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Cooking patties from a frozen state, endpoint temperature, and post-cookery chilling affect internal and external color and cooking losses in ground beef patties.

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Abstract

To determine the effects of cooking state (frozen vs. thawed), endpoint temperature (65.5 vs. 73.9°C), and post-cookery chilling on color of ground beef patties, 85% coarse-ground beef was purchased and ground through a 9.5-mm plate, formed into 115-g patties, and crust frozen before 4 patties were vacuum packaged and stored at -10 °C. Packages were either thawed in a water bath for 2 h prior to cooking or cooked directly from frozen. Within each package, patties were weighed before being cooked to their assigned temperature (65.5 or 73.9°C) and either allowed to cool at room temperature on paper plates or placed in a plastic baggie and submerged in an ice water bath. Patty temperature was monitored at 0, 1, 5, 10, 15, and 30 min post-cooking, and patties were reweighed to calculate cook loss percentage before external and internal instrumental color (L*, a*,and b*) was measured on each patty. Patties cooked from frozen, to 73.9°C, or cooled at room temperature had greater ($P < 0.05$) cooking losses than those cooked from a thawed state, to 65.5°C, or cooled in an ice bath, respectively. External color of patties cooked from a thawed state was lighter (greater L*; $P < 0.05$), redder (greater a*; $P < 0.05$), and more yellow (greater b*; $P < 0.05$) than those cooked from frozen. Moreover, L*, a*, and b* values were greater ($P < 0.05$) for the surface of patties cooked to 65.5 than 73.9°C, whereas L*, a*, and b* values were greater ($P < 0.05$) externally for patties cooled in an ice bath than those cooled at room temperature. Internally, patties cooked from frozen, cooked to 65.5°C, or cooled in an ice bath were lighter ($P < 0.05$) than those cooked from a thawed state, cooked to 73.9°C, or cooled at room temperature, respectively. Patties cooked to 65.5°C from a thawed state had the greatest ($P < 0.05$) internal a* and b* values, whereas frozen patties cooked to 73.9°C had the least red and yellow ($P < 0.05$) internal color. Moreover, thawed patties cooked and chilled in an ice bath were redder ($P < 0.05$) internally than other cooking state × cooling method combinations. It was expected that cooking to 65.5°C would result in redder internal cooked color, but persistent redness was also observed when patties were cooked from a thawed, rather than frozen, state and when cooled in an ice bath.

Keywords: Ground beef; Cooked Color, Persistent Pinking,

Introduction

Ground beef is the most popular product of the beef industry, in both the food service and retail sector. Ground beef sales totaled $10.094 billion, accounting for 35% of the total beef dollars (Technomic, 2016). In 2016, 5.023 billion pounds of ground beef were sold, accounting for 64% of the total pound of beef sold (Lundeen et al., 2017). Ground beef makes up approximately 65% of the total beef sales to foodservice industry and nearly 50% of the total beef sold in the retail sector (Lundeen et al., 2017). Full-service restaurants served 1.7 billion pounds of hamburger in 2016, and limited service restaurants (fast food restaurants) served an additional 3.5 billion pounds (Technomic, 2016).

Although ground beef is sold in both fresh and frozen states, cookery state is often dependent on the consumer. The majority of restaurants will cook patties from a preformed, frozen state; however, usage in the home varies. Previous research has shown differences in cooked ground beef color between the cooking states, with the majority reporting that cooking from the frozen produces a redder, rarer looking patty (van Laack, Berry, and Solomon, 1996a; Berry, 2001).

The cooked meat color phenomena of premature browning and persistent pinking have been well documented. Premature browning is a condition in which the internal color of ground beef patties possess a fully cooked color before it has reached the safe minimum internal temperature (71.1^{o}C). This poses a potential food safety issue for consumers. The other condition, persistent pinking, exists when the interior of the ground beef patty still appears pink and undercooked after it has reached the safe minimum internal temperature. This often leads to overcooking and quality losses for consumers. For this reason, recommendations from the USDA are to cook ground beef to an internal endpoint temperature of 71.1^{o}C (USDA FSIS, 2015).

However, using a thermometer to monitor endpoint temperature is still not a common practice among consumers. To ensure a safe, high quality product, more research is needed to find the causes and, thus, ways to prevent these issues in ground beef.

Experiments involving cooked color have no specific protocol for chilling method before analyzing color. Because of this, chilling methods vary from no chilling to cooling at room temperature. Dr. Melvin Hunt at Kansas State University suggested that meat be submerged in ice to stop the cooking process before examining instrumental color. To date, though, no research has examined directly differences in cooked color of ground beef chilled in ice or chilled by other methods. Therefore, the objective of this study was to determine the effects of cooking state, endpoint temperature, and chilling method on external and internal instrumental color and cooking losses in ground beef.

Literature Review

Muscle Composition

Muscle is comprised of approximately 75% water, 20% protein, 3% fat, and 2% non-protein substances. The non-protein substances consist of 45% non-protein nitrogen-containing substances, 34% carbohydrates, 18% inorganic compounds, and 3% metals and vitamins (Tornberg, 2005). According to Tornberg (2005), the proteins in meat can be broken down to three main categories: myofibrillar proteins (50 to 55% of total protein), sarcoplasmic proteins (30 to 34% of total protein), and stromal, or connective tissue proteins, (10 to 15% of total protein). Proteins are the primary compound that provide the structure to the meat product. (Tornberg, 2005).

Protein Structure

Proteins, also known as polypeptides, are made of long chains of amino acids (Tornberg, 2005). Amino acids share a basic structure and differing side chains. The interactions between the amino acid side chains in a protein strand determine the form of the protein molecule. Proteins have four different structural levels: primary, secondary, tertiary, and quaternary.

The primary structure is made of the chain of amino acids and is determined by DNA translation. The type of amino acids in the primary structure will determine the form of the protein in the secondary structure. In the secondary structure, the protein can be arranged in an alpha-helix, a beta-sheet, or other random coils (Tornberg, 2005). During formation of the tertiary structures, the side chains of the amino acids in the protein will interact with each other to form a three-dimensional structure (Tornberg, 2005). These tertiary structure subunits can then interact with each other forming a quaternary structure. These interactions are often a mixture of van der Waal's forces, hydrogen bonding, and hydrophobic interactions (Tornberg, 2005).

Globular proteins, such as myoglobin, are formed through the hydrophobic interactions at the tertiary level. Fibrous proteins, such as the structural meat proteins actin and myosin, as well as the most abundant connective tissue protein collagen, are comprised primarily of alpha-helices and anti-parallel beta-pleated sheets (Tornberg, 2005). Upon heating, protein structure is changed in a process called denaturation. During cooking, typically the fibrous proteins will contract while the globular proteins will expand (Tornberg, 2005).

Myoglobin

The primary protein that determines the color of fresh meat is the sarcoplasmic protein myoglobin. It is the heat denaturation of this protein that gives cooked meats the dull-brown, characteristic cooked color (Suman et al., 2016). The variety of pigments formed in cooked meats can be attributed to the state of myoglobin in raw meat.

Myoglobin exists in three states: deoxymyoglobin, oxymyoglobin, and metmyoglobin. Deoxymyoglobin contains the reduced ferrous iron form (Fe^{2+}) and is found in the absence of oxygen (this produces a purple-red fresh meat color). This state exists in the center of meats and when meat is stored in vacuum packaging (King and Whyte, 2006). When deoxymyoglobin is exposed to oxygen, the reduced iron will bind to the oxygen, forming oxymyoglobin (this produces the favorable bright red fresh meat color; King and Whyte, 2006). When meat is stored in an oxidizing environment, the iron in the deoxymyoglobin and oxymyoglobin can be oxidized to the ferric state (Fe^{3+}) and the resulting pigment that is formed is called metmyoglobin, which produces an undesirable brown color (King and Whyte, 2006).

The three forms of myoglobin will denature at different rates and form different end products. When metmyoglobin is denatured, ferrihemochrome is formed, which gives a dull-brown color. Denaturation of deoxymyoglobin and oxymyoglobin forms ferrohemochrome, which is pink-red in color, but will be oxidized to form ferrihemochrome (Suman et al., 2016). However, if the heme iron remains in the ferrohemochrome state, it is possible that a pink color will remain in the cooked meat (Suman et al., 2016).

Myoglobin and other proteins begin to denature between 55 and 65°C, with almost all denaturation occurring between 75 and 80°C (King and Whyte, 2006). However, myoglobin has various resistance to heat denaturation, depending on the state it exists in. Deoxymyoglobin in the most heat resistant formed, metmyoglobin is the least heat resistant form, and oxymyoglobin has an intermediate heat resistance (Suman et al., 2016). Therefore, meat with high concentrations of deoxymyoglobin is more prone to persistent pinking than meat containing higher amounts of metmyoglobin or oxymyoglobin (Suman et al., 2016). On the other hand, when fresh meat contains higher amounts of oxymyoglobin or metmyoglobin, it is more susceptible to experience premature browning (Kropf and Hunt, 1998).

Functions of Cooking

Cooking meat has two main functions to the consumer. First, the cooking of meat changes the product to one having a favorable texture and taste to the consumer. Secondly, cooking meat will deactivate any microorganisms that could be harmful to the consumer (King and Whyte, 2006). The original recommendation given to consumers by the USDA-FSIS (1989) was to cook meat patties until the juices run clear. Furthermore, the statement said the center of the patty should be a grayish-brown color and have no evidence of pink (Kropf and Hunt, 1998). These recommendations were amended in 1997 after numerous research projects disproved the reliability of using cooked color as an indication of doneness. The most recent USDA recommendations state that ground meat products should be cooked to an internal temperature of 71^{o}C (Kropf and Hunt, 1998).

The new guidelines came about after researchers discovered two phenomena that were occurring in meat products, especially ground beef. These phenomena were termed premature browning and persistent pinking.

Premature Browning

Premature browning occurs when the interior portion of a ground beef patty will appear brown and thoroughly cooked before it has reached an internal temperature (71.1^{o}C) great enough to inactivate microorganisms. Premature browning has been found to occur at temperatures as low as 55^{o}C (Kropf and Hunt, 1998). Factors that have been noted to have potential for premature browning include, meat that is pale, soft, and exudative (PSE), packaged in an aerobic or oxygenated environment, cooked after a long thaw, or frozen in bulk (King and Whyte, 2006).

Persistent Pinking

On the other hand, persistent pinking occurs when the inside of a patty still appears pink, even after it has reached a safe internal temperature. This is especially an issue in the food service industry, where consumers are unlikely to accept a product that is still appearing pink internally (Ryan et al., 2006). Although internal color is not an accurate measure of meat safety, many consumers still base food safety on color (Suman et al., 2016). Some of the factors that may increase the potential for persistent pinking include, meat products with a high pH, products that are dark, firm, and dry (DFD), products that stored in a modified atmosphere packaging that includes carbon monoxide, vacuum packaging, cooking from frozen, or cooking after a short thaw (Ryan et al., 2006).

In order to combat the problem of persistent pinking, the initial thought was to cook product to higher temperatures to eliminate the pink color. Studies by Ryan et al. (2006) found that an increase in endpoint temperature would generally lower the internal redness (a*) and vividness (C*), but that the extent of that change was dependent upon the rate of cooking. It was also assumed that with an increase in internal temperature came a decrease in tenderness and juiciness. Berry and Bigner-George (1999) found that cooking patties to between 81 and 85^{o}C did result in lower a* values, higher hue angles, and higher degree of doneness scores, but patties cooked to these temperatures had lower initial and final juiciness compared to patties cooked to 71^{o}C.

