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Effects of Thawing Method on Palatability Traits, Quality Attributes, and Thawing Characteristics of Beef Steaks[1]

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Abstract: While there are various studies investigating the effect of freezing on palatability characteristics, thawing has not received the same level of interest. Therefore, the objective of this study was to investigate the effects of various thawing methods on beef palatability. Paired beef strip loins ($n = 15$ pairs) were obtained from a commercial processing facility for palatability evaluation, and 6 additional strip loins were collected for thawing characteristic data. The paired loins were sectioned into 6 sections of 4 steaks each, and each section assigned a thawing method. Thaw methods included thawing in the refrigerator, cold water, microwave, hot water, on the counter, and cooking from frozen. Steaks were aged a total of 21 d prior to freezing. Consumer sensory panelists ($N = 120$) found no differences ($P > 0.05$) among all thawing methods for each palatability characteristic. Within trained sensory panels ($n = 8$ panelists/session), thawing in the refrigerator and cold water were rated higher ($P < 0.05$) for overall tenderness than thawing in the microwave and cooking from frozen. Cooking steaks from frozen was rated higher ($P < 0.05$) for beef flavor intensity than all other thawing methods by trained sensory panelists. Steaks thawed in the microwave had the highest ($P < 0.05$) percentage of cook loss, followed by cooking from frozen, with all other methods being similar ($P > 0.05$). Similarly, steaks thawed in the microwave and in hot water had a higher ($P < 0.05$) thawing loss percentage than steaks thawed on the counter, in cold water, or in the refrigerator. These results indicate thawing method had minimal differences on overall beef palatability and objective quality measures. Therefore, consumers and foodservice establishments should use their preferred thaw method based on convenience, taking food safety and time into consideration.

Keywords: consumer, thawing, eating quality, beef, sensory, palatability
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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 markets (Ren et al., 2022; USDA, 2023). Therefore, there has been significant 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.

Thawing is a necessary process associated with freezing in order for meat to be usable for consumers and foodservice. The USDA defines 4 methods of thawing as safe: thawing under refrigeration, thawing in cold water, microwaving, and cooking from a frozen state (USDA-FSIS, 2013a). These methods are determined as safe due to the low likelihood that meat products enter the "temperature danger zone" (4.4°C to 60°C) at which microorganisms have increased growth during the thawing process; or in the case of microwave thawing, are recommended to be cooked directly after thawing (USDA-FSIS, 2013a). However, consumers commonly use alternative methods, such as thawing on the counter and thawing in hot water to thaw meat (Benli, 2015).

While much is known about the impact of freezing on beef eating quality, little is known about how the 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 results as to whether faster thawing methods, such as thawing in the microwave or in hot water, increase or decrease the quality of beef. Eastridge and Bowker (2011), Hergenreder et al. (2013), and Bogdanowicz et al. (2018) all found that quicker thawed samples resulted in a less thawing loss, while Zahir (2021) and Gonzalez-Sanguinetti et al. (1985) suggested that slower thawing methods result in reduced thawing loss. Therefore, this conflicting literature leaves room for further investigation of thawing methods' effects on moisture loss throughout the thawing process. Additionally, there is no literature outlining and comparing the rate and total thawing time of different thawing methods nor a comprehensive comparison of the eating quality of beef thawed using varied thawing methods.

Therefore, the objectives of the current study were to evaluate palatability traits of beef strip loin steaks thawed utilizing the 4 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 (KSU) Institutional Review Board (IRB #7440.8, October 2022).

Sample selection

Paired beef strip loins (IMPS #180; North American Meat Institute, 2014) were collected from a midwestern beef processing facility ($n = 15$ pairs). In addition, 6 strip loins were collected for thawing curve development and assessment of thawing characteristics. All strip loins graded USDA Low Choice and were A-maturity, with carcass characteristics assessed and collected by trained KSU personnel. The subprimals were vacuum-packaged and transported under refrigeration (< 4°C) to the KSU Meat Laboratory.

