Cookery method and endpoint temperature can affect the Warner–Bratzler shear force, cooking loss, and internal cooked color of beef semimembranosus and infraspinatus steaks

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ABSTRACT: Steaks from USDA Select inside rounds (Exp. 1) and shoulder clods (Exp. 2) were used to test the interactive effect of cookery method and endpoint temperature on Warner–Bratzler shear force (WBSF) and internal cooked color. Pairs of 2.5-cm-thick semimembranosus (SM) or infraspinatus (INF) steaks (n = 360/muscle) were cut from each subprimal, labeled, vacuum packaged, and frozen at −30°C in the dark for approximately 60 d before being cooked to 65.5, 71.1, or 76.6°C using 1) a forced-air convection oven (FAC); 2) a forced-air impingement oven (IMP); 3) a gas-fired, open-hearth charbroiler (CHAR); 4) an electric countertop griddle (GRID); or 5) a clam-shell grill (CLAM). thawed steaks were cooked to their assigned endpoint temperature × cookery method combination, and, after a 5-min cooling period, steaks were weighed to calculate cooking loss percentage and subsequently sliced perpendicular to the cut surface to measure instrumental cooked color. Then, 6 cores were removed for measurement of WBSF. Cooking losses of SM steaks increased (P < 0.05) with each increase in endpoint temperature, whereas INF steaks cooked on a CHAR had the greatest (P < 0.05) cooking losses and cooking INF steaks with the GRID and the CLAM resulted in lesser (P < 0.05) cooking losses than cooking with the FAC and the IMP. Cooking SM steaks on the CHAR resulted in greater (P < 0.05) WBSF values than all other cookery methods when cooked to 65.5 and 76.6°C and greater (P < 0.05) WBSF values than those cooked on the FAC, GRID, and CLAM when cooked to 71.1°C. Shear force values were greater (P < 0.05) for INF steaks cooked to 71.1 and 76.6°C than those cooked to 65.5°C, but INF WBSF values were similar (P = 0.55) among cookery methods. At 65.5°C, FAC-cooked SM steaks were redder (P < 0.05) than those cooked with the GRID and the IMP and, at 71.1°C, CLAM-cooked SM steaks were redder (P < 0.05) than FAC- and IMP-cooked SM steaks; however, a* values were similar (P > 0.05) among cookery methods when cooked to 76.6°C. Redness did not (P > 0.05) differ among INF steaks cooked to 65.5 and 71.1°C with the FAC and the CHAR, whereas internal color of INF steaks cooked in the IMP and the FAC was redder (P < 0.05) than that of INF steaks cooked with the CLAM and the GRID to 76.6°C. Results suggest that endpoint temperature has a greater impact on cooking properties of SM and INF steaks than cookery method, yet it is apparent that internal cooked color of INF and SM steaks react differently to some cookery method–endpoint temperature combinations.

Key words: cookery method, endpoint temperature, infraspinatus, internal cooked color, semimembranosus, Warner–Bratzler shear force

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INTRODUCTION

Cookery methods used in research vary widely and are often dependent on several factors including availability, expense, time, and tradition. A forced-air convection oven is commonly used in beef tenderness research in spite of the fact that the American
Cooked semimembranosus and infraspinatus steaks

Meat Science Association (2015) guidelines do not recommend this cookery method. Conversely, conduction methods of cookery—belt grill and clam-shell grill—have become popular because of shorter cooking times, reductions in cooking losses, and superior Warner–Bratzler shear force (WBSF) repeatabilities (Gardner et al., 1996; Wheeler et al., 1998; Kerth et al., 2003). Over 40% of consumers use an outdoor grill to cook steaks (Lorenzen et al., 1999; McKenna et al., 2004b), and air-impingement ovens and electric, countertop griddles have been embraced as cookery methods for in-house research and development, yet little research has been published on these cookery methods. Beef cuts tend to become tougher as endpoint temperature increases (Parrish et al., 1973; Cross et al., 1976; Wulf et al., 1996), and Lorenzen et al. (1999) reported that 64 to 82% of U.S. consumers cook top loin steaks to “medium” or higher degrees of doneness. Moreover, the internal color of beef changes considerably as the endpoint cooking temperature increases due to myoglobin denaturation (García-Segovia et al., 2007). The majority of research on cookery methods and/or endpoint cooking temperatures on cooking properties and WBSF values of beef has been conducted with the LM (Kerth et al., 2003; McKenna et al., 2004a; Yancey et al., 2011), but research on other beef muscles, especially the semimembranosus (SM) and infraspinatus (INF), is limited (Lawrence et al., 2001). Therefore, the objective of this experiment was to determine the effects of cookery method and endpoint temperature on WBSF and internal cooked color of SM and INF steaks.