Effects of Cooking State

The effects of cooking patties from a frozen or thawed state have been inconsistent across previous research projects. Even though some studies have found thawed patties to appear more well done than frozen patties (van Laack, Berry, and Solomon, 1996a; Berry, 2001), other studies found no difference in visual color when cooking from frozen or thawed (Berry 1998b). Additionally, some studies have suggested the effects of freezing for long periods of time causes unexplained changes in cooked color (van Laack, Berry, and Solomon, 1996b).

van Laack, Berry, and Solomon (1996a) found thawed patties had lesser cooking losses and shorter cooking times, whereas thawed patties appeared more well done visually with doneness scores increasing as thaw time increased. Additionally, instrumental color readings supported this, as thawed patties were less red (lower a*) and less vivd (lower C*), with a greater hue angles (van Laack et al., 1996a). These researchers hypothesized that the thawing process produced physical or chemical changes that would affect myoglobin denaturation and, in turn, cooked color. It was concluded that refreezing patties would not reverse the effects of thawing. The second trial of the study echoed these results, as thawed patties were more done visually than frozen patties, which appeared more done than fresh patties. Additionally, thawed patties had the greatest myoglobin denaturation percentage; however, thawed patties were also more prone to premature browning.

An additional study by van Laack et al. (1996b) report that internal redness (a* values) was related to the denaturation of myoglobin. More importantly, they found that patties with a high pH did not always result in persistent pink patties, but pH appeared to be related to myoglobin denaturation. In the second trial, however, van Laack et al. (1996b) reported no correlation between a* values and myoglobin denaturation. Although not all myoglobin was denatured at high pH values, other unexplained factors seemed to play a role in the denaturation process. Additionally, though it was obvious storing the patties led to changes in cooked color, those changes could not be explained by the metmyoglobin content or changes in reducing capacity.

Berry (1998b) reported greater cooking yields and shorter cooking times for patties cooked from thawed compared to those cooked from frozen. Visually, the degree of doneness was unaffected by cooking state; however, instrumental color indicated thawed patties were lighter (greater L*), had greater hue angles, and were generally more vivid colored (greater C*). Frozen patties containing either 5, 20, or 25% fat were redder (greater a*) than thawed patties, whereas patties cooked from thawed were more yellow (greater b*) at all fat levels, except 5%. Most important, all patties in the study exhibited persistent pinking.

A second study by Berry (2001) found that thawed patties had shorter cooking times and greater cooking yields compared to frozen patties. The internal color of thawed patties had greater L*, and lower a* and b* values, as well as greater hue angles and lower C* values compared to frozen patties. Visually, thawed patties appeared more done than frozen patties; however, the mean visual color scores for both treatments indicated pink colors were present in most patties.

Hunt, Sorheim, and Slinde (1999) reported patties cooked from thawed were redder (greater a*) and had a smaller hue angle, regardless of the oxidative state of myoglobin. Thawed patties were more yellow (greater b*) and more vivid (greater C*) than frozen patties only when myoglobin was present in the deoxymyoglobin state.

Effects of Endpoint Temperature

In general, studies have consistently shown that cooking patties to a greater internal temperature produces a visually more well done product. However, instrumental color has varied across and within certain studies.

When comparing ground beef patties of different blends, Berry (1998a) reported that patties cooked to 68.3°C were more yellow (greater b*), more vivid (greater C*), had a smaller hue angle, and required a shorter cooking time than patties cooked to 71.1°C, regardless of patty composition. Redness (a*) was only different among the endpoint temperatures when patties consisted of young cow hindquarter muscle processed immediately after slaughter. In this blend, patties cooked to 68.3°C were redder than patties cooked to 71.1°C. Berry and Bigner-George (1999) found that patties cooked to between 81 and 85°C were less red (lower a*), less vivid (lower C*), and had greater hue angles than patties cooked to 71°C; however, lightness (L*) and yellowness (b*) were not affected by increased internal temperatures.

Ryan et al. (2006) found differing results when patties were cooked rapidly (1.0°C/s) from an oxymyoglobin compared to a deoxymyoglobin state. In the oxymyoglobin state, patties were lighter (greater L*) at 71.1 or 76.7°C than at 82.2°C. Patties were more yellow (greater b*) at 82.2°C than 71.1 or 76.6°C. Additionally, patties were most vivid (greater C*) at 82.2°C, whereas redness (a*), visual doneness, and percent denatured myoglobin did not vary across endpoint temperatures. Although L* and b* values did not differ among internal endpoint temperatures, when patties were in the deoxymyoglobin state, those cooked to 71.1°C were the reddest (greatest a*) and patties cooked to 82.2°C were the least red (lowest a*). Conversely, patties cooked to 82.2°C appeared more done than those cooked to 76.6°C or 71.1°C. Additionally, the proportion of denatured myoglobin was greatest for patties cooked to 82.2°C, whereas patties cooked to 71.1°C had the least percentage of denatured myoglobin, and patties cooked to 76.7°C were intermediate.

Brewer and Novakofski (1999) reported that increases in internal temperature had a greater effect on cook loss at low pH (5.3 to 5.5) than at high pH (6.0). Additionally, interactions between pH and endpoint temperature existed for lightness (L*), redness (a*), and yellowness (b*) values. As pH values increased, higher endpoint temperatures were needed to achieve similar redness values, whereas the yellowness (b*) at each endpoint temperature decreased with increasing patty pH.

Troutt et al. (1992) reported patties varying in lean percentage had greater cooking losses and cooking times when cooked to an internal temperature of 77 than 71°C. Additionally, patties were lighter (greater L*) and appeared less done visually when cooked to 71°C compared to 77°C. However, redness (a*) and yellowness (b*) values did not differ among endpoint temperatures.

Effects of Chilling

The chilling method used before examining instrumental color differs widely between experiments. Although some choose to chill in an ice bath after cooking (Ryan et al., 2006), others chose to cool at room temperature for varying times (Hunt et al., 1999; Warren, Hunt, & Kropf; 1996; van Laack et al., 1996a, 1996b;) or not at all (Brewer & Novakofski, 1999; Berry & Bigner-George, 1999; Berry 1998a, 1998b; Mendenhall, 1989). However, a direct comparison of the effects of different chilling method on color has not been reported in literature.

Effects of Myoglobin State

It has been discovered in previous studies that premature browning and persistent pinking have been linked to the state of myoglobin in meat. Premature browning is more likely to occur in meats with high concentrations of oxymyoglobin or metmyoglobin, while persistent pinking is most often seen in meats with high percentages of deoxymyoglobin (Suman et al., 2016).

Warren, Hunt, and Kropf (1996) found patties formulated from sources known to produce a normal color cooked to 55°C where lightest (greatest L*), reddest, (greatest a*), and most vivid (greatest C*) when cooked in the reduced state (deoxymyoglobin or oxymyoglobin). Visually, these patties appeared the most rare. However, patties of the same formulation that were oxidized were the darkest (lowest L*), least red (lowest a*), and least vivid (lowest C*). Additionally, these patties appear the most well done visually. The results confirmed that oxidative state of the raw patty was in fact important in determining cooked color.

Ryan et al. (2006) found that patties cooked from the deoxymyoglobin state were lighter (greater L*), redder (greater a*), more vivid (greater C*), had a lesser percentage of denatured myoglobin, and visually appeared more rare than patties in the oxymyoglobin state across three different endpoint temperatures. Additionally, Hunt, Sorheim, and Slinde (1999) reported that patties containing metmyoglobin or oxymyoglobin had greater hue angles and a greater percentage of denatured myoglobin, whereas patties containing deoxymyoglobin were redder (greater a*), more yellow (greater b*), and more vivid (greater C*) than all other patties.

Effects of Lean Percentage

The effects of lean percentage on instrumental color has been shown to vary, but, in general, differences in lean percentage have not been found to effect visual doneness. Berry

(1998b) compared ground beef at different lean percentages and found that patties containing 25% fat had the greatest cooking loss, whereas those that were 5 or 10% fat had the least cooking loss. As the lean percentage of patties decreased, hue angles increased, but visual doneness did not differ with differing lean percentages, with a pink color found in all fat levels. Troutt et al. (1992) compared ground beef ranging from 70 to 95% lean and reported that as fat level increased, internal cooked color of patties became lighter; however, no differences were found in a* or b* among lean percentages, nor did visual doneness scores differ among lean percentages.

Effects of Cooking Rate

Ryan et al. (2006) examined the effects of a slow cooking rate (0.2^{o}C/s), rapid cooking rate (1^{o}C/s), or rapid cooking rate with a holding time (1^{o}C/s, 6 min post cooking hold time) at different endpoint temperatures and found that patties cooked rapidly to either 65.6 or 71.1^{o}C were redder (greater a*), more vivid (greater C*), visually appeared less done, and less myoglobin denaturation than patties that had a holding time or patties cooked at a slow rate. At higher endpoint temperatures (82.2 vs. 87.8^{o}C), patties cooked at a rapid rate did not differ from those with a holding time in redness, vividness, or visual doneness. However, Brewer and Novakofski (1999) found no differences in cooking loss, visual doneness, or instrumental color when comparing ground beef cooked at a slow rate (0.7^{o}C/min) to a rapid rate (3^{o}C/min).

Materials and Methods

Patty Formation

Frozen, vacuum-packaged lean (85%) coarse-ground beef was purchased from a national beef supplier (Cargill Meat Solutions, Wichita, KS) and thawed 2 days at 4°C before grinding through a 9.5-mm plate. Then, 115-g patties were formed using a commercial patty-forming machine (Hollymatic Corporation, Countryside, IL), crust frozen 1 hour at -20°C, and subsequently vacuum packaged (4 patties/package) and stored at -10°C.

Treatments

Packages of patties were assigned randomly to either cooking from a frozen or thawed state (two hours in a 4°C water bath). Then, within each package one patty was assigned randomly to one of four treatments in a 2×2 factorial arrangement, with two internal endpoint temperatures (65.5 vs. 73.9°C) and two chilling methods (ice bath vs. no ice; each treatment contained 30 patties).

Cookery and Chilling

All patties were cooked on an electric griddle (National Presto Industries, Inc. Eau Claire, WI) preset to 204.4°C to the assigned endpoint temperature. Patties were turned every two minutes, and temperature was monitored using a hand-held thermometer, with the probe inserted into the geometric center of each patty. After reaching the endpoint temperature, patties were either allowed to cool at room temperature (25°C) or placed in a plastic baggie and immediately submerged in an ice-water bath.

Data Collection

Patties were weighed prior to cooking and after cooling to calculate cooking loss percentage. In addition, post cookery temperature change was monitored in the geometric center of the patty at 0, 1, 5, 10, 15, and 30 minutes during cooling using a hand-held thermometer. After cooling, external (surface) instrumental color (L*, a*, b*, C*, and hue angle) was measured in triplicate on each patty using the MiniScan EZ spectrophotometer (Hunter Associates Laboratory, Inc., Reston, VA, USA) using Illuminant A and a 2.54-cm aperature. Then, patties were sliced parallel to the surface in the middle of the patty, and internal (interior) instrumental color (L*, a*, b*, C*, and hue angle) was measured in triplicate on each patty using the MiniScan EZ spectrophotometer (Hunter Associates Laboratory, Inc., Reston, VA, USA). The miniscan was standardized against the white and black tile at the beginning of each day and as prompted.