On postmortem day 11, loins were fabricated in 2.5-cm thick steaks. The paired loins were cut into 6 sections of 4 steaks each, with 3 sections per each carcass side. Since a complete balance of thawing treatments across sections was not possible, sections were randomly assigned to one of 4 USDA recommended thawing treatments: thawing in the refrigerator (REF), thawing in cold water (CW), thawing during cooking (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 (SSF), cooked color, thawing loss, and cooking 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, vacuum packaged, aged for a total of 21 d postmortem, then frozen in a commercial freezer (−20°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 to the geometric center of the steaks, and steaks were vacuum-packaged and frozen (−20°C) until thawing and analysis.

Thawing procedures

For each thawing method, the internal temperature was targeted at 0°C (±1°C). A pilot study utilizing each thawing method was conducted prior to the study for determination of the approximate amount of time steaks would need for each method to complete thawing. Steaks designated REF were held at 2 to 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 2.8-L plastic containers of 2 to 3°C water for 24 h. The steaks in containers of water were placed in the same refrigerator as those designated for REF 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. Details related to the cooking of the COOK treatment are outlined in the subsequent section describing sample cooking procedures. Thawing power level and time for MIC were determined by a pilot study, with the target being steaks thawed completely (0°C), with minimal browning. The resulting procedure was microwaving steaks for 210 s at 50% power in a retail microwave (Amana, Over-The-Range Microwave, Benton Harbor, MI), flipped, 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 to 20°C for approximately 5 h, or until internal temperature reached 0°C. Steaks designated for thawing in hot water were thawed in 40°C water for 20 min (± 2 min) until internal temperature reached 0°C. 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 the geometric center of thawing curve 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. Data loggers for CT 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 for the COOK and MIC treatments were not included in thawing curve data collection due to the inability to safely insert probes and measure temperatures within these thawing methods.

Consumer sensory panels

Untrained consumer panelists ($n = 120$) from the Manhattan, KS area were recruited to participate. Each panelist was fed 6 samples, one from each of the 6 treatments, each from the same carcass. Panels were organized and conducted in a fashion like those held previously at KSU (Drey et al., 2019; Olson et al., 2019; Prill et al., 2019a; Beyer et al., 2021; Farmer et al., 2022). In short, steaks were cooked on Cuisinart Griddler Deluxe clam-shell style grills (East Windsor, NJ) to an internal peak temperature of 71°C, sliced into 1 × 1 cm cubes, and immediately served. For COOK steaks, temperature probes were inserted during the cooking process immediately upon being thawed. One piece (2.5-cm thick × 1-cm × 1-cm) was removed from all steaks following cooking and utilized for cooked water holding capacity assay.

A total of 5 consumer panel sessions, each consisting of 24 panelists and lasting 1 h each, were conducted. Samples from each steak were fed and evaluated by 8 individual consumers, with all data averaged across the individual consumer responses for a single mean for each sample. Each consumer was provided a tablet (Lenovo TB-8505F, Morrisville, NC), survey (Version 2417833; Qualtrics Software, Provo, UT), as well as apple juice and unsalted crackers as palate cleansers. Consumers completed a demographic and beef purchasing motivator questionnaire prior to sample evaluation. One-hundred-point sliding scales were utilized by consumers 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 whether the sample was acceptable for juiciness, tenderness, flavor, and overall liking (yes/no). Lastly, consumers rated the sample on their perception of the quality of the sample (unsatisfactory, everyday quality, better than everyday quality, or premium quality).

Trained sensory panels

Panelists from KSU 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

8 trained panelists were performed. Steaks were thawed according to their specific thawing method and cooked as described for consumer evaluation. Each panelist was served 6 samples, 1 of each treatment, from the same carcass in a random order. They were also provided with the same tablets (Lenovo TB-8505F, Morrisville, NC) and surveys created using the same survey software (Qualtrics Software, Provo, UT) used in the consumer panels. Moreover, a "warm-up" strip loin steak sample was provided and discussed prior to each panel session in order to prevent panelist drift and allow for panel calibration.