MATERIALS AND METHODS

Cookery Treatments

In 2 experiments, USDA Select-grade inside rounds (Institutional Meat Purchase Specifications [IMPS] number 169; Exp. 1; USDA, 2014) and shoulder clods (IMPS number 114; Exp. 2; USDA, 2014) were purchased and subsequently aged 0, 7, 14, 21, 28, or 35 d (from the box date) at 2°C (10 rounds and clods/aging period) to develop a wide range in possible tenderness differences. After the assigned aging period, no more than 3 pairs of 2.5-cm-thick, adjacent SM steaks (n = 360) or INF steaks (n = 360) were cut from each primal, labeled, vacuum packaged, and frozen (in the dark) at −30°C for approximately 60 d before cooking. Then, frozen steak pairs from each muscle were assigned to 1 of 15 treatments in a 3 × 5 factorial arrangement, with 65.5, 71.1, or 76.6°C endpoint temperatures (corresponding to “medium rare,” “medium,” and “medium well” degrees of doneness, respectively) and 5 cookery methods. Pairs of steaks were randomly assigned within each aging period so that the aging period was equally represented in each treatment, and individual steaks from each pair were cooked on separate days. Steaks were thawed in the dark overnight (16 h) at 2°C, removed from vacuum packages, and weighed. Cooking time was measured as the time from when a steak was placed in, or on, the oven or grill until it was removed from the heat source. Steaks were then cooked to their assigned endpoint temperature using 1 of 5 cookery methods:

1) Steaks cooked in the forced-air convection oven (FAC; Zephaire E model; Blodgett Oven Co., Burlington, VA) preheated to 165°C were cooked on racks and turned once at 35.0, 37.8, and 40.6°C for final endpoint temperatures of 65.5, 71.1, and 76.6°C, respectively. The internal temperature was monitored during cooking with copper-constantan thermocouples (Type T; Omega Engineering Inc., Stamford, CT) placed in the geometric center of each steak and attached to a multichannel data recorder (model 245A; VAS Engineering Inc., San Diego, CA), and the final temperature was confirmed with a handheld thermometer (Foodcheck Thermometer; Comark Instruments, Inc., Hitchin, Herefordshire, UK). This cookery method is entirely composed of convection heating, as the heat is transferred through the air in the oven to the meat.

2) The forced-air impingement oven (IMP; model 1100; Lincoln Enodis, Fort Wayne, IN) was set at 182.2°C, with belt speeds of 20, 25, and 30 min, to produce endpoint temperatures of 65.5, 71.1, and 76.6°C, respectively. Steaks were placed on the conveyor chain and the internal temperature was checked when steaks reached the opposite end of the oven with the handheld probe inserted into the geometric center of each steak. Steaks that had not reached the correct temperature when the chain was exiting the oven were pushed back into the oven until the specified endpoint temperature was achieved. The impingement oven cooks using convection cookery, as the heat is transferred through air from the gas burners blown over the steaks by electric fans.

3) Steaks cooked on the gas-fired, open-hearth charbroiler (CHAR; model 6148RCBD; Star Manufacturing International, Inc., Smithville, TN) set at medium-high heat were turned every 4 min, and the internal temperature was monitored with the handheld thermometer. The charbroiler cooks steaks through a combination of convection and conduction heating; the heat is transferred to the steaks through hot air coming
directly from the gas burners and from the hot grills that are in direct contact with the meat.

4) Steaks cooked on electric countertop griddle (GRID; National Presto Industries, Inc., Eau Claire, WI) set at 182.2°C were turned every 4 min, and the internal temperature was monitored with the handheld thermometer. The griddles cook steaks through conduction heating, as the heat is transferred directly from the hot griddle surface to the meat.

5) Two steaks at a time were cooked to their specified endpoint temperature in an electric clam-shell grill (CLAM) with a ribbed cooking surface (model CG14; Star Manufacturing International, Inc.) at a temperature setting of 6. Again, the internal temperature during cooking was monitored with copper-constantan thermocouples placed in the geometric center of each steak, whereas final internal temperatures were confirmed with the handheld thermometer. The clam-shell grill cooks steaks with 2 heated surfaces transferring heat to the steaks from both sides and is a conduction cookery method.

Internal Cooked Color Measurement

After allowing the steaks to cool for 5 min at room temperature, steaks were weighed to calculate cooking loss percentages. Then, each steak was sliced perpendicular to the cut surface, and instrumental color (L*, a*, and b* values) was measured with 3 scans for each steak immediately after cutting with a Hunter MiniScan XE Plus (Hunter Associates Laboratory, Reston, VA), equipped with a 9-mm aperture using illuminant A and a 10° observation angle. The spectrophotometer was calibrated each day prior to data collection against standard white and black tiles. Additionally, the hue angle (representing a change from the true red axis) was calculated as tan⁻¹ (b*/a*), whereas chroma (C*), or saturation index (representing the total color or vividness), was calculated as (a*² + b*²)¹/².

