-2.8^{a}	-1.9^{b}	< 0.01	1.22
9:00	.	.	-3.2^{a}	-2.2^{b}	< 0.01	0.22
10:00	.	.	-4.6^{a}	-2.7^{b}	< 0.01	0.39
11:00	.	.	-5.7^{a}	-3.0^{b}	< 0.01	0.35
12:00	.	.	-6.0^{a}	-3.2^{b}	< 0.01	0.55
13:00	.	.	-7.0^{a}	-3.8^{b}	0.01	0.98
14:00	.	.	.	-5.2		0.35
15:00	.	.	.	-6.5		0.23

[1] (hours : min)

[2] SEM (largest) of the least square means.

[3] Degrees / minutes to reach 0° C

[4] Minutes to reach 0° C

[abc] Least squares means in the same row without a common superscript differ ($P < 0.05$).

Table 2.9. Standard error measures of consumer sensory evaluation for palatability traits

Study	Juiciness	Tenderness	Flavor	Overall Liking	Panelists Number
Farmer et al., 2022[1]	2.5	2.6*	2.2	2.4	144
Beyer et al., 2021[1]	2.0	2.6*	2.5	2.2	118
Vierck et al., 2021	1.6	1.5	1.9*	1.7	300
Olson et al., 2019[1]	2.0	2.0	1.9	2.2*	236
Drey et al., 2019[1]	1.8	2.1*	1.5	1.6	360
Prill et al., 2019[1]	2.2	2.1	1.8	2.9*	283
Nyquist et al., 2018[1]	2.4**	2.4**	2.1	2.3	210
Gredell et al., 2018[1]	4.0*	3.6	2.9	2.9	120
Chail et al., 2017[2]	0.2**	0.2**	0.1	0.2**	120
McKillip et al., 2017[1]	1.9	2.5*	2.0	2.0	252
Wilfong et al., 2016[1]	2.8	2.9*	2.2	2.2	112
Lucherk et al., 2016[1]	1.7	2.0*	1.6	1.7	252
Legako et al., 2016[1]	2.7	2.6	2.7	2.8*	108
Chail et al., 2016[2]	0.11	0.12**	0.12**	0.11	120
O'Quinn et al., 2015[3]	0.05	0.06**	0.06**	0.06**	315
Corbin et al., 2015[1]	7.5	5.8	7.7*	7.3	120
Legako et al., 2015[1]	3.2	5.9*	3.8	4.2	278
Garmyn et al., 2014[3]	0.2*	0.1	0.1	0.1	400
Hunt et al. 2014[1]	2.0	2.2*	2.0	2.4	120
O'Quinn et al., 2012[1]	5.3	6.0*	5.5	5.9	120

[1] Sensory scores: 0 = not tender/juicy, dislike flavor/overall extremely; 50 = neither tough nor tender, dry nor juicy or neither like or dislike flavor/overall; 100 = very tender/juicy, like flavor/overall extremely.

[2] Sensory scores: 9-point hedonic scale, 1= dislike extremely, 9= like extremely

[3] Sensory scores: 1= extremely tough, dry, dislike flavor extremely, dislike overall extremely; 8= extremely tender, juicy, like flavor extremely, like overall extremely

*Attribute within each row with the highest standard error of least squares means

** Attributes within each row tied for the highest standard error of least squares means

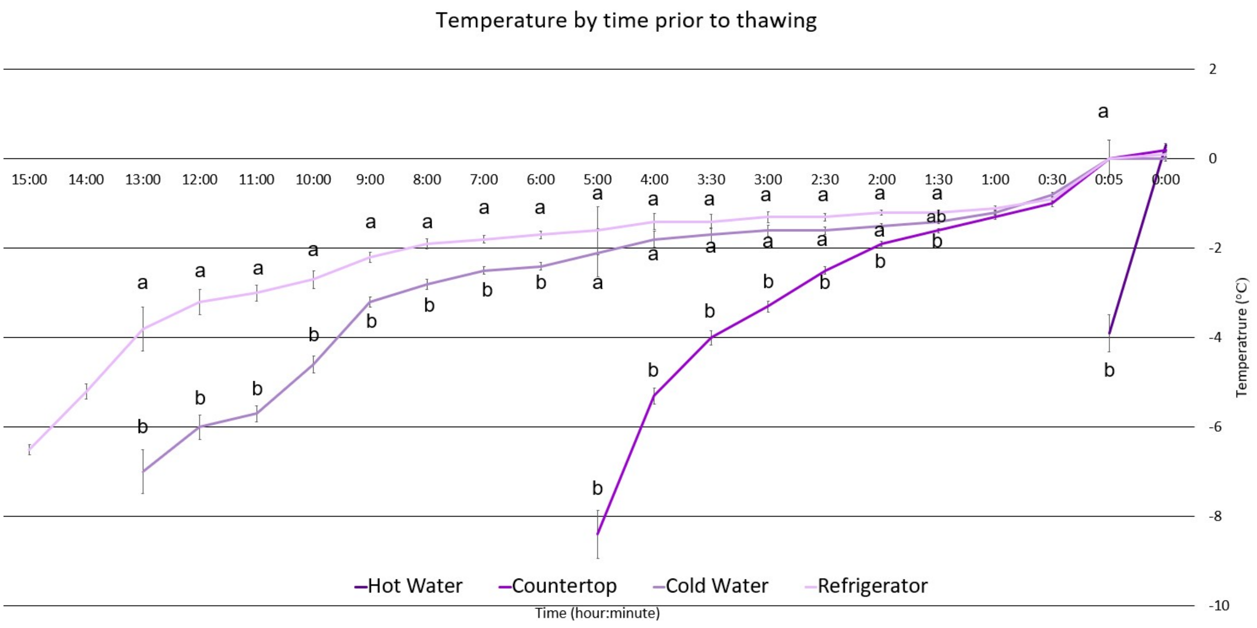


Figure 5. *Thaw curves of various thawing methods where time equals hours until thawed*

Appendix

Consumer Panel Evaluation Forms

Informed Consent Statement

1. I volunteer to participate in research involving Sensory Evaluation of Meat. This research will be conducted by personnel in the Department of Animal Sciences and Industry at Kansas State University.