Data Analysis

Data were analyzed in PROC MIXED of SAS (SAS Institute Inc., Cary, NC). The experimental unit for data analysis was the individual patty. Post-cookery temperature decline was analyzed as a repeated measure, with patty as the subject. Least square means were statistically separated at $P \leq 0.05$ using paired t-tests (PDIFF option of SAS). There were no three-way interactions (cooking state × endpoint temperature × chilling method, $P \geq 0.06$).

Results

Cooking State

Frozen patties exhibited greater cooking loss than thawed patties (cooking state × chilling, $P = 0.04$; Figure 1). Externally, patties that were cooked from thawed were lighter (greater L*; $P = 0.001$), redder (greater a*; $P < 0.001$), more yellow (greater b*; $P < 0.001$), and more vivid (greater C*; $P < 0.001$) than patties cooked from frozen (Table 1). Among patties cooled at room temperature, those cooked from thawed state had greater hue angles than those cooked from frozen (cooking state × chilling, $P = 0.003$; Figure 2). Among those chilled in an ice bath, there were no differences in hue angle between frozen and thawed patties.

Internally, thawed patties were lighter ($P < 0.001$) than patties cooked from frozen (Table 1). At both endpoint temperatures, thawed patties were redder than frozen patties (cooking state × endpoint temperature, $P < 0.001$; Figure 3). Thawed patties cooked to 65.5^{o}C were the most yellow internally and frozen patties cooked to 65.5^{o}C were the least yellow, but b* values did not differ between thawed patties cooked to 73.9^{o}C and frozen patties cooked to 65.5^{o}C (cooking state × endpoint temperature, $P < 0.001$; Figure 4). In addition, frozen patties cooled at room temperature were more yellow than those chilled in an ice bath (cooking state × chilling, $P = 0.002$; Figure 5). At both endpoint temperatures, patties cooked from the thawed state were more vivid than those cooked from frozen (cooking state × endpoint temperature, $P < 0.001$; Figure 6). Patties cooked from frozen had greater hue angles for both chilling methods (cooking state × chilling method, $P = 0.015$; Figure 7) and at both endpoint temperatures (cooking state × endpoint temperature, $P = 0.001$; Figure 8)

Endpoint Temperature

Cooking loss was greater for patties cooked to 73.9°C than 65.5°C ($P < 0.001$; Figure 9). Externally, patties that were cooked to an internal temperature of 65.5°C were lighter ($P < 0.001$), redder ($P < 0.001$), more yellow ($P = 0.001$), and more vivid ($P < 0.001$) than patties cooked to 73.9°C (Table 1).

Internally, patties cooked to 65.5°C were lighter ($P = 0.032$) than patties cooked to 73.9°C (Table 1). Patties that were cooked to 65.5°C were redder than those cooked to 73.9°C (cooking state × endpoint temperature, $P < 0.001$; Figure 4). Patties cooked to 65.5°C were more yellow than patties cooked to 73.9°C. Although a* values did not vary among patties cooked to 65.5°C, between patties cooked to 73.9°C those cooled at room temperature were more yellow internally than those chilled in an ice bath (endpoint temperature × chilling, $P = 0.045$; Figure 10). Patties cooked to an internal temperature of 65.5°C were more vivid than patties cooked to 73.9°C (cooking state × endpoint temperature, $P < 0.001$; Figure 6). Additionally, patties that were cooked to the greater internal temperature had greater hue angles than patties cooked to the lower endpoint temperature (cooking state × endpoint temperature, $P = 0.001$; Figure 8).

When post-cookery temperature decline was measured, as expected, patties that were cooked to 73.9°C started at a greater temperature than those cooked to 65.5°C. Temperature increased slightly between 0 and 1 min for patties cooked to 65.5°C, but temperature then decreased from 1 to 30 min. The internal temperature for patties cooked to 73.9°C declined throughout the entire post-cookery period. The patties reached the same internal temperature after chilling for 30 minutes (Endpoint temperature × time, $P < 0.001$; Figure 11).

<u>Chilling Method</u>

Frozen patties that were allowed to cool at room temperature had greater cooking loss than those chilled in an ice bath (cooking state × chilling, $P = 0.04$; Figure 1). Externally, patties that were chilled in an ice bath were lighter ($P < 0.001$), redder ($P = 0.012$), more yellow ($P < 0.001$), and more vivid ($P < 0.001$) than patties cooled at room temperature (Table 1). Additionally, patties chilled in an ice bath had greater hue angles than those cooled at room temperature (cooking state × chilling, $P = 0.003$; Figure 2).

Internally, those chilled in an ice bath were lighter ($P < 0.001$) than patties cooled at room temperature (Table 1). Among the thawed patties, those that were chilled in an ice bath were redder than those cooled at room temperature (cooking state × chilling, $P = 0.002$; Figure 12). Among frozen patties, there were no differences in a* values for those cooled at room temperature and those chilled at room temperature. Frozen patties cooled at room temperature were more yellow than those chilled in an ice bath (cooking state × chilling, $P = 0.002$; Figure 5). However, among thawed patties b* values did not differ between chilling methods. Furthermore, between patties cooked to 73.9^{o}C, patties cooled at room temperature were more yellow internally than those chilled in an ice bath, while b* values did not differ between chilling methods when patties were cooked to 65.5^{o}C (endpoint temperature × chilling, $P = 0.045$; Figure 10). Between patties cooked from thawed, those chilled in the ice bath were more vivid than those cooled at room temperature (cooking state × chilling, $P = 0.001$; Figure 13). Among frozen patties, there was no difference in C* values for those cooled at room temperature and those chilled in an ice bath. Patties cooked from frozen that were allowed to cool at room temperature had the greatest hue angles. Thawed patties that were chilled in an ice bath had the smallest hue angles, and frozen patties cooled in an ice bath and thawed patties cooled at room temperature were intermediate (cooking state × chilling method, $P = 0.015$; Figure 7).

While patties chilled in an ice bath and those cooled at room temperature started out at the same temperature at time 0, patties cooled at room temperature had a slight increase in internal temperature between times 0 and 1 before declining steadily. Patties chilled in an ice bath declined throughout the chilling period, and saw the greatest decrease between time 0 and 5 minutes, with internal temperature dropping over 20°C. Additionally, patties chilled in an ice bath had a final internal temperature at less than 10°C after 30 minutes, while those cooled at room temperature had a final internal temperature at just under 35°C at 30 minutes (chilling × time, $P < 0.001$; Figure 14).

Discussion

Cooking State

Patties cooked from thawed were lighter (greater L*), redder, (greater a*), more yellow (greater b*), and more vivid (greater C*) externally. This was to be expected, as the cooking time for frozen patties was on average 267.7 seconds longer ($P < 0.05$) than for thawed patties (Table 1). Thawed patties exhibited less cooking loss than frozen patties. This agreed with previous studies (van Laack, Berry, and Solomon, 1996a; Berry, 1998b; Berry, 2001). This also agrees with the shorter cooking times for the thawed patties. Additionally, patties that were thawed were susceptible to more water lost during the thawing process, which would lead to less cooking loss.

Patties cooked from thawed were also lighter internally compared to those cooked from frozen, as previously found in a study by Berry (2001). Thawed patties were also redder internally, agreeing with results reported by Hunt, Sorheim, and Slinde (1999). However, other studies (Berry, 2001; Berry, 1998b; van Laack, Berry, and Solomon, 1996a) found frozen patties to be redder internally. Thawed patties were more yellow than frozen patties, as found previously by Berry (1998b) and Hunt, Sorheim, & Slinde (1999). Conversely, Berry (2001) found thawed patties to have decreased b* values than frozen patties. Thawed patties were found to be more vivid than frozen patties, agreeing with results by Berry (1996b) and Hunt, Sorheim, and Slinde, (1999) Conversely, Berry (2001) and van Laack, Berry, and Solomon (1996a) found frozen patties to be more vivid.

Thawed patties had greater variation in internal color than frozen patties did. This agrees with van Laack, Berry, and Solomon (1996a) who stated the thawing process caused physical and chemical changes that could not be reversed by refreezing. These unexplained changes could be contributing factors to the variation within thawed patties. Additionally, when comparing differences in results across studies, these difference could be linked to variations in thawing times and conditions between various studies.

Endpoint Temperature

Externally, patties cooked to the lower endpoint temperature (65.5^{o}C) were lighter, redder, more yellow, and more vivid than patties cooked to a higher endpoint temperature. Cooking loss was greater for patties cooked to 73.9^{o}C than for patties cooked to 65.5^{o}C, which agrees with previous work by Trout et al. (1992). The main cause for external color differences and cooking loss can likely be attributed to shorter (P < 0.05; Table 1) cooking times for patties cooked to 65.5^{o}C (564.4 seconds versus 663.8 seconds).

Internally, patties cooked to 65.5^{o}C were lighter than patties cooked to 73.9^{o}C. Ryan et al. (2006) had similar results, but only found differences when the myoglobin in the patty was in the oxymyoglobin form. Similarly, Troutt et al. (1992) found patties cooked to a lower degree of doneness were lighter than those cooked to greater degrees of doneness. Additionally, Berry and Bigner-George (1999) found no differences in lightness across various endpoint temperatures.

Patties cooked to a lower endpoint temperature were redder internally. Previous work by Brewer and Novakofski (1999) found similar results, Ryan et al. (2006) found that if patties were in the deoxymyoglobin state, redness increased with decreasing endpoint temperature. However, the same study noted that if patties were in the oxymyoglobin state, redness values did not differ among different endpoint temperatures. Berry (1998a) noted similar results, as redness values only differed across endpoint temperatures in certain blends. Conversely, Troutt et al. (1992) found no differences in redness values across different endpoint temperatures.

Patties cooked to 65.5^{o}C were more yellow than those cooked to 73.9^{o}C, which agrees with previous findings by Berry, 1998a. Ryan et al. (2006) only found differences in yellowness when patties were in the oxymyoglobin state, and additionally, found that patties cooked to a greater degree of doneness were more yellow. Brewer and Novakofski (1999) found that yellowness values at each endpoint temperatures decreased as the pH of the patty increased. Troutt et al. (1992) and Berry and Bigner-George (1999) reported no differences in yellowness values across endpoint temperatures.

Furthermore, patties cooked to a lower endpoint temperature were more vivid than those cooked to a higher endpoint temperature. This agrees with results of Berry (1998a) and Berry and Bigner-George (1999). However, Ryan et al. (2006) found vividness to be related to the state of myoglobin, reporting patties in the oxymyoglobin state were more vivid at a higher degree of doneness while patties cooked from the deoxymyoglobin state were more vivid at a lower degree of doneness.

Two different endpoint temperatures were chosen for this study, one below the minimum safe internal temperature and one above to create different color conditions. However, a persistent pink color was seen at 73.9^{o}C.

<u>Chilling Method</u>

No previous research was found comparing differences in chilling method on external or internal color. However, when chilled in an ice bath, patties were lighter, redder, more yellow, and more vivid externally than those that were allowed to cool at room temperature. Internally, patties chilled in the ice bath were lighter, redder when cooked from thawed, and more vivid when cooked from thawed than those that were allowed to cool at room temperature. These differences might be attributed to the changes in post-cookery temperature for the different chilling methods.

When comparing temperatures changes, those that were allowed to cool at room temperature increased in internal temperature between zero and one minute, before declining. Conversely, patties that were chilled in the ice bath declined throughout the entirety of the chilling period. Additionally, patties that were chilled in an ice bath reached a final internal temperature of less than 10^{o}C after the 30 minute chilling period, while those that were cooled at room temperature were still at 35^{o}C.