Warner–Bratzler Shear Force Measurement

After cooked color data collection, steaks were allowed to cool to room temperature (21°C) before six 1.3-cm-diameter cores were removed parallel with the muscle fiber orientation. Each core was then sheared once with a WBSF device attached to an Instron Universal Testing machine (model 4466; Instron Corp., Canton, MA) with a 55-kg tension/compression load cell and a crosshead speed of 200 mm/min. The average peak WBSF of the 6 cores was used for statistical analyses.

Statistical Analysis

Data were analyzed as an incomplete block design, with treatments in a 3 × 5 factorial arrangement (24 replications of each treatment combination), subprimal as the block, and individual steak as the experimental unit. Within each muscle, ANOVA was generated with PROC MIXED of SAS (SAS Inst., Inc., Cary, NC), with cookery method, endpoint temperature, and the 2-way interaction included in the model as fixed effects and subprimal as the random effect. Least squares means were calculated and statistically separated using pairwise t tests (PDIF option) when a significant (P ≤ 0.05) F-test was identified.

RESULTS AND DISCUSSION

Cooking Time

Cooking SM steaks in the CLAM required the least (P < 0.05) amount of time of all cookery methods, regardless of endpoint temperature, and cooking times for SM steaks cooked in the CLAM did not (P > 0.05) differ among endpoint temperatures (cooking method × endpoint temperature, P < 0.001; Fig. 1A). Conversely, cooking SM steaks in the FAC required the greatest (P < 0.05) amount of time to reach each endpoint temperature, and cooking times to reach 65.5, 71.1, and 76.6°C endpoint temperatures were greater (P < 0.05) when SM steaks were cooked in the IMP than when cooked on the CHAR and the GRID. Interestingly, cooking times were similar (P > 0.05) among SM steaks cooked to 76.6°C in the CLAM and those cooked to 65.5°C on the CHAR and the GRID.

Similarly, cooking INF steaks in the FAC required the greatest (P < 0.05) amount of time to reach 65.5, 71.1, and 76.6°C, whereas INF steaks cooked in the CLAM required the shortest (P < 0.05) cooking times to each endpoint temperature; however, among INF steaks cooked in the CLAM, cooking times were greater (P < 0.05) in steaks cooked to 76.6°C than in steaks cooked to 65.5 and 71.1°C (cooking method × endpoint temperature, P < 0.001; Fig. 1B). In addition, when INF steaks were cooked to 65.5°C, those cooked in the IMP had greater (P < 0.05) cooking times than steaks cooked on the CHAR and the GRID, but cooking times for INF steaks cooked in the IMP and on the GRID were longer (P < 0.05) than those cooked on the CHAR when cooked to 71.1 and 76.6°C.

Cooking times of beef steaks routinely increase as internal endpoint temperature increases from as low as 55°C to as high as 85°C (Shaffer et al., 1973; Bowers et al., 1987; Pohlman et al., 1997). Moreover, a number of studies have demonstrated that cooking times are reduced when LM steaks were cooked in the CLAM compared with electric, open-hearth broilers.
Cooked semimembranosus and infraspinatus steaks

Figure 1. Interactive effect of cookery method (FAC = forced-air convection oven [Blodgett Oven Co., Burlington, VA]; CHAR = gas-fired, open-hearth charbroiler [Star Manufacturing International, Inc., Smithville, TN]; GRID = electric countertop griddle [National Presto Industries, Inc., Eau Claire, WI]; IMP = forced-air impingement oven [Lincoln Enodis, Fort Wayne, IN]; CLAM = clam-shell grill [Star Manufacturing International, Inc.]) and internal endpoint temperature on cooking time for A) semimembranosus steaks ($P < 0.001$) and B) infraspinatus steaks ($P < 0.001$). a–iWithin each panel, bars lacking a common letter differ ($P < 0.05$).

(OHB; Berry, 1993; Pringle et al., 1998; McKenna et al., 2004a), electric grills (Berry and Bigner, 1995), and FAC (Kerth et al., 2003), and Berry and Leddy (1990) reported that cooking times were reduced when LM steaks were cooked on a CHAR compared with an electric OHB. When LM steaks were cooked using the same cookery method–endpoint temperature combinations used in the present experiment, Yancey et al. (2011) also noted that cooking in the CLAM produced the shortest cooking times, regardless of endpoint temperature, whereas the longest cooking times to reach each endpoint temperature were for steaks cooked in the FAC. Few studies have measured cooking times in muscles other than the LM, yet cooking times for steaks from the biceps femoris (BF), deep pectoral (DP), gluteus medius (GM), and semitendinosus (ST) were longer when steaks were cooked on electric OHB or in the FAC compared with the conduction cookery methods of the CLAM (Pringle et al., 1998) or belt grill (Lawrence et al., 2001). Although it was not the intent of this study to compare muscles, it was noted that SM steaks generally took longer to cook than INF steaks. The larger size (both weight and surface area) and lack of uniformity in steak shape was likely responsible for the observed longer cook times in SM steaks.
Cooking Loss Percentages