2. I fully understand the purpose of the research is for the evaluation of beef steaks, pork chops, lamb chops, goat meat, poultry meat, ground meat, and processed meat products from the previously mentioned species for the sensory traits of tenderness, juiciness, flavor intensity, connective tissue amount, off flavor presence, odor, and color and sensory evaluation will last approximately one hour.

3. I understand that there are minimal risks associated with participating and that those risks are related to possible food allergies. All meat products will be USDA inspected and all ingredients are GRAS (generally accepted as safe) by FDA.

4. I understand that my performance as an individual will be treated as research data and will in no way be associated with me for other than identification purposes, thereby assuring confidentiality of my performance and responses.

5. My participation in this study is purely voluntary; I understand that my refusal to participate will involve no penalty or loss of benefits to which I am otherwise entitled and that I may discontinue participation at any time without penalty or loss of benefits to which I am otherwise entitled.

6. If I have any questions concerning my rights as a research subject, injuries or emergencies resulting from my participation, I understand that I can contact the Committee on Research Involving Human Subjects, 203 Fairchild Hall, Kansas State University, Manhattan, KS 66506, at (785) 532-3224. 7. If I have questions about the rationale or method of the study, I understand that I may contact, Dr. Travis O'Quinn, 247 Weber Hall, Kansas State University, Manhattan, KS 66506, at (785) 532-3469 or Sally Stroda, 107 Weber Hall, at 785-532-1273. 59

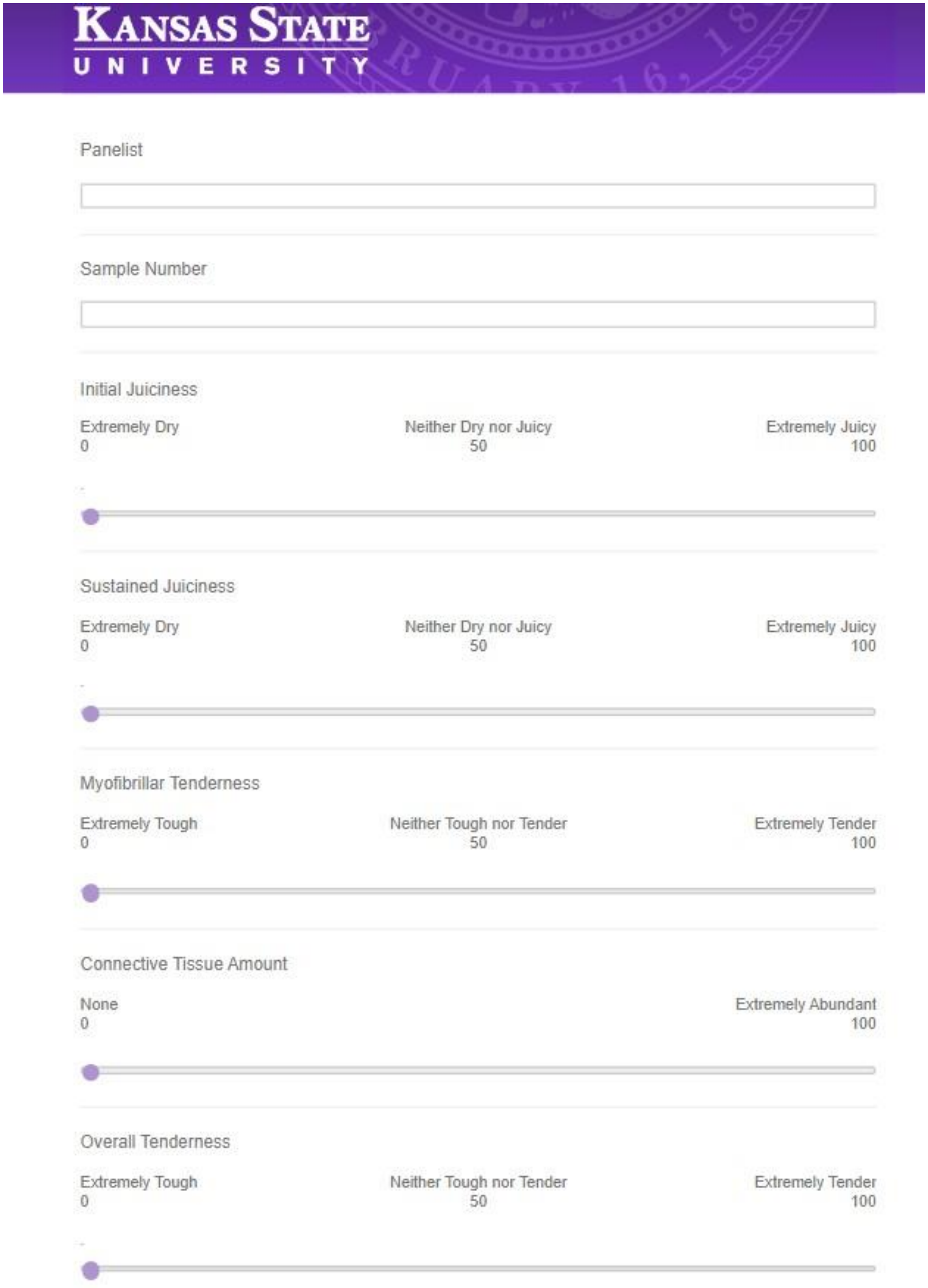
I have read the Subject Orientation and Test Procedure statement and signed this informed consent statement, this ________________________ day of _____________________,

________________________________ ____________________________________

Printed name Signature

Please sign and return one copy. The second copy is for your records.