Internal color, shear force, cooking characteristics, and instrumental juiciness measures

Each steak was thawed according to its individual method as previously outlined. To calculate thawing loss for HW, CW, REF, and CT steaks, weights were taken for the thawed steak still in package, raw steak once removed from the package and patted dry, and the dry package and tag. Total thawing loss was calculated as in Farmer et al. (2022). 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 thawing loss data. 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 by adding the moisture lost from both the thawing and cooking, and divided by the raw steak weight.

Immediately following the peak temperature recording, a cut was made 2 cm from the lateral end of the steak, followed by a second cut 5 cm from the first cut to determine muscle fiber orientation for SSF utilizing the protocol outline in Shackelford et al. (1999). The warm sample was then sheared using the SSF machine (Model GR-152; Tallgrass Solutions, Manhattan, KS) and the peak force recorded. Moreover, a 1 cm slice was taken immediately medial to the SSF sample for PJP evaluation as described by Lucherk et al. (2017). In short, three 1-cm-wide pieces were cut from the 1-cm-thick slice and placed on preweighed filter paper, and a pre-weighed filter paper was placed on top of the sample and compressed (Instron Model 5569, Canton, MA). PJP was calculated for each piece, and the 3 pieces were averaged for each steak to obtain final PJP value.

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. Cooked instrumental color (L^*, a^*, b^*) was obtained following the AMSA Color Guidelines (King et al., 2023). 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 calibrated 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.

After SSF and PJP, the remainder of samples were refrigerated (2 to 4°C) overnight prior to WBSF measurement. The AMSA Sensory Guideline (AMSA, 2015) protocol was utilized. In short, 6 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 250 mm/min using a load cell of 100 kg. The peak force was recorded for each core and averaged 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), placed in sterile sample bags and stored in a −80°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 sample 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 acid reactive substances (TBARS) assay as outlined by Dahmer et al. (2022). In short, 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, and 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 as 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 the protocol from Lucherk et al. (2017) and altered slightly. One cube (2.5 cm × 1 cm × 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 was 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, NC) 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. For consumer acceptability and quality level data, a model with a binomial error distribution was used. An α of 0.05 was considered significant for the comparison of all treatment means.

Results

Consumer demographic and purchasing motivators

The demographic information of the 120 consumer panelists that participated in the consumer panels is shown in Table 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 30 years of age (63.3%) and Caucasian

Table 1. Demographic characteristics of consumers ($N = 120$) 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
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

Table 1. (*Continued*)

Characteristic	Response	Percentage of consumers
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. Fresh beef steak purchasing motivators of consumers (N = 120) 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

[a–j]Least-squares 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.

(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 had 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%), and 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%), and 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 and 3 times per week (43.3%) and 4 to 5 times per week (35.0%).

Consumers were presented with 17 beef traits and asked to rate the importance of each trait in terms of purchasing motivation. Results of this are shown in Table 2. "Price" was rated more ($P < 0.05$) important than all traits other than "size, weight and thickness," "color," "USDA Grade," and "marbling," which were not different ($P > 0.05$). Moreover "size, weight and thickness," "color," "USDA Grade," and "marbling" were also rated more important ($P < 0.05$) 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 (Table 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 for tenderness and juiciness, on average. Additionally, consumers were asked to rate samples as acceptable or unacceptable for each palatability trait (Table 3), with all thawing methods having a similar ($P > 0.05$) percentage of samples rated as acceptable. For each trait, all treatments had more than 80.0% of samples rated acceptable. Lastly, a similar ($P > 0.05$) percentage of samples from all treatments were classified at the varying quality levels, with most samples rated as everyday quality (Table 3).