Within each cookery method, cooking loss percentages of SM steaks increased \((P < 0.05)\) with each increase in endpoint temperature (cooking method \(\times\) endpoint temperature, \(P = 0.002\); Fig. 2A). When SM steaks were cooked to medium rare \((65.5^\circ C)\), those cooked in the CLAM had lower \((P < 0.05)\) cooking losses than steaks cooked in the FAC, CHAR, and IMP and, among steaks cooked to medium \((71.1^\circ C)\), the least \((P < 0.05)\) cooking loss percentage was in CLAM-cooked steaks and SM steaks cooked on the GRID had lower \((P < 0.05)\) cooking losses than steaks cooked in the FAC, CHAR, and IMP. In addition, when cooking SM steaks to medium well \((76.6^\circ C)\), cooking in the FAC resulted in greater \((P < 0.05)\) cooking loss percentages than cooking in the IMP, and, interestingly, cooking losses of SM steaks cooked to 76.6°C in the CLAM were similar \((P > 0.05)\) to SM steaks cooked to 65.5°C in either the FAC or the CHAR.

Although there was no cookery method \(\times\) endpoint temperature interaction for cooking loss percentage among INF steaks \((P = 0.060)\), INF steaks cooked to 65.5°C had the least \((P < 0.01)\), and INF steaks cooked to 76.6°C had the greatest \((P < 0.01)\), cooking loss percentages (Table 1). Moreover, INF steaks cooked...
on the CHAR had the greatest ($P < 0.01$) cooking losses, whereas steaks cooked on the GRID and in the CLAM had lesser ($P < 0.01$) percent cooking losses than those cooked in the FAC and the IMP.

As internal endpoint temperatures increased from 55 to 85°C, cooking loss percentage also increased in steaks from the SM (Shaffer et al., 1973; Milligan et al., 1997; Modzelewksa-Kapitula et al., 2012) and INF (Modzelewksa-Kapitula et al., 2012) as well as the LM (Parrish et al., 1973; Cross et al., 1976; Bowers et al., 1987), DP (Pohlman et al., 1997), and BF (Bowers et al., 2012). In addition, cooking LM steaks on an electric OHB (combination convection and conduction cookery method) typically produces greater cooking losses than cooking on the CHAR (Berry and Leddy, 1990) or belt grill (Wheeler et al., 1998) and in the FAC (Lawrence et al., 2001). However, research comparing cooking loss percentages from LM steaks cooked in the CLAM with other cookery methods is variable. McKenna et al. (2004a) reported reduced cooking losses in LM steaks cooked in the CLAM compared with an electric OHB, whereas cooking losses were greater in LM steaks cooked in the CLAM than when cooked on an electric grill (Berry and Bigner, 1995) or OHB (Pringle et al., 1998) or did not differ between LM steaks cooked in the CLAM and OHB (Berry, 1993) or a FAC (Kerth et al., 2003). In addition, Yancey et al. (2011) noted similar cooking loss percentages for LM steaks cooked using FAC, CHAR, GRID, IMP, and CLAM. When testing cookery methods on beef muscles other than the LM, Pringle et al. (1998) reported that cooking GM steaks in the CLAM reduced cooking loss percentage when compared with cooking GM steaks on the OHB, whereas Lawrence et al. (2001) demonstrated that cooking BF, DP, and GM steaks on the faster, conduction-heating belt grill produced less cooking losses than cooking either in the FAC or on the OHB.

### Warner–Bratzler Shear Force

Cooking SM steaks to medium well on the CHAR resulted in the greatest ($P < 0.05$) WBSF values, and WBSF values were greater ($P < 0.05$) for SM steaks cooked on the CHAR than for SM steaks cook in the FAC, GRID, and CLAM when cooked to endpoint temperatures of 71.1 and greater than all other cookery methods at 65.5°C (cooking method × endpoint temperature, $P = 0.001$; Fig. 2B). As expected, SM steaks cooked to medium well produced greater ($P < 0.05$) WBSF values than those cooked to medium rare or medium when cooked in the FAC and the CHAR; however, when cooked in the CLAM, SM steaks cooked to 71.1 and 76.6°C had greater ($P < 0.05$) WBSF values than those cooked to 65.5°C and, when cooked in the IMP, SM steaks cooked to medium actually had greater ($P < 0.05$) WBSF values than those cooked to medium rare, but medium rare and medium well were similar. Interestingly, WBSF values did not ($P > 0.05$) differ among endpoint temperatures when SM steaks were cooked on the GRID. On the other hand, cookery method did not ($P = 0.55$) affect WBSF values of INF steaks, but INF steaks cooked to medium (71.1°C) and medium well (76.6°C) had greater ($P < 0.05$) WBSF values than INF steaks cooked to 65.5°C (degree of doneness, Table 1).