Trained Sensory Panelist Ballot



KANSAS STATE
UNIVERSITY

Panelist

Sample Number

Initial Juiciness

Extremely Dry 0	Neither Dry nor Juicy 50	Extremely Juicy 100

Sustained Juiciness

Extremely Dry 0	Neither Dry nor Juicy 50	Extremely Juicy 100

Myofibrillar Tenderness

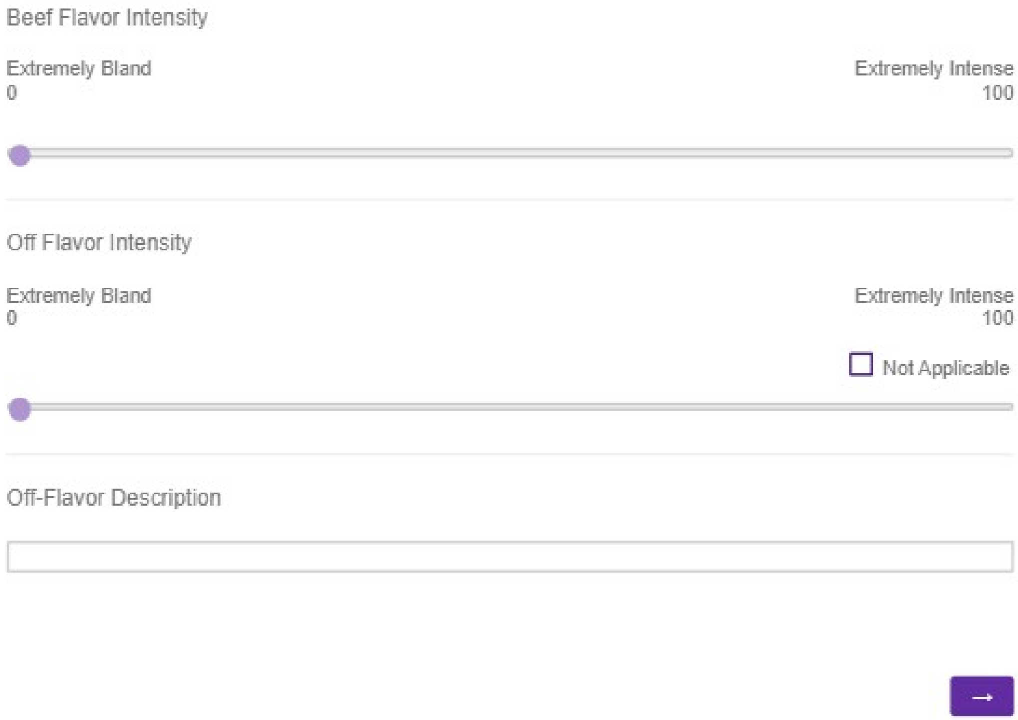
Extremely Tough 0	Neither Tough nor Tender 50	Extremely Tender 100