Trained sensory evaluation

As a whole, thawing method had a minimal impact on trained sensory panelist evaluation (Table 4). All thawing methods were similar ($P > 0.05$) for initial juiciness, sustained juiciness, and connective tissue amount. For 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 other thawing methods. Likewise, CW and REF steaks were rated higher ($P < 0.05$) for overall tenderness than COOK and MIC steaks, and CT and HW were similar ($P > 0.05$) to all other treatments for the same trait. Additionally, COOK samples were rated higher ($P < 0.05$) than all treatments for flavor intensity.

Table 3. Least-squares means for consumer sensory evaluation of palatability characteristics,[1] percentage of samples rated acceptable,[2] and perceived quality levels[3] of frozen beef strip loin steaks thawed using various thaw methods

Trait	CT[4]	COOK[5]	CW[6]	HW[7]	MIC[8]	REF[9]	*P*-value	SEM[10]
Palatability rating[1]								
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
Acceptability[2]								
Juiciness	82.6	81.8	92.0	80.9	79.1	80.0	0.17	4.2
Tenderness	82.2	79.9	87.9	91.6	80.6	81.5	0.12	3.9
Flavor	87.4	87.4	91.1	87.4	84.8	85.7	0.80	3.5
Overall	85.2	82.6	95.2	86.3	87.4	83.7	0.13	4.0
Quality rating[3]								
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]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]Percentage of samples rated as acceptable (yes/no) by consumer sensory panelists.

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

[4]Thawed at 17 to 20°C for approximately 5 h, or until internal temperature reached 0°C.

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

[6]Thawed in individual plastic containers of 2 to 3°C water for 24 h.

[7]Thawed in 40°C water for 20 min (±2 min) utilizing a sous vide machine to maintain water temperature.

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

[9]Thawed at 2 to 3°C in open air in a refrigerator.

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

Table 4. Least-squares means for trained sensory panel evaluation (8 panelists/session)[1] of palatability characteristics of frozen beef strip loin steaks thawed using various thaw method

Trait	CT[2]	COOK[3]	CW[4]	HW[5]	MIC[6]	REF[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

[a,b]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 to 20°C for approximately 5 h, or until internal temperature reached 0°C.

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

[4]Thawed in individual plastic containers of 2 to 3°C water for 24 h.

[5]Thawed in 40°C water for 20 min (±2 min) utilizing a sous vide machine to maintain water temperature.

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

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

[8]SEM (largest) of the least-squares means of the same row.

Instrumental quality measurements

Results for instrumental quality measurements are shown in Table 5. 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 had higher ($P < 0.05$) a^* and b^* than MIC steaks. Moreover, WBSF and SSF for all thawing methods were similar ($P > 0.05$). Also, MIC had the highest ($P < 0.05$) cook loss, followed by COOK, with no difference ($P > 0.05$) among the other treatments. Steaks in the MIC treatment had the greatest ($P < 0.05$) amount of cooking loss, followed by COOK steaks having a greater ($P < 0.05$) amount of cooking loss than all of the other treatments, which did not differ ($P > 0.05$). In terms of thawing loss, MIC and HW were similar ($P > 0.05$), but higher ($P < 0.05$) than CT, CW, and REF (MIC = HW > CT = CW = REF). For total moisture loss (a measure of combined cooking and thawing loss), MIC, HW, and COOK were similar ($P > 0.05$), but had a higher ($P < 0.05$) total moisture loss than CW, CT, and REF (MIC = HW = COOK > CT = CW = REF). However, there were no PJP differences ($P > 0.05$) among all treatments. When evaluating raw proximate composition, CW, REF, and HW steaks had a higher ($P < 0.05$) percentage of moisture than COOK, while CT was similar ($P > 0.05$) to all treatments. There were no differences ($P > 0.05$) in lipid oxidation among all treatments. Additionally, COOK had higher ($P < 0.05$) cooked expressible moisture than CT, CW, and REF,