It is well established that degree of doneness and cookery method affect the tenderness of beef steaks, especially tougher cuts of meat. Yancey et al. (2011) observed that WBSF values of LM steaks increased with increasing endpoint temperature from 65.5 to 71.1°C and from 71.1 to 76.6°C, and WBSF values of

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### Table 1. Main effects of cookery method and internal endpoint temperature on quality attributes of semimembranosus and infraspinatus steaks

<table>
<thead>
<tr>
<th>Quality attribute</th>
<th>Cookery method(^1)</th>
<th>Endpoint temperature, °C</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>FAC</td>
<td>CHAR</td>
<td>GRID</td>
</tr>
<tr>
<td>Lightness (L*)(^2)</td>
<td>58.29(^a)</td>
<td>57.27(^b)</td>
<td>57.46(^b)</td>
</tr>
<tr>
<td>Hue angle,°(^3)</td>
<td>50.08(^c)</td>
<td>51.84(^a)</td>
<td>51.44(^b)</td>
</tr>
<tr>
<td>Cooking loss, %</td>
<td>31.02(^b)</td>
<td>33.46 (^b)</td>
<td>26.95 (^c)</td>
</tr>
<tr>
<td>Shear force, kg</td>
<td>3.02</td>
<td>3.21</td>
<td>3.09</td>
</tr>
<tr>
<td>Lightness (L*)(^2)</td>
<td>53.68(^b)</td>
<td>53.77(^b)</td>
<td>53.18(^c)</td>
</tr>
</tbody>
</table>

\(^a\)Within a row and main effect, least squares means lacking a common superscripted letter differ ($P < 0.05$).

\(^1\)FAC = forced-air convection oven (Blodgett Oven Co., Burlington, VA); CHAR = gas-fired, open-hearth charbroiler (Star Manufacturing International, Inc., Smithville, TN); GRID = electric countertop griddle (National Presto Industries, Inc., Eau Claire, WI); IMP = forced-air impingement oven (Lincoln Enodis, Fort Wayne, IN); CLAM = clam-shell grill (Star Manufacturing International, Inc.).

\(^2\)L* is a measure of darkness to lightness (greater L* value indicates a lighter color).

\(^3\)Hue angle is a measure of the change from the true red axis (greater value indicates a shift from the true red axis to the true yellow axis).
INF (Ahrens et al., 2008; Modzelewka-Kapitula et al., 2012) and SM steaks (Modzelewka-Kapitula et al., 2012) also increased with increasing degree of doneness. Even though Parrish et al. (1973) and Lorenzen et al. (2003) failed to discern an effect of increasing internal endpoint temperature on WBSF values, a number of studies have demonstrated that tenderness ratings decrease (become tougher) as the internal endpoint temperature increases in steaks from the LM (Gilpin et al., 1965; Parrish et al., 1973; Cross et al., 1976), ST (Gilpin et al., 1965), SM (Milligan et al., 1997), and DP (Pohlman et al., 1997). Moreover, Wulf et al. (1996) reported a linear increase in WBSF of LM steaks with increasing degree of doneness as well as quadratic increases in WBSF of SM and GM steaks as degree of doneness increased from rare to very well done.

Shear force values were greater when LM steaks were cooked in the CLAM than when cooked in the IMP and FAC (Yancey et al., 2011) or on an electric grill (Berry and Bigner, 1995) and OHB (McKenna et al., 2004). Additionally, both Pringle et al. (1998) and Wheeler et al. (1998) reported that conduction-heating cookery methods—CLAM and belt grill, respectively—increased WBSF values in LM steaks compared with convection-heating cookery methods, whereas other researchers have observed no difference in WBSF values of LM steaks when comparing conduction-heating cookery methods with convection-heating cookery methods (Berry and Leddy, 1990; Lawrence et al., 2001; Kerth et al., 2003).