Connective Tissue Amount

None 0	Extremely Abundant 100

Overall Tenderness

Extremely Tough 0	Neither Tough nor Tender 50	Extremely Tender 100



Beef Flavor Intensity

Extremely Bland 0 — Extremely Intense 100

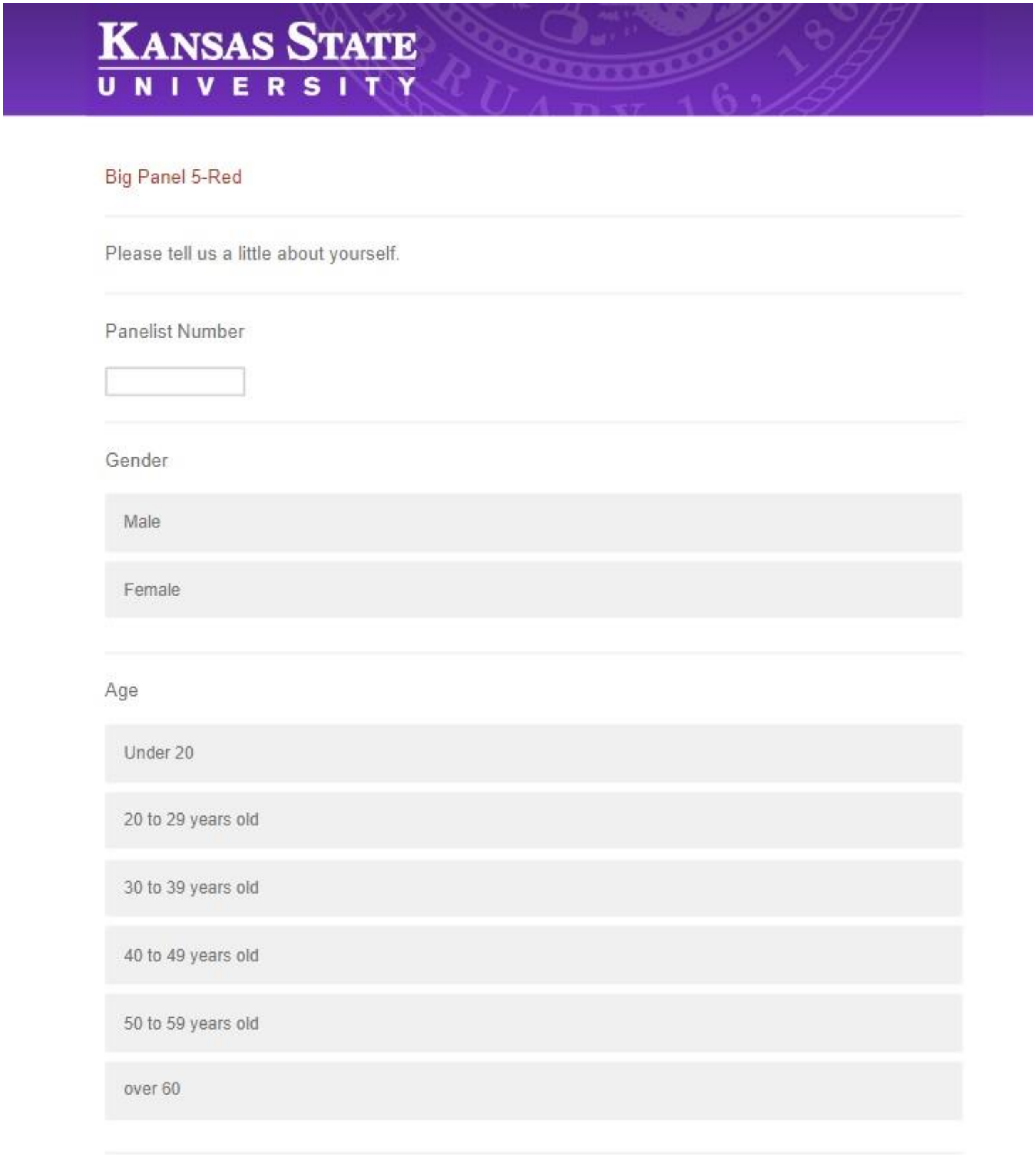
Off Flavor Intensity

Extremely Bland 0 — Extremely Intense 100

☐ Not Applicable

Off-Flavor Description

Consumer Sensory Analysis Ballot



KANSAS STATE UNIVERSITY

Big Panel 5-Red

Please tell us a little about yourself.