Table 5. Least-squares means for Warner-Bratzler shear force (WBSF), slice shear force (SSF), cooking characteristics, and instrumental cooked color of frozen beef strip loin steaks thawed using various thaw methods

	CT[1]	COOK[2]	CW[3]	HW[4]	MIC[5]	REF[6]	P-value	SEM[7]
L^*[8]	56.7	55.0	56.0	55.3	55.5	55.9	0.16	0.6
a^*[9]	21.3^{a}	18.2^{bc}	20.4^{ab}	20.3^{ab}	16.4^{c}	20.5^{ab}	0.02	1.1
b^*[10]	19.2^{a}	17.7^{bc}	18.9^{ab}	18.7^{ab}	16.9^{c}	18.9^{ab}	< 0.01	0.5
SSF, 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, %[11]	15.0^{c}	18.1^{b}	14.6^{c}	14.4^{c}	19.4^{a}	15.4^{c}	< 0.01	0.5
Thaw loss, %[12]	1.2^{b}	—	0.9^{b}	3.7^{a}	4.2^{a}	0.8^{b}	< 0.01	0.4
Total loss, %[13]	16.1^{b}	18.3^{a}	15.4^{b}	18.1^{a}	19.4^{a}	16.0^{b}	< 0.01	0.8
PJP, %[14]	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[15]	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, %[16]	92.2^{a}	89.9^{b}	92.1^{a}	91.1^{ab}	91.2^{ab}	91.7^{a}	0.03	0.5

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

[1]Thawed at 17 to 20°C for approximately 5 h, or until internal temperature reached 0°C.

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

[3]Thawed in individual plastic containers of 2 to 3°C water for 24 h.

[4]Thawed in 40°C water for 20 min (±2 min) utilizing a sous vide machine to maintain water temperature.

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

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

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

[8]L^*: 0 = black, 100 = white.

[9]a^*: −60 = green, 60 = red.

[10]b^*: −60 = blue, 60 = yellow.

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

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

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

[14]Pressed juice percentage.

[15]mg of Malonaldehyde/kg of meat.

[16]Water holding capacity.

while MIC and HW were similar ($P > 0.05$) to all treatments. Similarly, CT, CW, and REF had a higher ($P < 0.05$) cooked water holding capacity than COOK, and MIC and HW were similar ($P > 0.05$) to all treatments.

Thawing rate, time, and temperature

Thawing rate, time, and temperature data are presented in Table 6 and Figure 1. HW had the highest ($P < 0.05$) thawing rate, followed by CT, with no difference ($P > 0.05$) between REF and CW (HW < CT < REF = CW). Similarly, HW had the fewest ($P < 0.05$) min to thawed, followed by CT, CW, and REF (HW < CT < CW < REF). Moreover, when evaluating sample temperatures at various time points prior to thawing, CW was at a lower ($P < 0.05$) temperature than REF from 13 h to 6 h prior to thawed, but were at a similar ($P > 0.05$) temperature from 5 h until completely thawed. Additionally, CT samples remained at a lower ($P < 0.05$) temperature than CW or REF from 5 h to 2 h prior to thawed and remained at a lower ($P < 0.05$) temperature than REF at 1.5 h prior to thawing. REF, CT, and CW were similar ($P > 0.05$) in temperature from 1 h prior to and up until thawed. HW was at a lower ($P < 0.05$) temperature than CT at 10 min prior to being thawed.

Discussion

Consumer preferences

The most important palatability trait to consumers when consuming beef steaks in recent research,

Table 6. 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]	HW[2]	CT[3]	CW[4]	REF[5]	P-value	SEM[6]
Thaw rate[7]	0.811[a]	0.028[b]	0.010[c]	0.007[c]	< 0.01	0.09
Thaw time[8]	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

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

[1](h : min).

[2]Thawed in 40°C water for 20 min (±2 min) utilizing a sous vide machine to maintain water temperature.

[3]Thawed at 17 to 20°C for approximately 5 h, or until internal temperature reached 0°C.