Early research indicated that WBSF values began increasing as the endpoint increased from 60°C to between 80 and 85°C and then decreased when cooked to internal temperatures of 90°C or greater (Bouton et al., 1975, 1981; Bouton and Harris, 1981); therefore, it was suggested that the rate of cooking affected beef tenderness more than the cookery method per se. Both Berry and Leddy (1990) and James and Calkins (2008) reported that faster cookery methods (charbroiling) produced more tender beef steaks than slower cookery methods. Yet McKenna et al. (2004a) and Yancey et al. (2011) noted that steaks cooked using methods requiring shorter cooking times reduced WBSF values when compared with methods requiring longer cooking times. Cross et al. (1976) indicated that cooking rate (time) had little to no effect on beef tenderness evaluations, and this is supported by experiments conducted by Berry (1993), who failed to find tenderness differences between cooking on the slower OHB vs. cooking on the faster electric grill, or Lawrence et al. (2001) and Kerth et al. (2003), who varied the temperature settings for the belt grill and the CLAM, respectively, resulting in substantial differences in cooking times but not WBSF values. It was thought that the negative relationship between cook time and WBSF would be more pronounced in the SM steaks in Exp. 1 of the current study, but that was not consistently the case. Steaks cooked on the CLAM had by far the shortest cooking times but were among the lowest WBSF values at each degree of doneness. Conversely, SM steaks cooked on the CHAR had the greatest WBSF values at 65.5°C and 76.6°C, as well as among the greatest WBSF values when cooked to 71.1°C but intermediate to other cookery methods in cooking time. Therefore, development of tenderness as measured by WBSF may be dependent on more factors, including cookery method, than merely cooking time.

**Internal Cooked Color**

No cookery method × endpoint temperature interactions were noted for the internal cooked lightness (L*) of either SM (P = 0.405) or INF steaks (P = 0.184); however, SM steaks cooked to 76.6°C were darker (lesser L* value; P < 0.05) than SM steaks cooked to 65.5°C, but cooked L* values did not (P = 0.32) differ among endpoint temperatures in INF steaks (Table 4). Furthermore, internal cooked color of SM steaks cooked in the IMP and FAC was lighter (greater L* values; P < 0.05) than SM steaks cooked on the CHAR, GRID, and CLAM, whereas INF steaks cooked in the IMP were lighter (P < 0.05) than INF steaks cooked in the FAC and the CLAM or on the CHAR and the GRID. It should be noted that, regardless of muscle, the range in mean L* values among cookery methods and among endpoint temperatures was less than 2 in 1 units, respectively; therefore, the magnitude of these differences is not overly relevant, although main effect differences in L* values were statistically significant.

As expected, SM steaks cooked to medium rare (65.5°C) were redder (greatest a* values; P < 0.05) and steaks cooked to medium well (76.6°C) were least red (P < 0.05), with the lone exception being that internal cooked a* values were similar (P > 0.05) between SM steaks cooked in the IMP to medium (71.1°C) and medium well degrees of doneness (cooking method × endpoint temperature, P = 0.022; Fig. 3A). Among SM steaks cooked to 65.5°C, those cooked in the FAC were internally redder (P < 0.05) than those cooked on the GRID and in the IMP, whereas SM steaks cooked in the IMP were less (P < 0.05) red than those cooked on the CHAR or in the CLAM. When cooked to a medium degree of doneness, steaks cooked in the CLAM were redder (P < 0.05) than SM steaks cooked in the FAC and the IMP; however, a* values did not differ (P > 0.05) among cookery methods when cooked to a medium well degree of doneness. Interestingly, internal cooked a* values of SM steaks cooked to 71.1°C
Cooked semimembranosus and infraspinatus steaks

Even though there was an interactive effect of endpoint temperature and cookery method on cooked internal color (a* values) of INF steaks (P = 0.001), the differences among endpoint temperatures within each cookery method were not as apparent as those observed in SM steaks. For example, even though INF steaks cooked to 76.6°C had the least red internal cooked color within each cookery method, a* values were similar (P > 0.05) for steaks cooked to 65.5°C and 71.1°C when cooked either in the FAC or on the CHAR. When cooked to a medium degree of doneness, steaks cooked in the FAC and on the CHAR had greater (P < 0.05) a* values than INF steaks cooked in the IMP, CLAM, and GRID, and steaks cooked in the IMP were redder (P < 0.05) than those cooked on the GRID and the CLAM. Among the INF steaks cooked to 76.6°C, the internal color of those cooked in the CLAM and on the GRID was less (P < 0.05) red than INF steaks cooked in the IMP and FAC, and an interesting finding was that INF steaks cooked to medium well in the FAC had (P > 0.05) internal cooked a* val-
ues similar to those of INF steaks cooked to medium in the CLAM, IMP, and GRID.

Hue angles are a measure of the change from the true red axis, and hue angles of SM steaks increased ($P < 0.05$) with each increase in endpoint temperature, indicating that the internal cooked color was the reddest when cooked to 65.5°C (medium rare) and least red when cooked to 76.6°C (medium well; Table 1). In accordance with $a^*$ values, internal cooked color of SM steaks cooked in the FAC were the redder (lower hue angles; $P < 0.01$) than those cooked with the CHAR, GRID, and IMP, whereas SM steaks cooked on the CHAR and in the IMP were less (higher hue angles; $P < 0.01$) red than those cooked in the CLAM.