Panelist Number

Gender

Male

Female

Age

Under 20

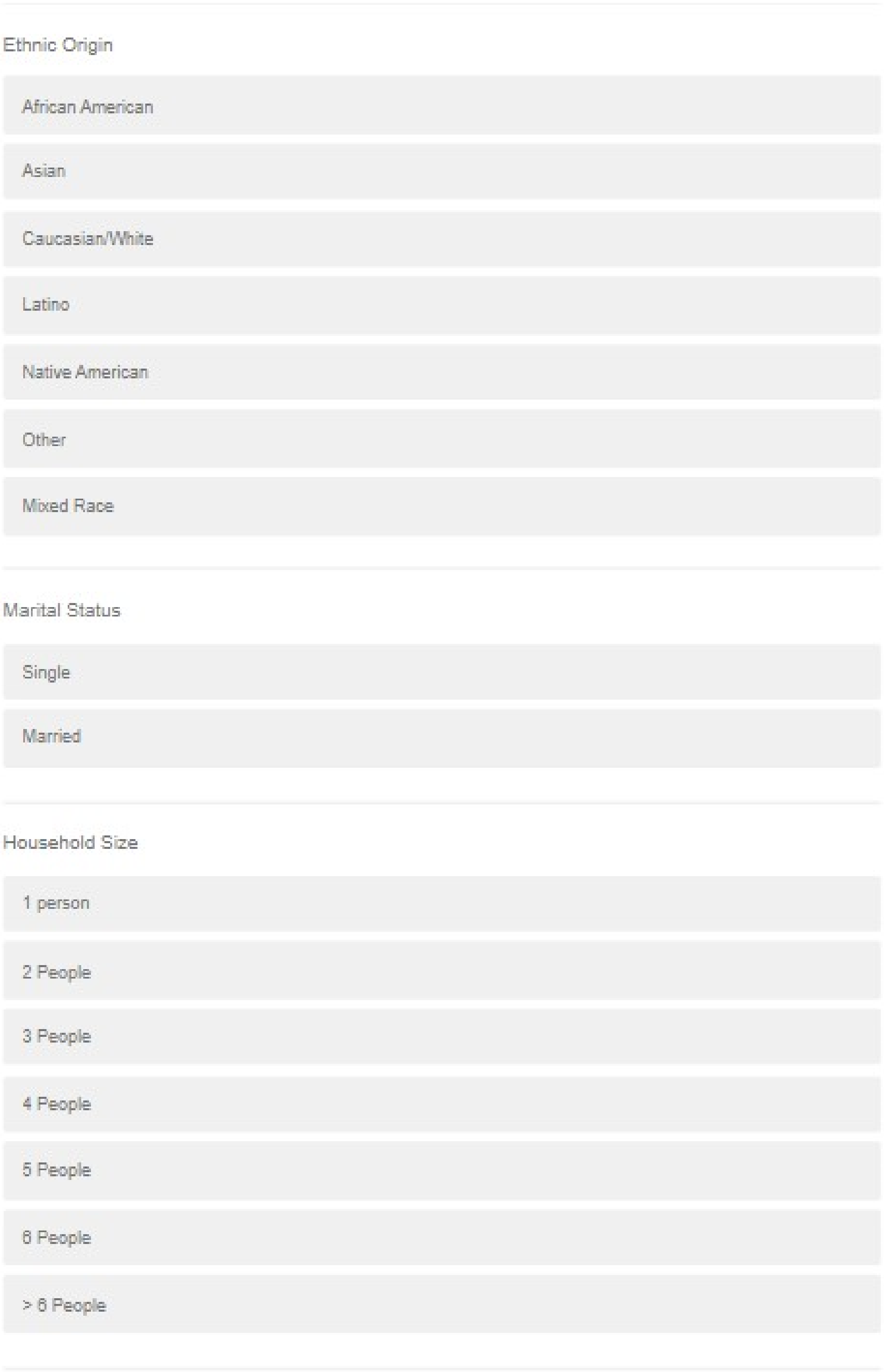
20 to 29 years old

30 to 39 years old

40 to 49 years old

50 to 59 years old

over 60



Ethnic Origin

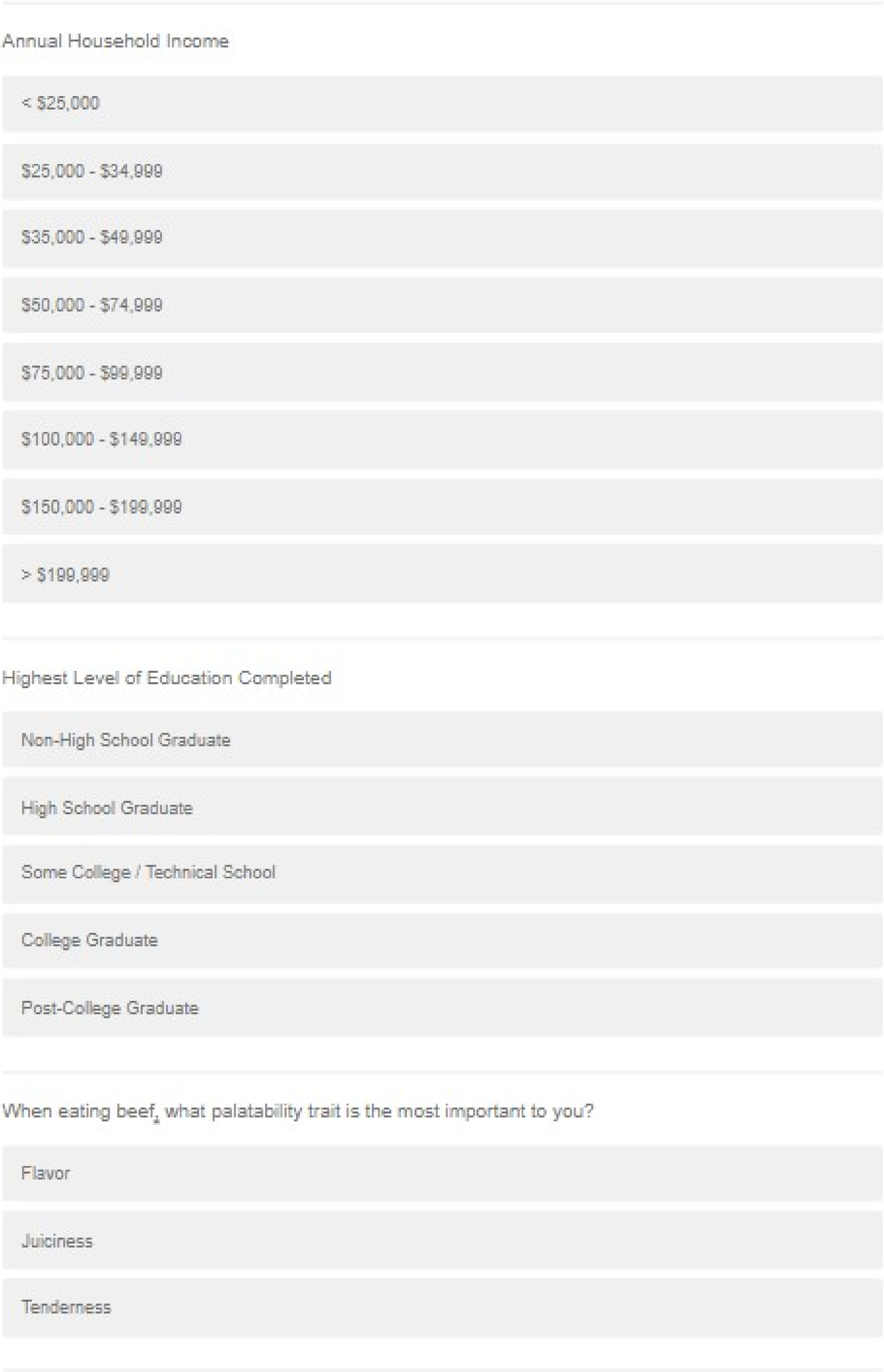
- African American
- Asian
- Caucasian/White
- Latino
- Native American
- Other
- Mixed Race

Marital Status

- Single
- Married

Household Size

- 1 person
- 2 People
- 3 People
- 4 People
- 5 People
- 6 People
- > 6 People



Annual Household Income

- < $25,000
- $25,000 - $34,999
- $35,000 - $49,999
- $50,000 - $74,999
- $75,000 - $99,999
- $100,000 - $149,999
- $150,000 - $199,999
- > $199,999

Highest Level of Education Completed

- Non-High School Graduate
- High School Graduate
- Some College / Technical School
- College Graduate
- Post-College Graduate

When eating beef, what palatability trait is the most important to you?