These differences in internal temperature likely affected myoglobin denaturation throughout the entirety of the chilling process, causing variations in internal color. Similarly, surface temperature could have undergone similar changes leading to external color differences between chilling methods. It is also plausible that variations in cooling methods between different studies could impact cooked color results, as there is no set protocol for chilling before taking color readings.

Conclusions

Cooking from frozen instead of thawed, cooking to different internal endpoint temperatures, and chilling in an ice bath or at room temperature caused differences in external and internal instrumental color. Cooking from thawed, to a lower endpoint temperature, and chilling in an ice bath produced patties that were lighter, redder, more yellow, and more vivid externally. Similarly, those conditions produced patties that were lighter, redder, and more vivid internally. Most importantly, persistent pinking was observed when patties were cooked from thawed and when patties were cooled in an ice bath.

Differences in cooking state differed from results of previous studies. The inconsistencies show further proof that cooked meat color is a dynamic process that is effected by the interaction of many different factors. It is certain that many other factors have been found to play a role in variation in cooked color including but not limited to cooking method, pH, myoglobin state, and the age of the animal at harvest. While these factors did not contribute to differences within this study, it is possible that they lead to differences between this study and previous research. Since this data was not recorded, they cannot be compared. To further understanding the phenomena associated with cooked color, more research should be done to further examine the relationship these factors have with the cooking state, endpoint temperature, and chilling methods.

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Figures and Tables

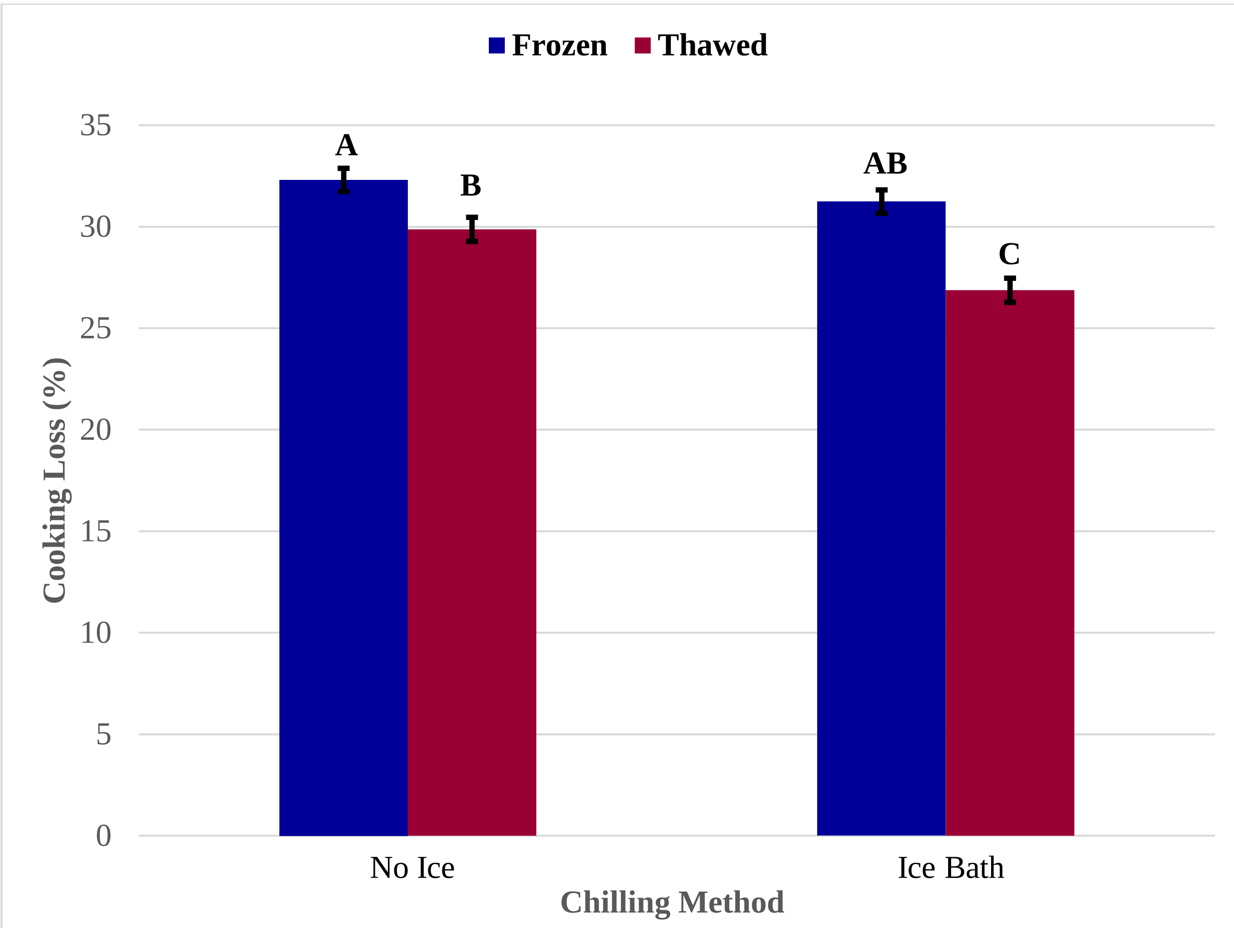

Figure 1. Interaction effect of cooking state × chilling method on cooking loss percentage (*P* = 0.04).

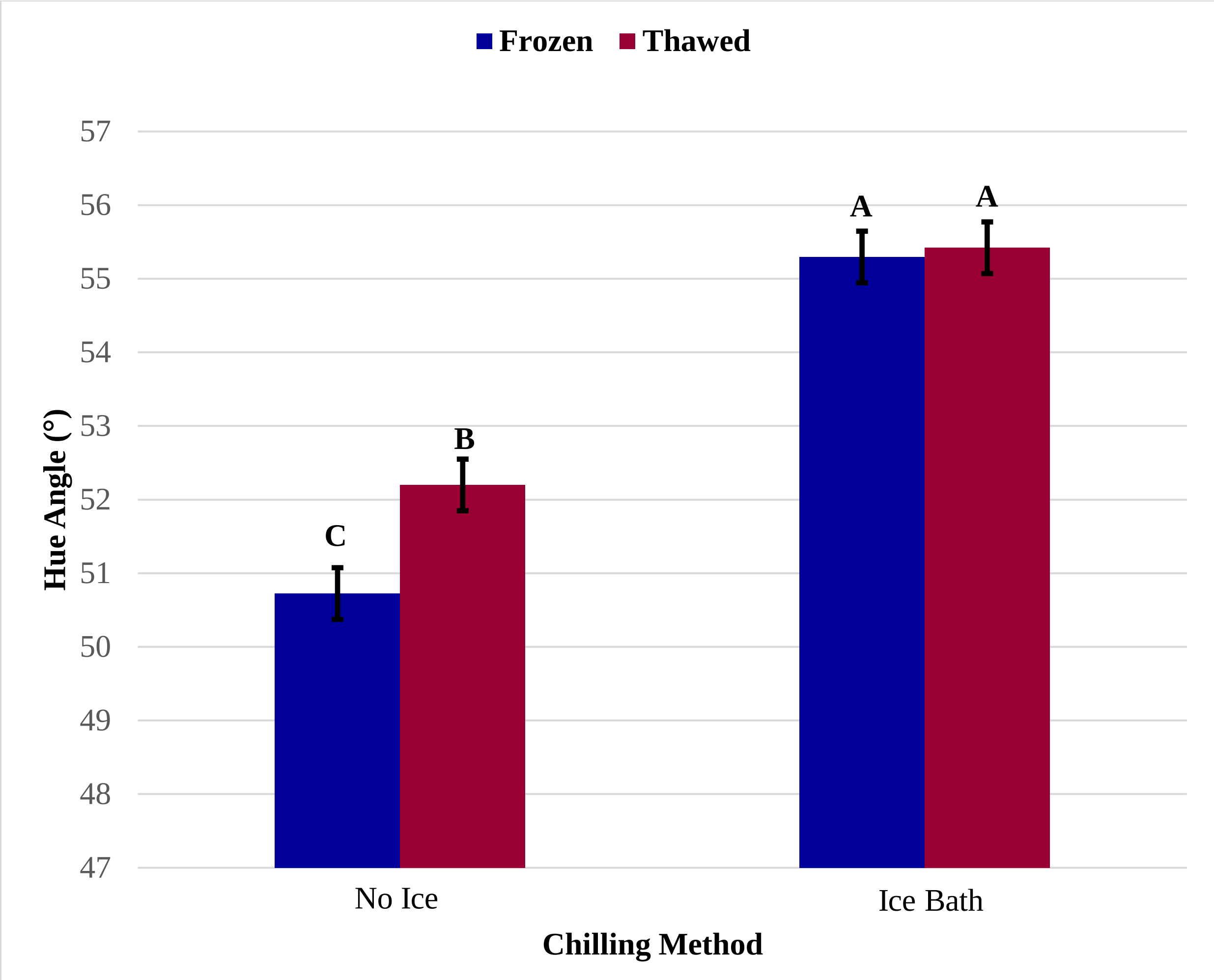

Figure 2. Interaction effect of cooking state × chilling method on external hue angle (P = 0.003).

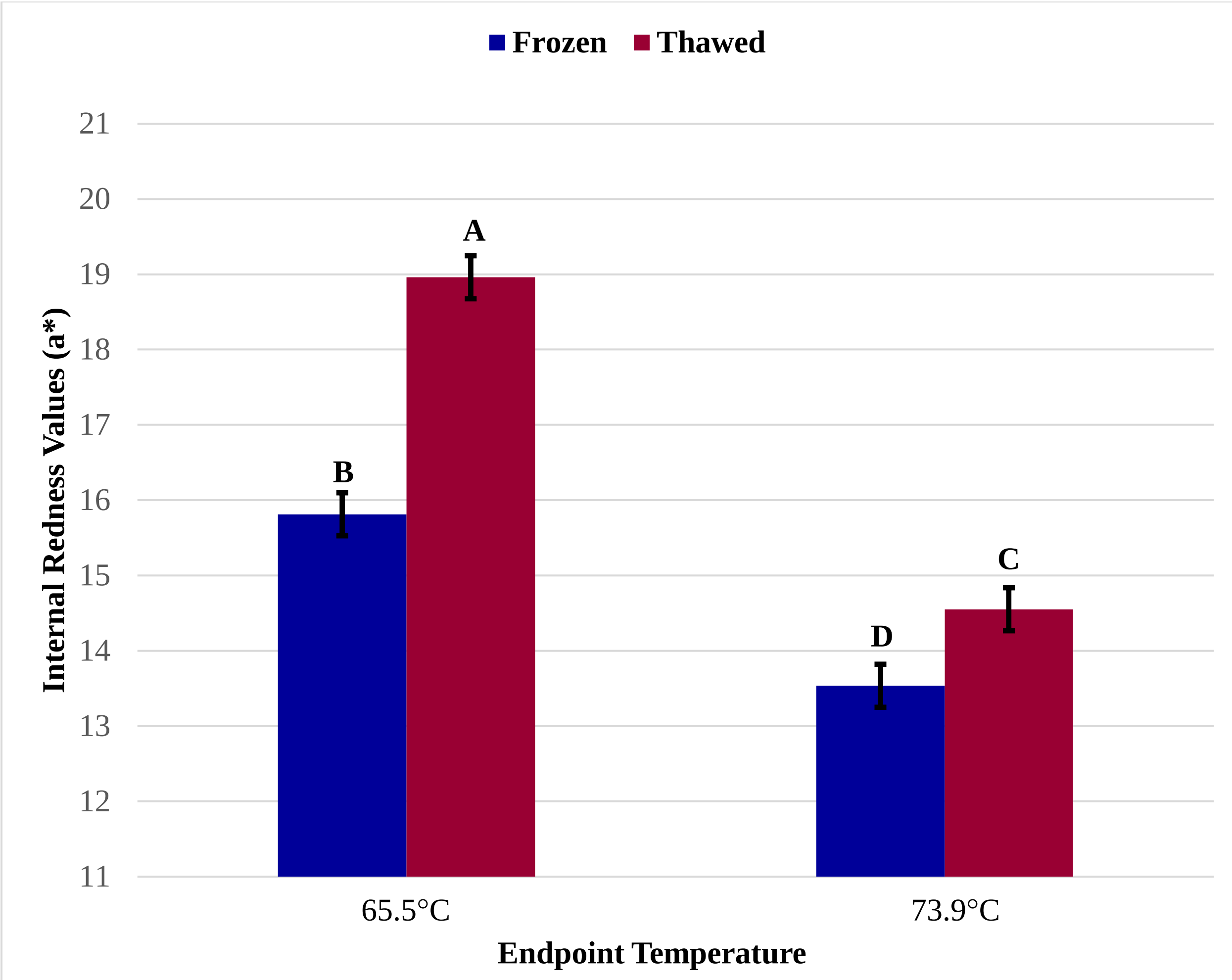

Figure 3. Interaction effects of cooking state × endpoint temperature on internal redness (a*) values (*P* < 0.001).