[4]Thawed in individual plastic containers of 2 to 3°C water for 24 h.

[5]Thawed at 2 to 3°C in open air in a refrigerator.

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

[7]Degrees/min to reach 0°C.

[8]Min to reach 0°C.

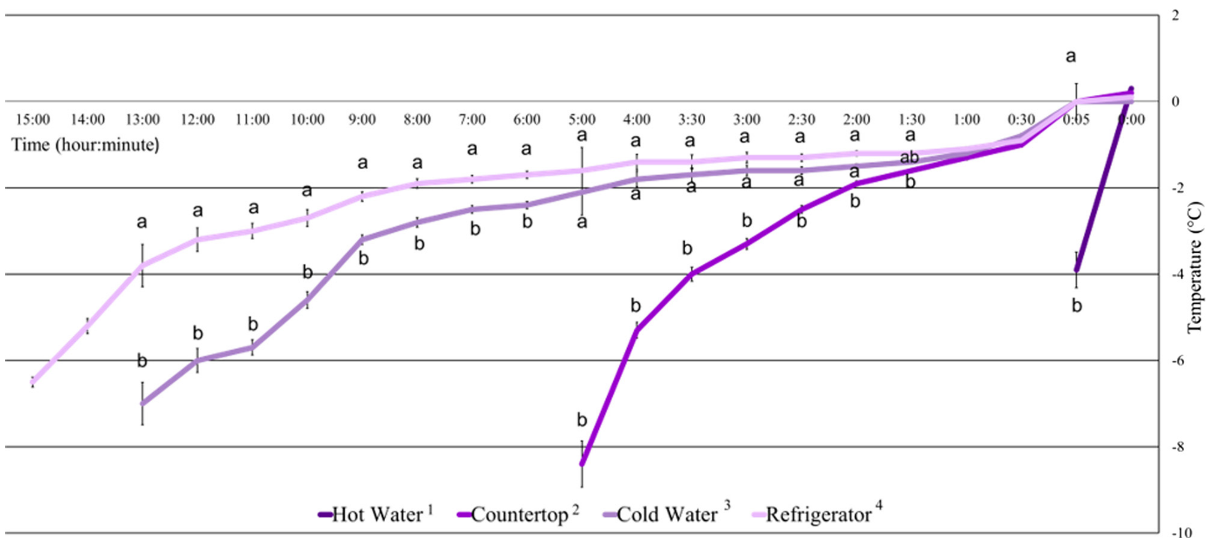

Figure 1. Mean (± SEM) internal temperature for beef strip loin steaks thawed using a variety of thawing methods various hours before thawed (0°C). [ab]Means at the same time-point lacking a common superscript differ ($P < 0.05$), [1]Thawed in 40°C water for 20 min (±2 min) utilizing a sous vide machine to maintain water temperature. [2]Thawed at 17 to 20°C for approximately 5 h, or until internal temperature reached 0°C. [3]Thawed in individual plastic containers of 2 to 3°C water for 24 h. [5]Thawed at 2 to 3°C in open air in a refrigerator.

including the current study, has been consistently flavor (Drey et al., 2019; Beyer et al., 2021; Hernandez et al., 2023). However, consumers in the current study reported finding the most variation in tenderness. Though this has not been a question typically directly asked of consumers in previous studies, Table 7 compiled standard error measures of twenty studies evaluating juiciness, tenderness, flavor, and overall liking by consumer panelists over the past 10 years. These studies used standard error to evaluate the variability within each palatability trait, with a higher standard error indicating more variability within the trait. Across all of the studies, 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 between 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, though were limited in sample number ($n = 5$). 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 impact tenderness (Kim et al., 2011). Despite this apparent increase in power level used in the Zahir (2021) study compared to the current work, our results indicated a tougher product for the MIC samples compared to the REF. This may indicate that microwave duration may play a greater role in tenderness development rather than power level alone.