- Flavor
- Juiciness
- Tenderness

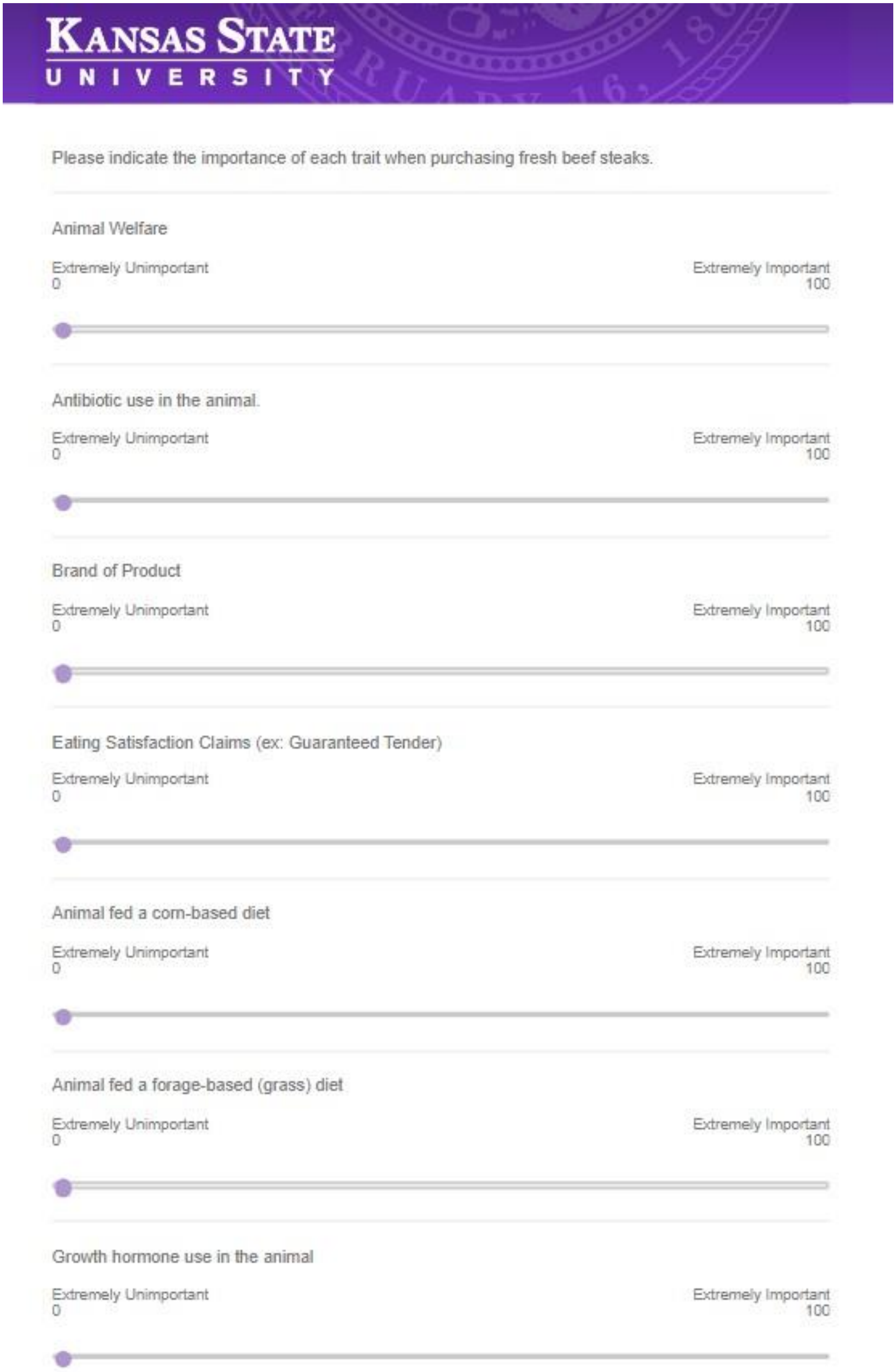
When consuming beef, which palatability trait do you experience the greatest amount of **variation** with?

- Flavor
- Juiciness
- Tenderness

When eating beef steaks, what degree of doneness do you prefer?

- Very Rare
- Rare
- Medium-Rare
- Medium
- Medium-Well
- Well-Done
- Very Well-Done

How many times a week do you consume beef?



Please indicate the importance of each trait when purchasing fresh beef steaks.

Animal Welfare

Extremely Unimportant 0 — Extremely Important 100

Antibiotic use in the animal.

Extremely Unimportant 0 — Extremely Important 100

Brand of Product

Extremely Unimportant 0 — Extremely Important 100

Eating Satisfaction Claims (ex: Guaranteed Tender)