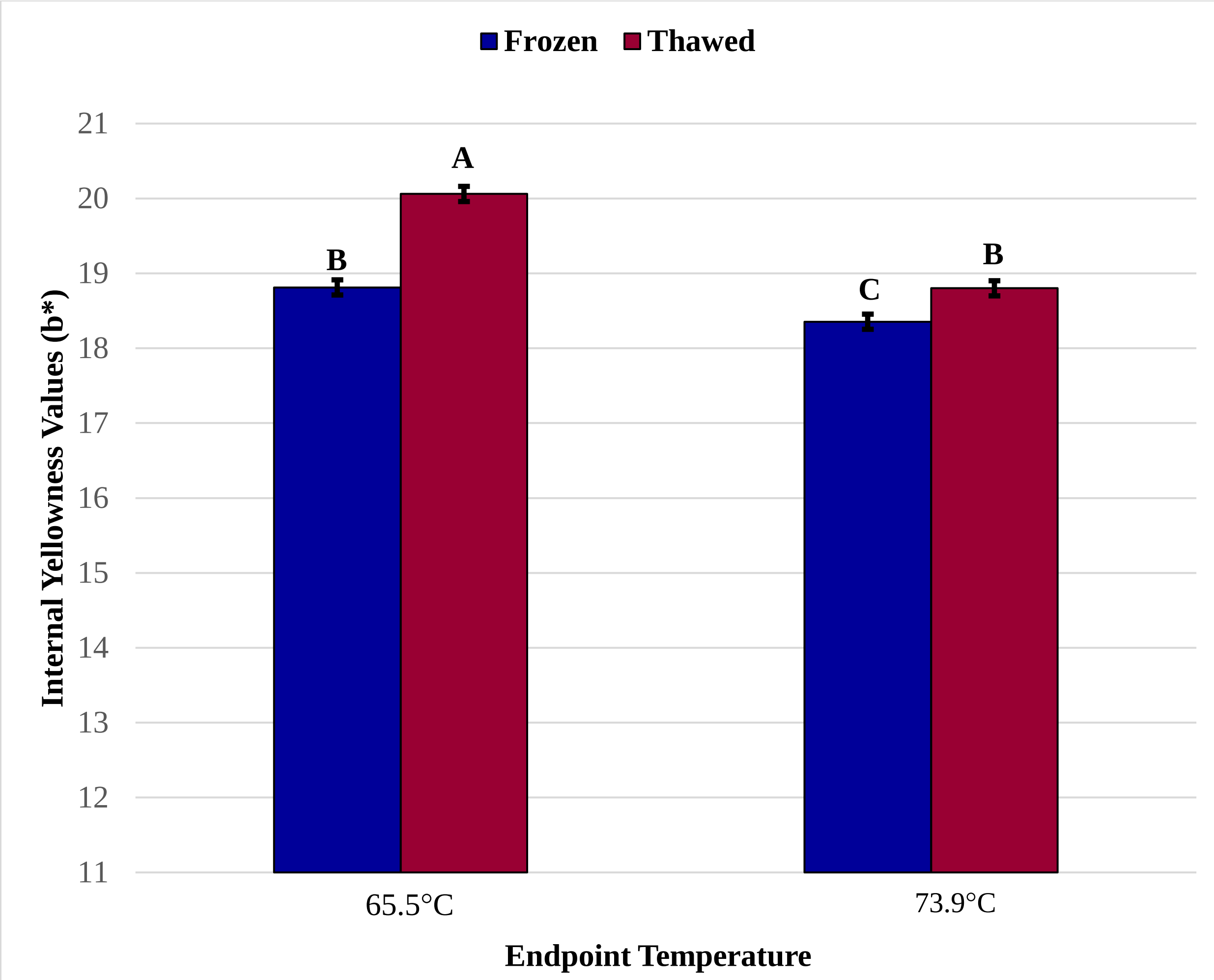

Figure 4. Interaction effect of the cooking State × endpoint temperature on internal yellowness (b*) values (*P* < 0.001).

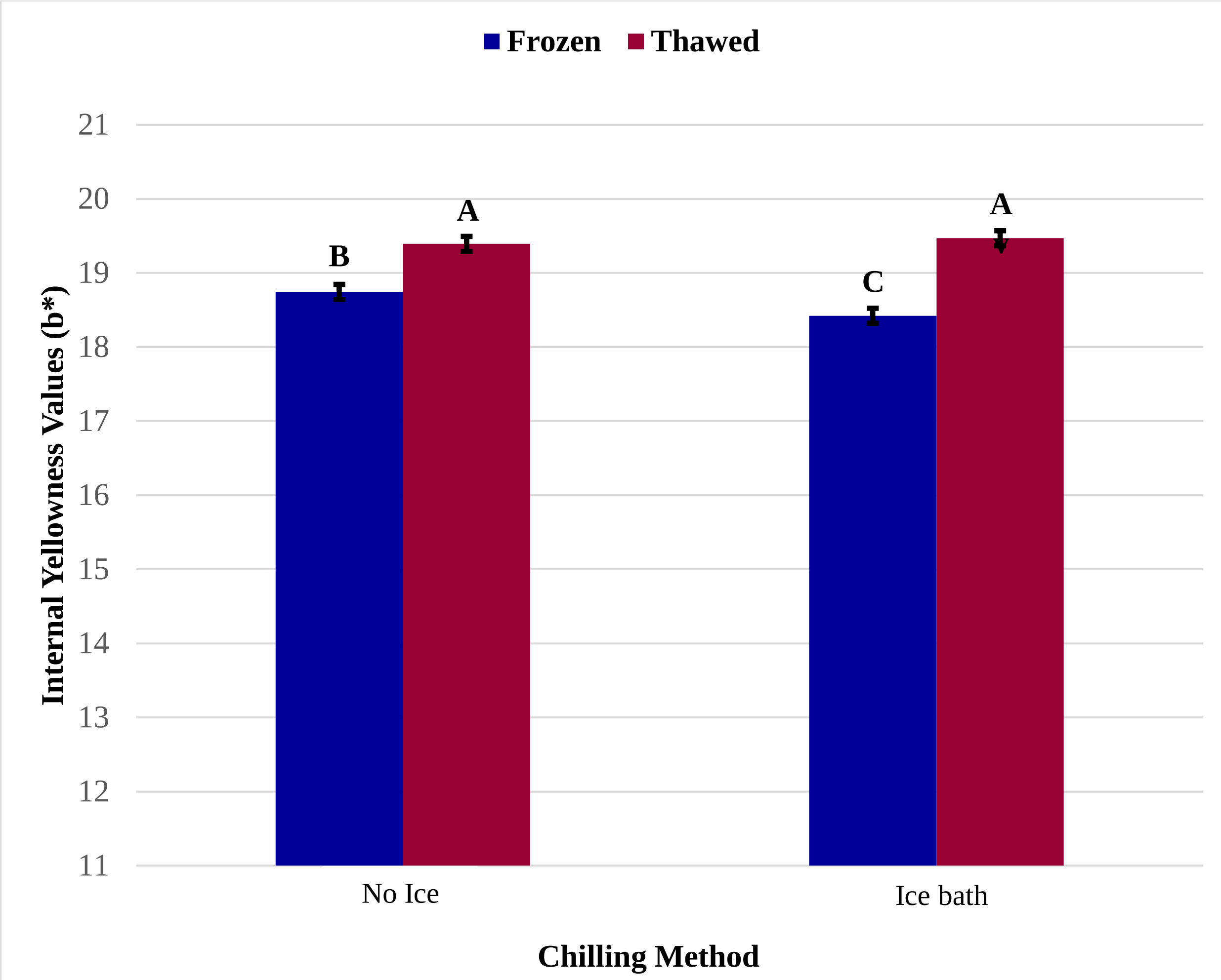

Figure 5. Interaction effect of cooking state × chilling method on internal yellowness (b*) values (*P* = 0.002).