In support of the internal cooked $a^*$ results, INF steaks cooked to medium well were, internally, the least red than steaks cooked to medium rare and medium, regardless of cookery method (cooking method $\times$ endpoint temperature, $P < 0.001$; Fig. 4). Moreover, hue angles were similar ($P > 0.05$) among steaks cooked to 65.5 and 71.1°C either in the FAC or on the CHAR, and INF steaks cooked to 65.5°C in the CLAM were less ($P < 0.05$) red than steaks cooked to the same endpoint on the GRID or in the IMP, whereas when cooked to 71.1°C, CLAM-cooked steaks had greater ($P < 0.05$) hue angles than those cooked in the FAC and IMP and on the CHAR. Again, INF steaks cooked to medium well in the FAC were still internally redder ($P < 0.05$) than all other cookery methods to the same degree of doneness, and hue angles for these steaks were similar ($P > 0.05$) to those of INF steaks cooked to medium doneness either on the GRID or in the IMP or the CLAM.

Chroma, or saturation index, is a measure of the color intensity; therefore, a greater $C^*$ values is indicative of a more vivid color. So it was not surprising that within each cookery method, SM steaks cooked to medium rare (65.5°C) had a more ($P < 0.05$) vivid (greater $C^*$ values) internal color than SM steaks cooked to medium and medium well degrees of doneness (cooking method $\times$ endpoint temperature, $P = 0.006$; Fig. 5A). More specifically, SM steaks cooked in the IMP had a less ($P < 0.05$) vivid internal color (lower $C^*$ value) than all other cookery methods at an endpoint temperature of 65.5°C, whereas $C^*$ values were less ($P < 0.05$) in SM steaks cooked to 71.1°C in the FAC and the IMP than those cooked to 71.1°C in the CLAM and on the GRID; however, $C^*$ values were not ($P > 0.05$) different among cookery methods when SM steaks were cooked to medium well (76.6°C). Interestingly, $C^*$ values did not ($P > 0.05$) change between medium and medium well degrees of doneness when SM steaks were cooked in either the FAC or the IMP.

When INF steaks were cooked to 65.5°C, those cooked in the CLAM had a less ($P < 0.05$) intense color (lower $C^*$ values) than only those cooked in the FAC (cooking method $\times$ endpoint temperature, $P$
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Furthermore, C* values decreased (P < 0.05) with each increase in endpoint temperature when INF steaks were cooked on the GRID or in the IMP and the CLAM; however, INF steaks cooked to medium rare (65.5°C) and medium (71.1°C) had a more (P < 0.05) vivid internal color than those with an endpoint temperature of 76.6°C when cooked in the FAC or on the CHAR.

The color in all skeletal muscles is driven by the presence of myoglobin and other heme proteins (Lytras et al., 1999), and cooked color development is a function of the heat-induced degradation of those proteins (Hunt et al., 1999). Increasing degree of doneness and its association with internal cooked color is well documented. Research has shown that the internal cooked color becomes lighter (greater L or L* values) and/or less red (lesser a or a* values) with increasing internal endpoint temperature beef steaks from the LM (Gilpin et al., 1965; Bowers et al., 1987), ST (Gilpin et al., 1965), SM (Shaffer et al., 1973; Milligan et al., 1997; Kondjoyan et al., 2014), and BF (Bowers et al., 2012). In addition, Yancey et al. (2011) reported that a* and C* values decreased and hue angles increased as end-

Figure 5. Interactive effect of cookery method (FAC = forced-air convection oven [Blodgett Oven Co., Burlington, VA]; CHAR = gas-fired, open-hearth charbroiler [Star Manufacturing International, Inc., Smithville, TN]; GRID = electric countertop griddle [National Presto Industries, Inc., Eau Claire, WI]; IMP = forced-air impingement oven [Lincoln Enodis, Fort Wayne, IN]; CLAM = clam-shell grill [Star Manufacturing International, Inc.]) and internal endpoint temperature on internal cooked chroma (C*) values for A) semimembranosus steaks (P = 0.006) and B) infraspinatus steaks (P = 0.009). * #Within each panel, bars lacking a common letter differ (P < 0.05).
point temperature increased from 65.5 to 71.1°C and again from 71.1 to 76.6°C in LM steaks.