Extremely Unimportant 0 — Extremely Important 100

Animal fed a corn-based diet

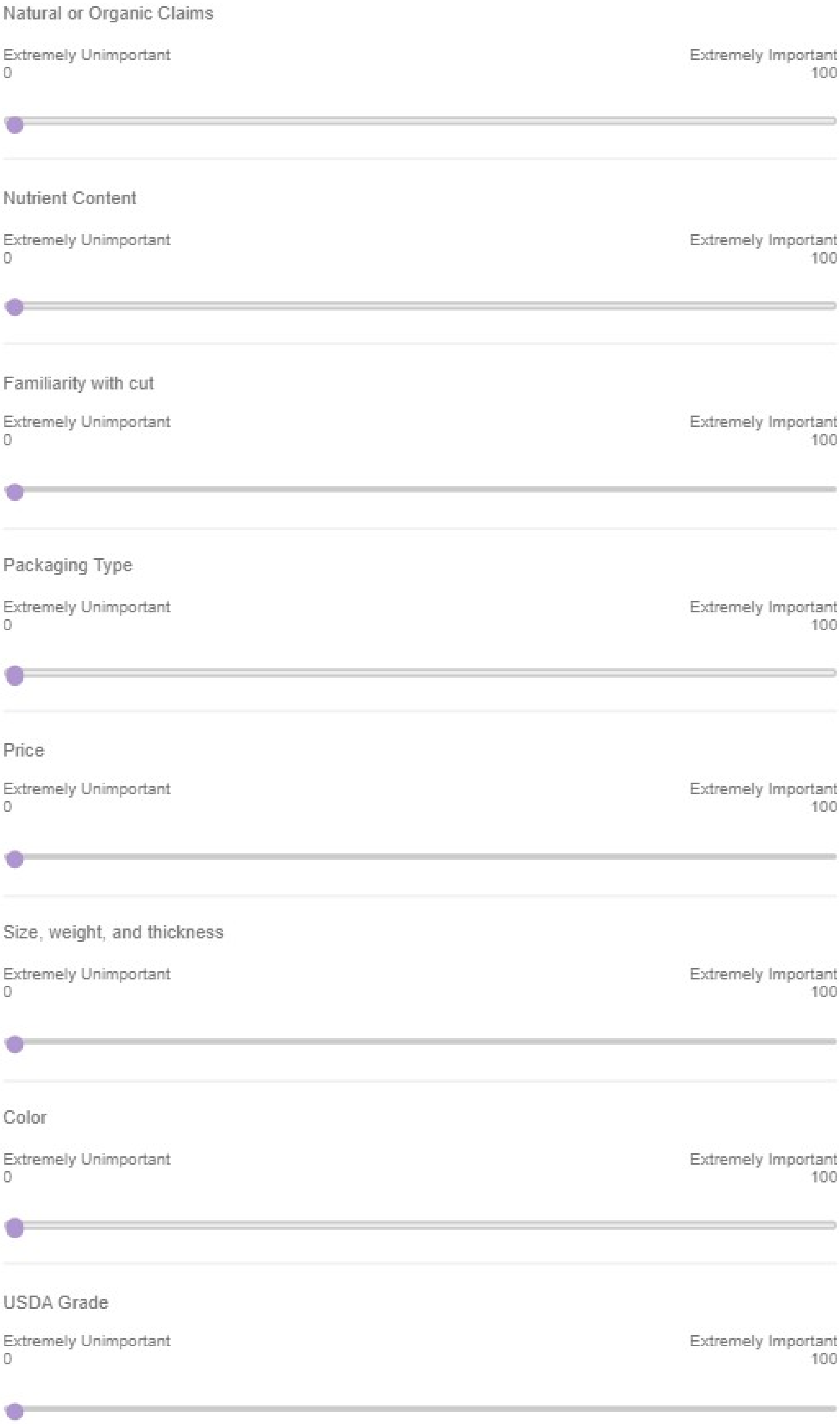
Extremely Unimportant 0 — Extremely Important 100