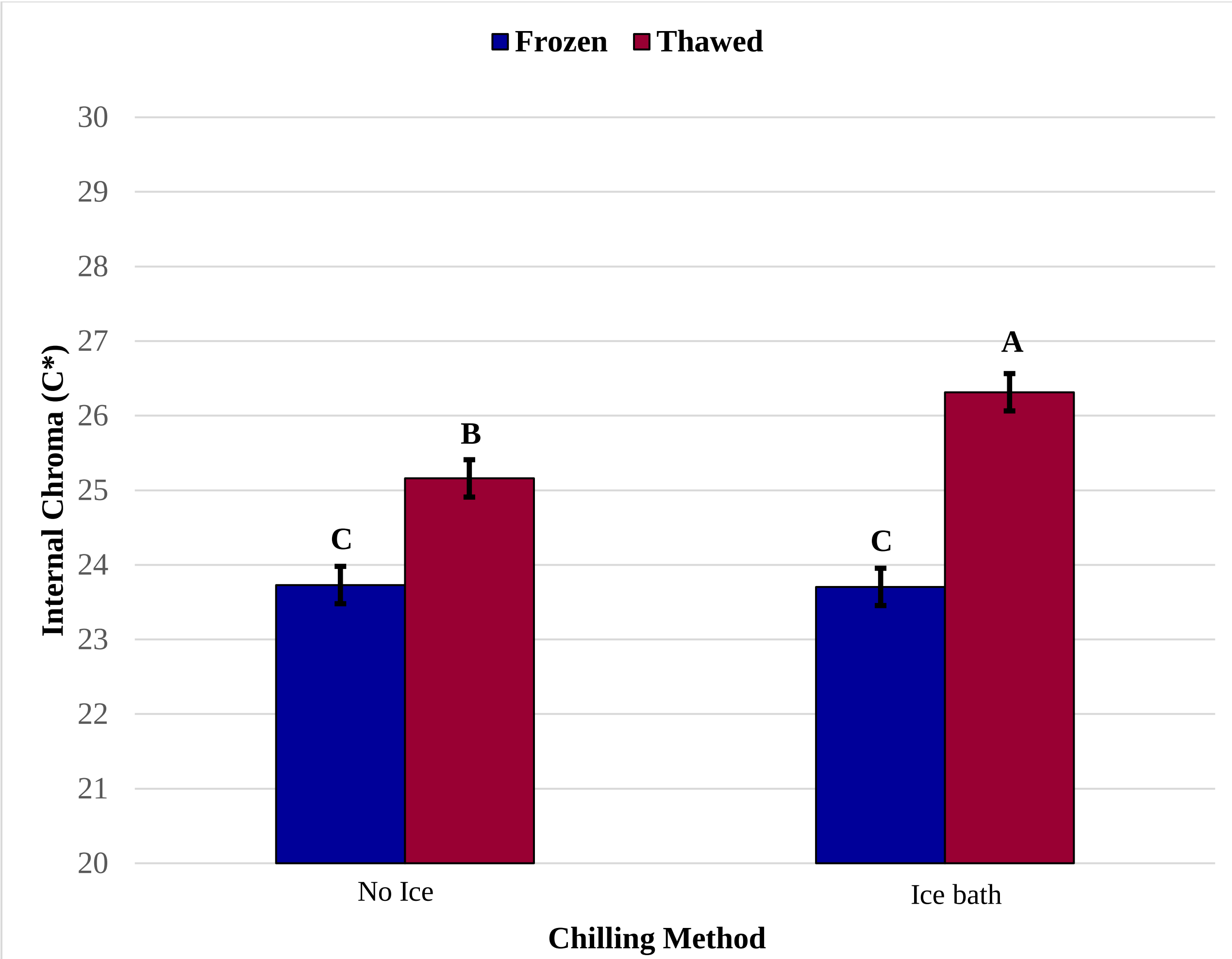

Figure 6. Interaction effect of cooking state × chilling method on internal chroma (C*) values (*P* = 0.001).

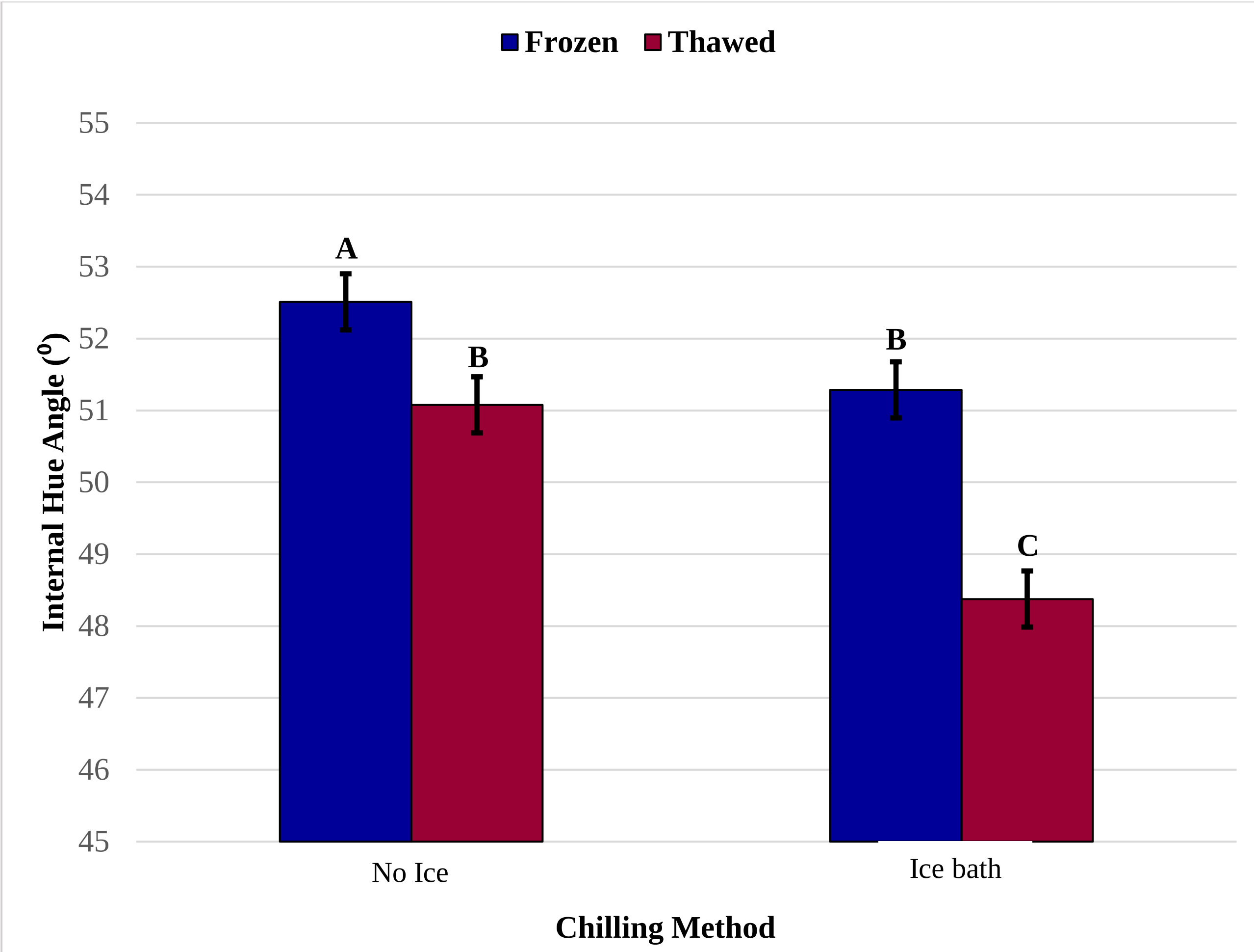

Figure 7. Interaction effect of cooking state × chilling method on internal hue angle (P = 0.015).

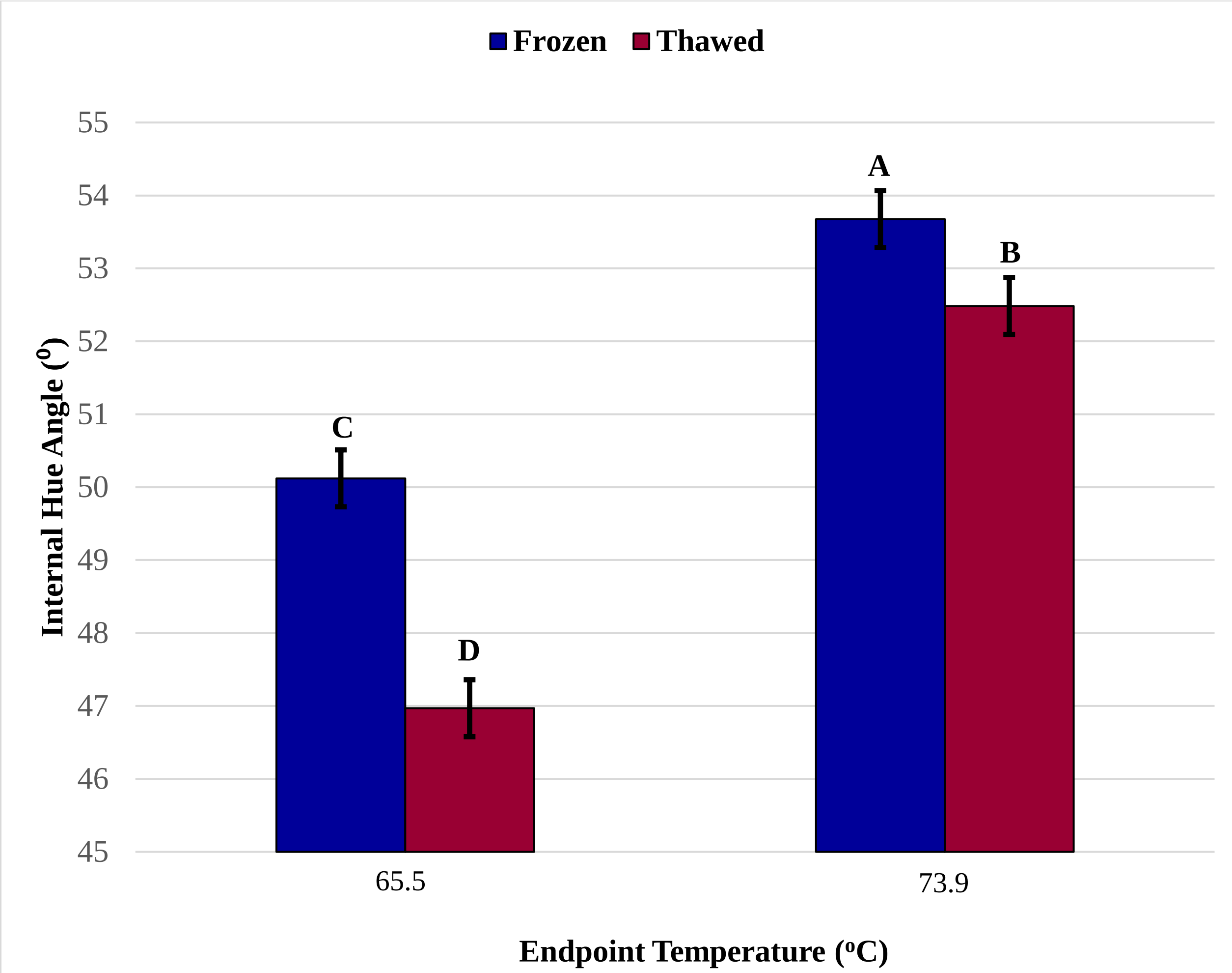

Figure 8. Interaction effect of cooking state × endpoint temperature on internal hue angle (*P* = 0.001).