In an older study, Obuz and Dikeman (2003) evaluated thawing steaks in the refrigerator (4°C) and steaks cooked 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

Table 7. Standard error measures of consumer sensory evaluation for palatability traits from published literature

Study	Juiciness	Tenderness	Flavor	Overall liking	Number of panelists
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]	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., 2019a[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.

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 work. 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. A previous study has reported as cooking surface temperature increases, beef flavor attributes such at beef identification, and brown/roasted flavors increase (Wall et al., 2019). 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 reported 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 discernable by consumer sensory 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 min (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 and lightness 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 by 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 as steaks thawed using other methods. This should be considered by consumers and food-service establishments who use MIC as their thawing method and who prepare steaks to an ordered degree of doneness.

Objective tenderness measurements of thawing methods have been previously evaluated by numerous authors who have 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 among steaks thawed in the refrigerator (3 to 4°C; 18 to 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 steaks thawed in the refrigerator (4°C) and on the counter (20°C). All these results align with those in the current study, where no differences were found among thawing treatments for WBSF or SSF. This further aligns with the consumer sensory data, where consumers found no tenderness differences among all treatment methods. However, trained sensory 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 steaks thawed on the countertop and 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 that utilized in Zahir (2021). It has been shown that microwaving meat as a thawing method may result in uneven thawing, and that this 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 portions of the steak beginning to brown 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, coupled with a rest time after thawing and prior to cooking to allow for the temperature to equilibrate throughout the steak. Therefore, the likelihood of the final MDA concentrations in Zahir (2021) being overestimated due to method, as well as a variation in power level and microwave time between the studies, may explain the differences in results from the current work.

Effects of thawing on moisture loss

There is conflicting literature on the effect of thawing method on 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.

However, in another study, Hergenreder et al. (2013) found conflicting results, in which a more extended thawing time resulted in a higher thawing loss. It is noteworthy that in their 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 shown 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 and thus negatively impact 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 thawing in the refrigerator resulted in the highest thawing loss, followed by thawing in hot water and 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 to 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 having the highest thawing loss, with no differences among thawing in the refrigerator, and in cold water. Of note, Kim et al. (2013) utilized beef frozen 2 d 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 was 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 estimates for what can be expected across a wide variety of thawing methods representative of variations in thawing rates and times.

When evaluating the cooking loss among different thawing methods, 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. However, the current study had far lower total cooking loss, where REF had a cooking loss of 15.4% and COOK had a cooking loss of 18.1%, although this may again be attributed to being cooked on a griddle rather than electric belt grill. 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 study's results of MIC having a higher cook loss than CT or REF. But the current study found CT and REF to be similar for cooking loss, although overall cooking loss was much lower in the current study. Furthermore, cooking loss in Zahir (2021) 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 cooking loss observed by Zahir (2021), as well as the minimal differences in cooking loss results.

Published literature evaluating objective juiciness measures for thawing methods outside of thawing and cooking loss is sparse. Zahir (2021) evaluated water holding capacity for the various thawing methods used in their study. 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 measures 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 as a result of thawing method used.

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 paints 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 heat 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 1.4× greater than CW, further evidencing the increase in heat transfer by water. Additionally, multiple studies have shown higher thawing temperatures have resulted in 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 study, 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 61× faster than CW steaks in terms of thawing time, while CT steaks thawed over 3× 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-FSIS, 2013b). 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.

Conclusions

As a whole, thawing method has minimal impact on the overall quality of beef steaks. Consumers and trained sensory panelists found minimal differences in palatability traits among all thawing methods tested. Nonetheless, a notable thawing loss increase in steaks thawed in hot water and the microwave can have a negative economic impact and reduced fresh meat yield. While there is other published literature evaluating thawing methods, few utilize more than 3 thawing methods nor complete an 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 foodservice establishments should utilize their preferred method when thawing beef steaks, while taking safety, time, and quality into consideration.

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