Animal fed a forage-based (grass) diet

Extremely Unimportant 0 — Extremely Important 100

Growth hormone use in the animal

Extremely Unimportant 0 — Extremely Important 100



Natural or Organic Claims

Extremely Unimportant 0
Extremely Important 100

Nutrient Content

Extremely Unimportant 0
Extremely Important 100

Familiarity with cut

Extremely Unimportant 0
Extremely Important 100

Packaging Type

Extremely Unimportant 0
Extremely Important 100

Price

Extremely Unimportant 0
Extremely Important 100

Size, weight, and thickness

Extremely Unimportant 0
Extremely Important 100

Color

Extremely Unimportant 0
Extremely Important 100

USDA Grade

Extremely Unimportant 0
Extremely Important 100

Marbling

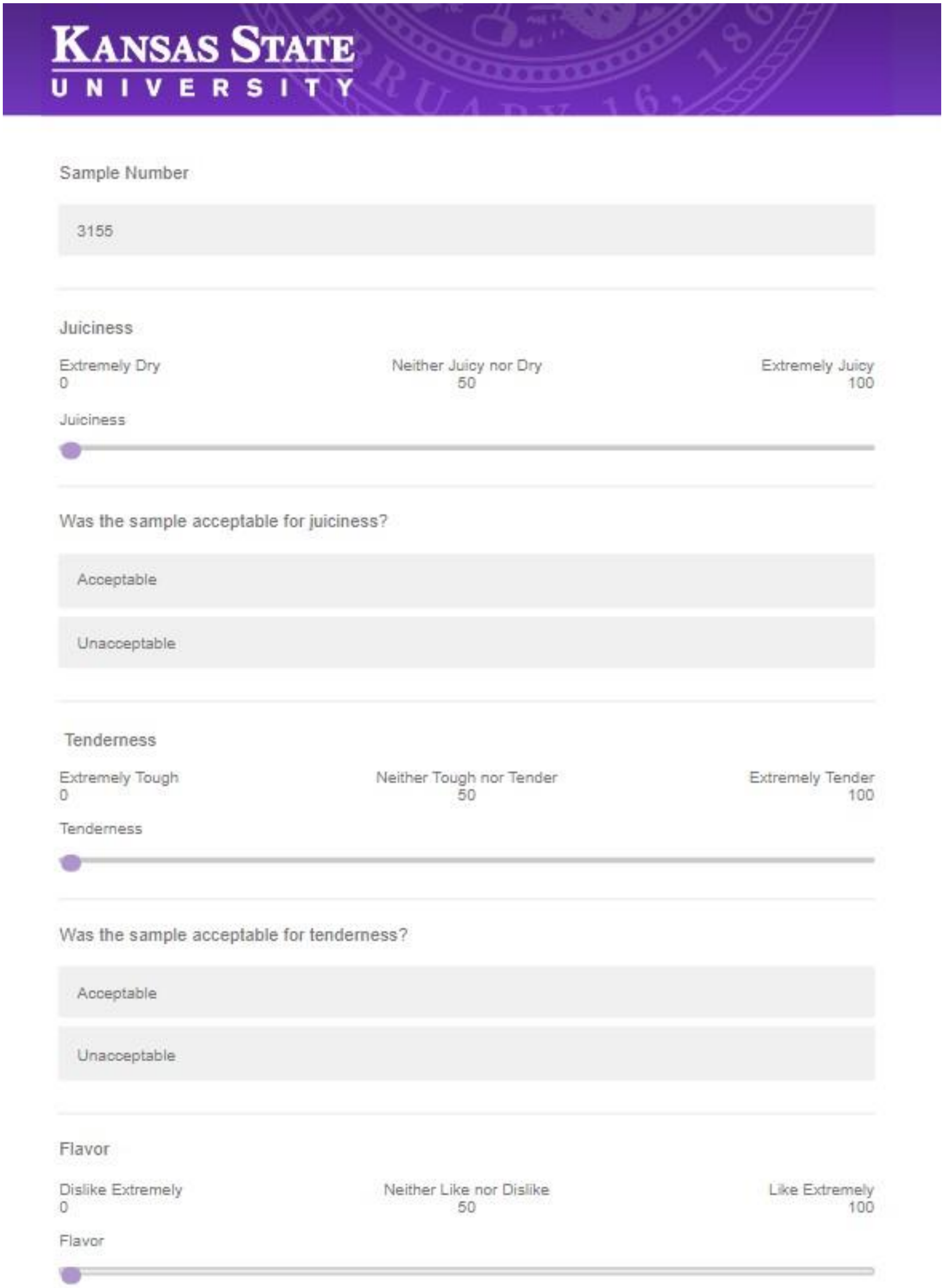
Extremely Unimportant
0

Extremely Important
100

Fresh Never Frozen

Extremely Unimportant
0

Extremely Important
100



Sample Number

3155

Juiciness

Extremely Dry 0	Neither Juicy nor Dry 50	Extremely Juicy 100

Juiciness

Was the sample acceptable for juiciness?

Acceptable

Unacceptable

Tenderness

Extremely Tough 0	Neither Tough nor Tender 50	Extremely Tender 100

Tenderness

Was the sample acceptable for tenderness?

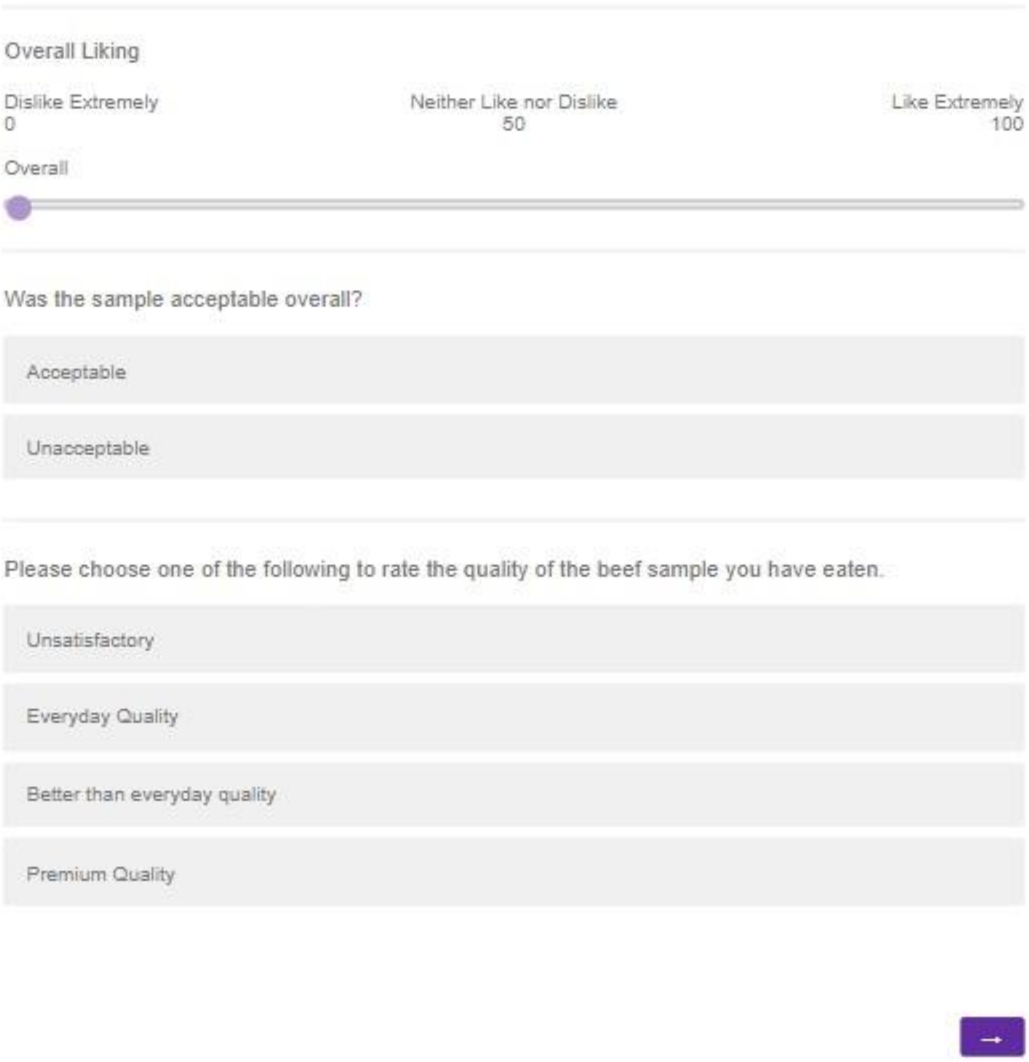
Acceptable

Unacceptable

Flavor

Dislike Extremely 0	Neither Like nor Dislike 50	Like Extremely 100

Flavor



Overall Liking

Dislike Extremely 0 | Neither Like nor Dislike 50 | Like Extremely 100

Overall

Was the sample acceptable overall?

- Acceptable
- Unacceptable

Please choose one of the following to rate the quality of the beef sample you have eaten.

- Unsatisfactory
- Everyday Quality
- Better than everyday quality
- Premium Quality