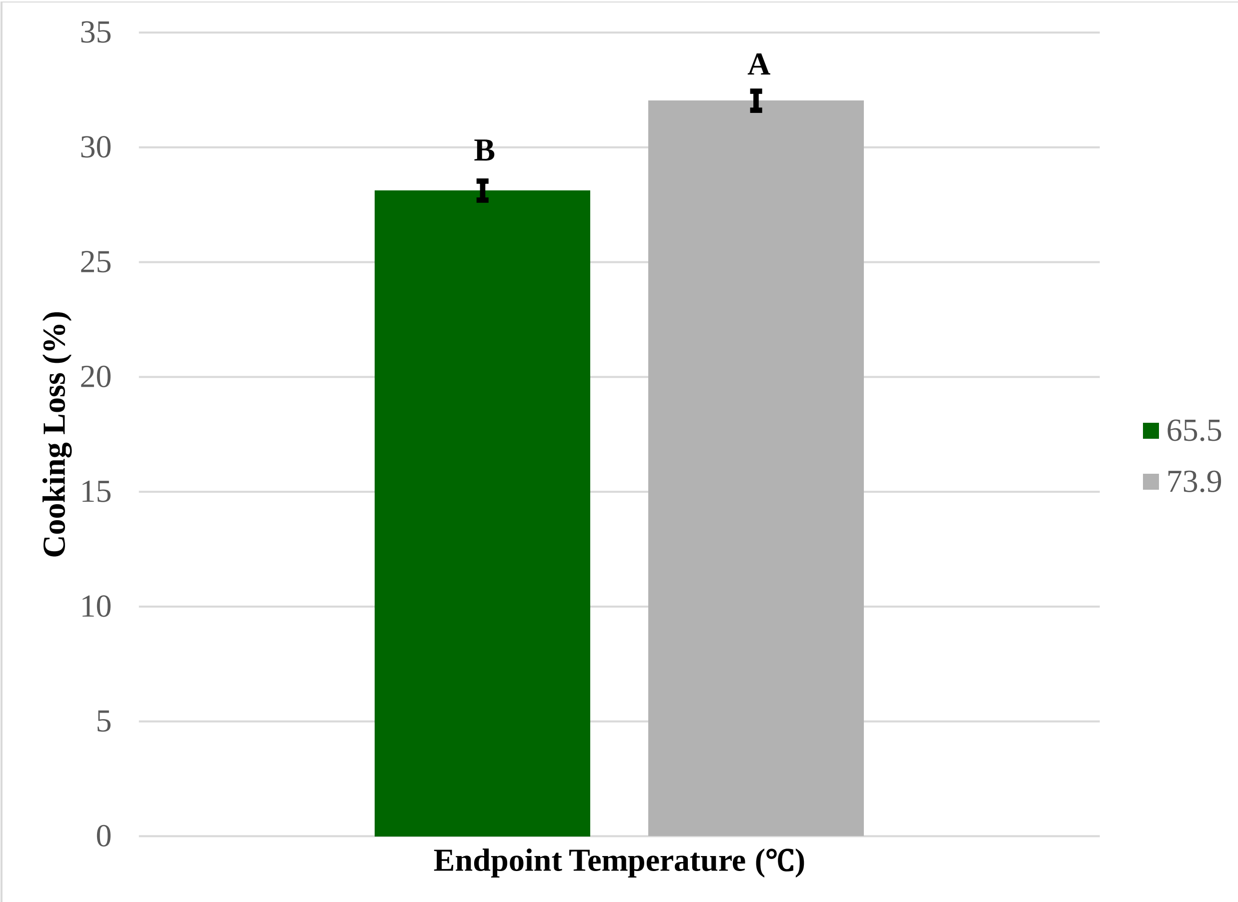

Figure 9. Main effect of endpoint temperature on cooking loss percentage (P < 0.0001).

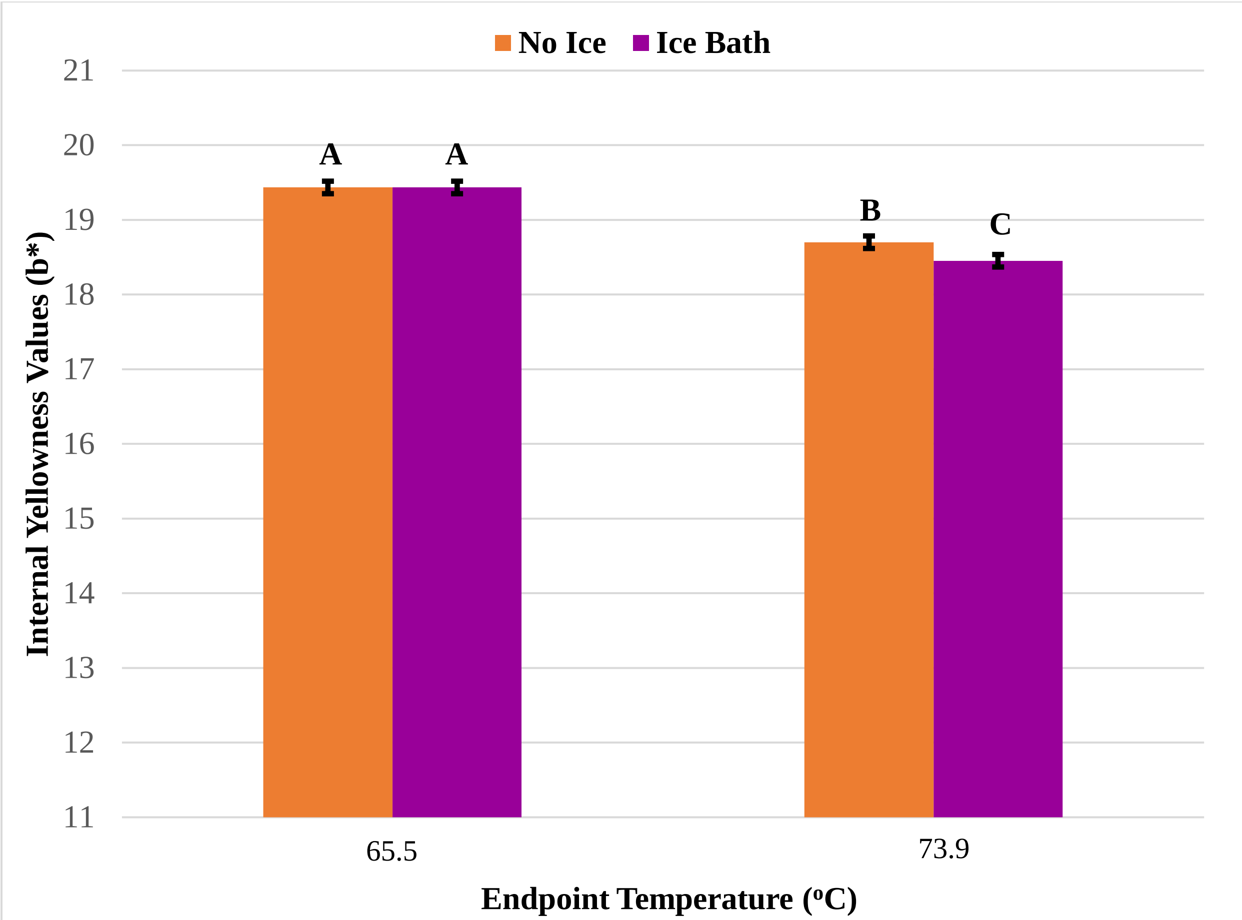

Figure 10. Interactive effect of endpoint temperature × chilling method on internal yellowness (b*) values (*P* = 0.045).

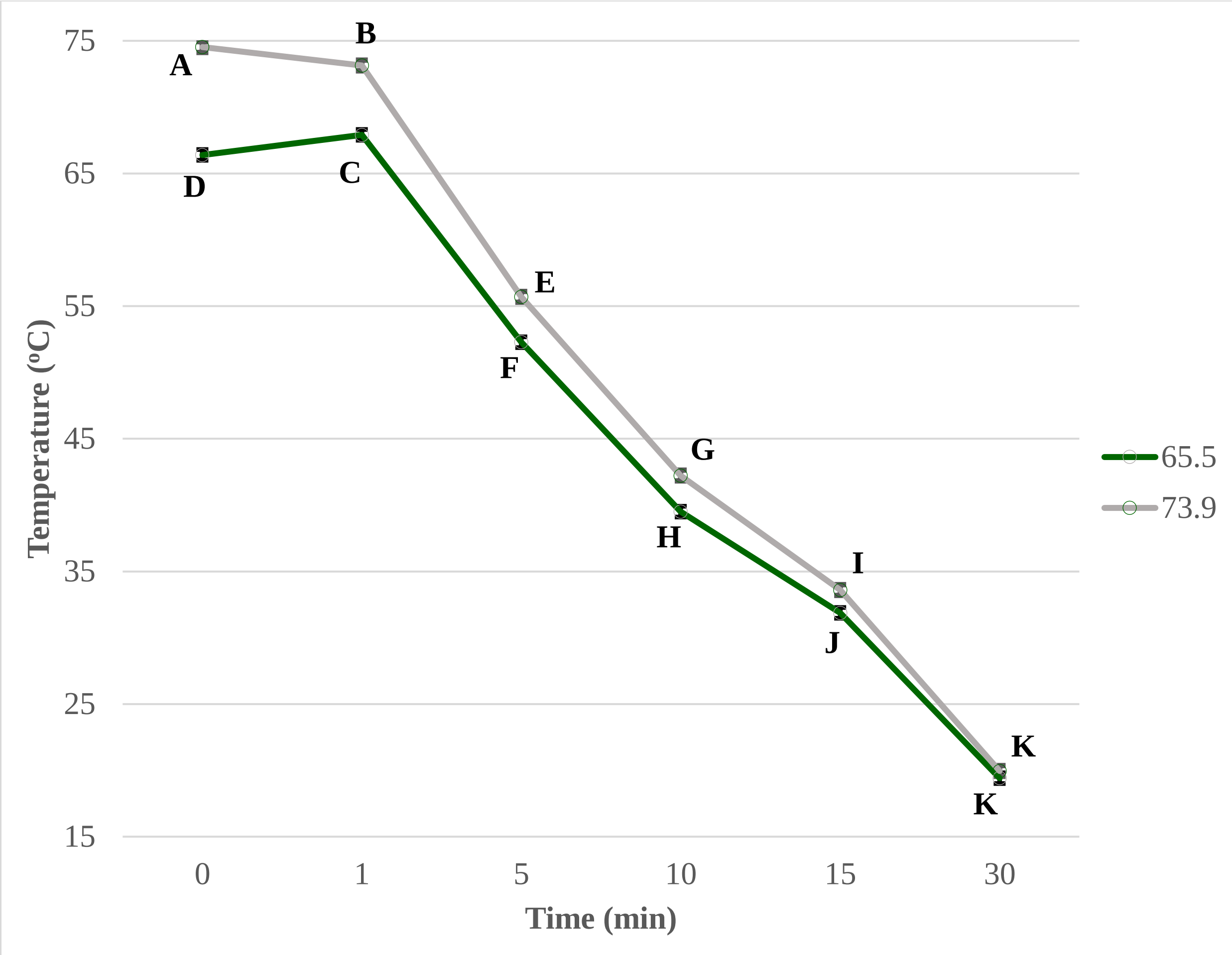

Figure 11. Interaction between endpoint temperature × time on internal temperature post cookery (*P* < 0.001).