On the other hand, research focused on the effect of cookery method on cooked beef color is scarce. Bowers et al. (1987) reported that internal cooked color of oven-broiled LM steaks was visually browner than oven-roasted LM steaks, and Powell et al. (1990) found that LM steaks cooked in the IMP appeared rarer than steaks cooked on the OHB. More recently, Yancey et al. (2011) observed that LM steaks cooked in the FAC and the IMP were lightest (greatest \(L^*\) values) and those cooked in the CLAM were the darkest, whereas LM steaks cooked in the CLAM were the least red (least \(a^*\) values and greatest hue angles) and the internal cooked color of LM steaks cooked in the FAC were the reddest, regardless of internal endpoint temperature. In the present study, the magnitude of differences in internal cooked color, especially measures of redness (\(a^*\) values and hue angles), were greater among degrees of doneness (endpoint temperatures) than among the cookery methods; however, there were obvious cookery effects. For example, when SM steaks were cooked to 65.5°C, the FAC produced a redder internal cooked color than the GRID, and when INF steaks were cooked to 76.6°C, those cooked in the FAC were considerably redder than those cooked with the CHAR, GRID, IMP, and CLAM. The beef INF has a greater myoglobin concentration than either the SM or LM (McKenna et al., 2005), which may have contributed to how each cookery method affected myoglobin denaturation and consequential changes in the internal cooked color of SM and INF steaks.

**Summary and Conclusions**

The challenges of the large size and intramuscular variation of SM steaks (Sawyer et al., 2007; Lee et al., 2008) continually contribute to the problems associated with research projects using the SM. Although the INF has been shown to be second only to the psoas major in tenderness (Rhee et al., 2004), it has not been as extensively studied as other beef muscles, particularly the LM. The study was not designed to compare muscles, but it is apparent that cooking properties, particularly internal color, of steaks from both muscles may not react similarly to some cookery method × endpoint temperature combinations. Therefore, it may be concluded that the relationship of endpoint temperature and cooked color is very dynamic and will depend on several factors, including muscle along with cookery method.

**Forced-Air Convection Oven.** Steaks from the SM cooked in the FAC had among the greatest WBSF values compared with other cookery methods when cooked to medium well (76.6°C) but had among the lowest WBSF values when cooked to medium (71.1°C) or medium rare (65.5°C); however, WBSF values of INF steaks were not affected by any cookery method. Both SM and INF steaks cooked in the FAC required among the longest cooking times, and even though SM steaks cooked in the FAC produced among the greatest cooking losses, INF steaks cooked in the FAC were intermediate in cooking losses among cookery methods. Additionally, SM and INF steaks cooked to medium rare in the FAC were among the reddest steaks when compared with the other cookery methods. Conversely, SM steaks cooked in the FAC to both medium and medium well were among the least red, whereas INF steaks cooked to medium and medium well in the FAC were among the most red compared with the other cookery methods used in this study.

**Air Impingement Oven.** Cooking SM steaks using the IMP resulted in intermediate WBSF values but required among the longest cooking times and had among the greatest cooking losses, especially when cooked to 71.1°C. For INF steaks, cooking on the IMP required more time than all methods other than the FAC but yielded intermediate cooking losses. Both SM and INF steaks cooked in the IMP were among the lightest of any cookery method; however, SM steaks cooked in the IMP were among the least red at medium and medium rare degrees of doneness, whereas INF steaks cooked in the IMP were intermediate in redness among the cookery methods.

**Char-Grill.** When cooked to 76.6°C using the CHAR, SM steaks had the greatest WBSF values of any cookery method × temperature combination, and WBSF values of SM steaks cooked on the CHAR were greatest at 65.5°C and among the greatest at 71.1°C. Cooking both SM and INF steaks on the CHAR resulted in intermediate cooking times and produced among the greatest cooking losses. The internal cooked color of SM steaks cooked on the CHAR was among the most red, internally, compared with other methods, and when cooked on the CHAR, SM steaks became less red with each increase in degree of doneness. Nevertheless, redness values of INF steaks cooked on the CHAR did not differ between medium rare and medium degrees of doneness but were among the most red, internally, of any cookery method, whereas INF steaks cooked to medium well on the CHAR were less red than other endpoint temperatures and among the least red of other cookery methods.

**Electric Griddles.** Steaks from the SM cooked using the GRID had among the lowest WBSF values of all cookery methods, and interestingly, the WBSF of SM steaks cooked on the GRID did not differ in response to endpoint temperature. Furthermore, SM and INF steaks cooked on the GRID were interme-
ate in cooking time and had among the least cooking loss percentages at each respective degree of doneness. The internal cooked color values of SM steaks cooked using the GRID were intermediate to other cookery methods when cooked to medium rare and among the most red when cooked to medium. On the other hand, INF steaks cooked to medium rare on the GRID were among the most red and were among the least red when cooked to medium and medium well.

**Clam-Shell Grill.** Cooking in the CLAM produced SM steaks with among the lowest WBSF values at each endpoint temperature. Furthermore, the CLAM required the least cooking time and produced among the least cooking losses at each endpoint temperature for both SM and INF steaks. When cooked in the CLAM to medium rare and medium, SM steaks were among the reddest in internal cooked color, but INF steaks cooked on the CLAM were among the least red at each endpoint temperature.

**LITERATURE CITED**


Cooked semimembranosus and infraspinatus steaks