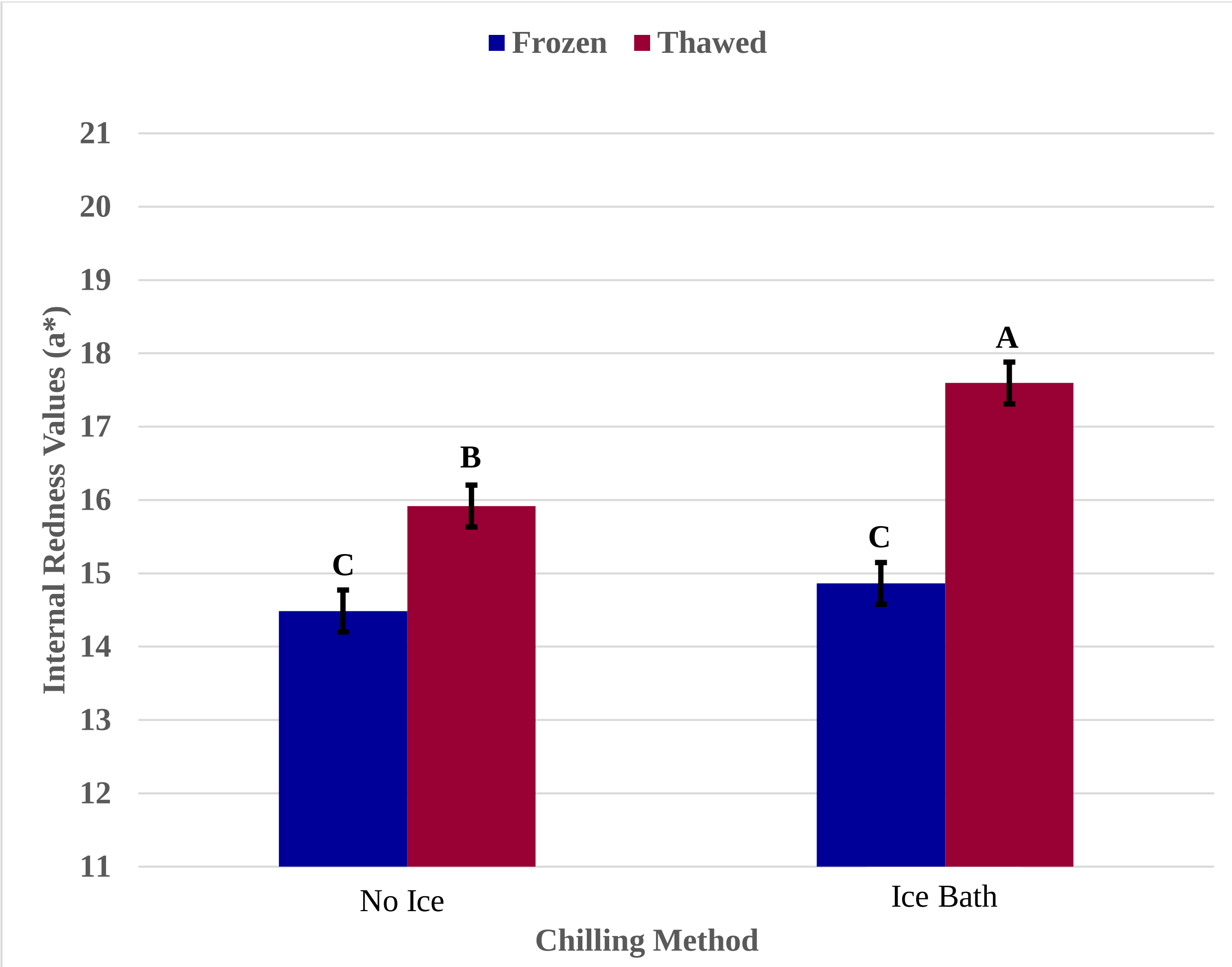

Figure 12. Interaction effect of cooking state × chilling method on internal redness (a*) values (*P* = 0.002).

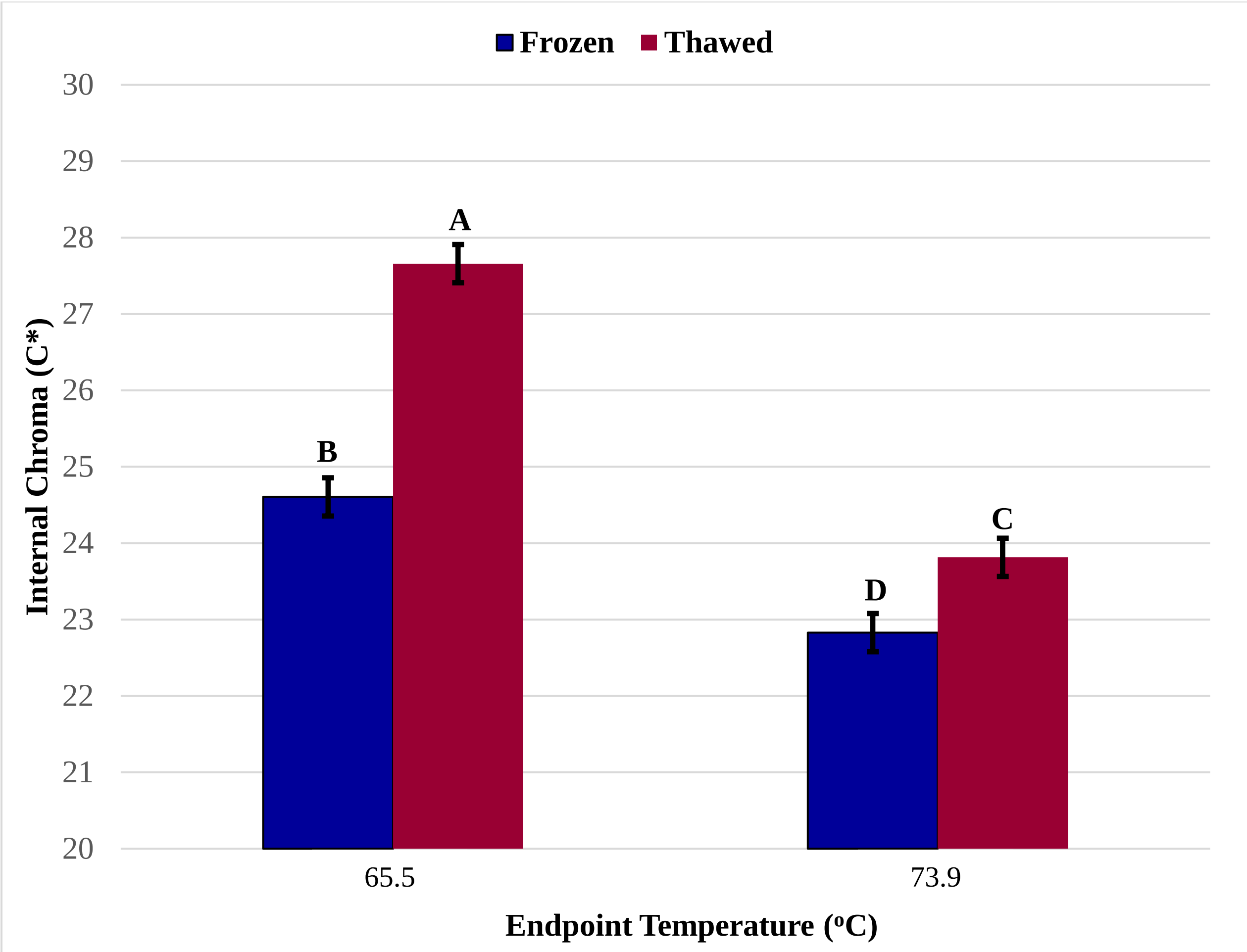

Figure 13. Interaction effect of cooking state × endpoint temperature on internal chroma (C*) values ($P < 0.001$).

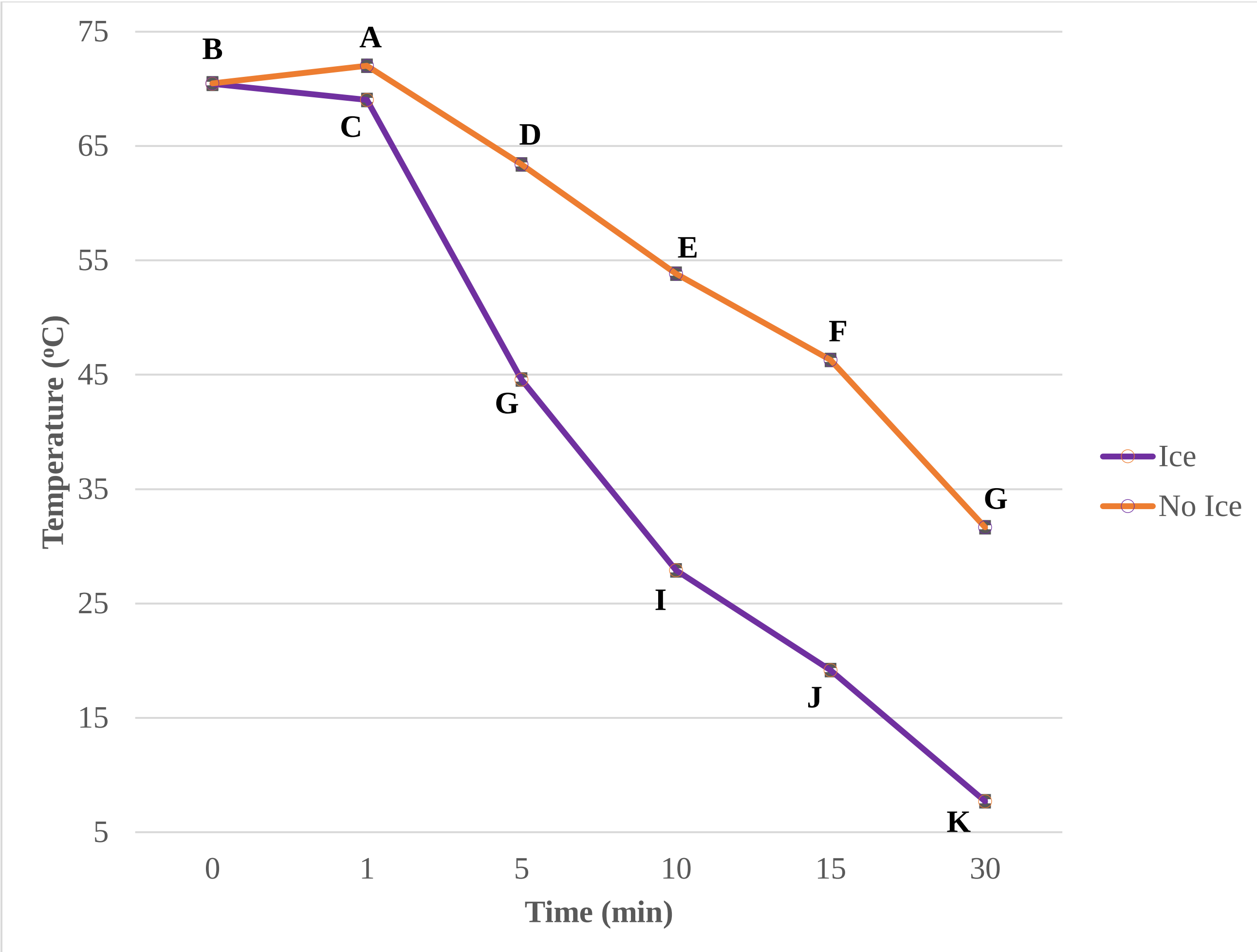

Figure 14. Interaction of chilling method × temperature on internal temperature post cookery (*P* < 0.001).

Table 1. Main effects of cooking state, internal endpoint temperature, and post-cooking chilling on cooking time and instrumental external (surface) and internal cooked color of ground beef patties.

	Cooking state			Internal temperature (°C)			Post-cooking ice bath		
Color Measure	Frozen	Thawed	SEM	65.5	73.9	SEM	None	Ice	SEM
Cooking time (s)	734.4^{x}	466.8^{y}	7.56	564.4^{x}	663.8^{y}	6.01	612.5^{x}	597.7^{y}	6.01
Patty Surface									
Lightness (L*)[1]	31.1^{y}	33.8^{x}	0.58	33.5^{x}	31.4^{y}	0.46	29.9^{y}	35.0^{x}	0.46
Redness (a*)[1]	11.6^{y}	13.0^{x}	0.18	12.6^{x}	12.0^{y}	0.14	12.1^{y}	12.5^{x}	0.14
Yellowness (b*)[1]	15.7^{y}	18.0^{x}	0.35	17.3^{x}	16.4^{y}	0.28	15.4^{y}	18.2^{x}	0.28
Chroma (C*)[2]	19.5^{y}	22.2^{x}	0.38	21.4^{x}	20.3^{y}	0.30	19.7^{y}	22.1^{x}	0.30
Patty Interior									
Lightness (L*)[1]	56.6^{y}	59.1^{x}	0.17	58.1^{x}	57.7^{y}	0.14	57.0^{y}	58.8^{x}	0.14

^{x,y}Within a row and main effect, least square means lacking a common superscripted letter differ, $P < 0.05$.

[1]L* is a measure of darkness to lightness (greater L* values indicate a lighter color); a* is a measure of redness (greater a* values indicate a redder color); and b* is a measure of yellowness (greater b* values indicate a more yellow color).

[2]C* is a measure of the total color of the sample (greater C* values indicate a more vivid color).