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Bloom Development of the Beef *Semimembranosus* and *Triceps Brachii* as Influenced by Wet-Aging[1]

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Abstract: The *semimembranosus* (SM) and *triceps brachii* (TB) from USDA Select beef carcasses were used to test the effect of wet-aging period on bloom development. Inside rounds (IMPS#168) and shoulder clods (IMPS #114) were randomly allocated to 0, 7, 14, 21, 28, and 35 d wet-aging at 2°C (n = 10 subprimal cuts/aging period). Each week, two 2.54-cm-thick, non-adjacent steaks were cut from aged inside rounds and shoulder clods, and instrumental color (L*, a*, and b*) of the SM and TB was measured at 10-min intervals for 2 h after cutting. Steaks from the SM and TB became a more vivid (greater C* values; $P < 0.05$), redder (greater a* values; $P < 0.05$), and yellower (greater b* values; $P < 0.05$) color during the 120-min bloom period. Moreover, the calculated proportion of oxymyoglobin (OMb) in SM and TB steaks increased (linear, $P < 0.001$) during the first 80 min after cutting but stabilized thereafter. Redness (a* and hue angles), b*, and C* values decreased (linear, $P \leq 0.050$) in SM steaks as duration of wet-aging increased from 0 to 35 d, but length of wet-aging had no ($P \geq 0.127$) effect on instrumental color measures of TB steaks. Neither the percentage of calculated OMb ($P = 0.580$) nor OMb asymptotic point ($P \geq 0.214$) for SM steaks was affected by duration of wet-aging, and, even though the proportion of OMb in TB steaks was not altered ($P = 0.459$) by postmortem aging, OMb asymptotic points increased (linear, $P = 0.001$) in TB steaks with increasing durations of wet-aging. Results of these experiments indicate that 90%, or more, of the change in color was achieved within the first 50 to 60 min after cutting, but duration of wet-aging had little to no impact on bloom development in SM and TB steaks.

Keywords: beef, bloom development, instrumental color, *semimembranosus*, *triceps brachii*, wet-aging
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Introduction

Tenderness (Gruber et al., 2006; Rhee et al., 2004; Keith et al., 1985) and color (Lee et al., 2008c; Sawyer et al., 2007; McKenna et al., 2005; Sammel et al., 2002) of the *semimembranosus* (SM) have been well documented over the past few decades. Moreover, the promotion of the ranch steak (boneless, chuck shoulder, center-cut steak) from the shoulder clod as a less expensive alternative to rib or loin steaks has led to renewed investigations into the quality attributes of the *triceps brachii* (TB). Several studies have noted palatability differences within the TB (Searls et al., 2005; Denoyelle and Lebihan, 2004), as well as in comparison to other beef muscles (Sullivan and Calkins, 2011; Gruber et al., 2006; Von Seggern et al., 2005; Rhee et al., 2004); however, only a handful of studies have compared visual and(or) instrumental color stability of the TB to other muscles (Moon et al., 2015; McKenna et al., 2005;

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O'Keeffe and Hood, 1982; Hood, 1980), and there are no reports on color development in the TB.

When beef is exposed to air, it turns to a bright cherry-red color with progressing time, which is typically referred to as blooming (Ledward, 1992). Bloom occurs when oxygen binds to the heme iron portion of deoxymyoglobin to form oxymyoglobin, and the time it takes to oxygenate deoxymyoglobin to oxymyoglobin is known as the bloom(ing) time. Bloom times over 10 to 12 min were necessary to obtain repeatable and stable instrumental color measurements in the *longissimus thoracis* of beef carcasses after ribbing (Rentfrow et al., 2004; Wulf and Wise, 1999). In contrast, very little information is available on bloom development in vacuum-packaged beef primal cuts. Lee et al. (2008a, 2008b) reported that 40 to 50% of the changes in instrumental color values of steaks from wet-aged beef ribeye rolls and top sirloin butts occurred during the first 10 min of exposure to air, whereas 90% of the color changes associated with bloom development occurred within 1 h of steak fabrication. However, wet-aging between 0 and 35 d had no appreciable effect on bloom development in *longissimus thoracis* steaks (Lee et al., 2008a), whereas bloom development was greater in *gluteus medius* steaks from top sirloin butts wet-aged 0 to 21 d than those wet-aged 28 and 35 d (Lee et al., 2008b). More recently, Wyrwisz et al. (2016) noted that instrumental color measures stabilized faster during blooming in beef SM steaks from 21-d wet-aged inside rounds than vacuum-packaged inside rounds aged only 1 d. Because development of the characteristic bright, cherry-red color of fresh beef is the single most important quality attribute affecting consumer purchases (Carpenter et al., 2001; Kropf, 1980), 2 experiments were conducted to evaluate the influence of wet-aging duration on bloom development in SM (Exp. 1) and TB (Exp. 2) steaks from beef inside rounds and shoulder clods, respectively.

Materials and Methods

Inside rounds (IMPS #169A; USDA, 2014) and shoulder clods (IMPS #114G; USDA, 2014) from USDA Select beef carcasses were obtained from a commercial beef slaughter facility and transported under refrigeration to the University of Arkansas Red Meat Abattoir within 3 d of slaughter. Upon arrival, inside rounds (n = 60) and shoulder clods (n = 60) were allocated randomly to 0, 7, 14, 21, 28, and 35 d of aging (10 subprimals/aging period) in the dark at 2°C from the boxed date.

After the appropriate aging period, inside rounds and shoulder clods were removed from vacuum-bags, the *adductor* was removed from all inside rounds, and 2.54 cm of the anterior end of the SM or ventral end of the TB was removed and discarded. Then, a 2.54-cm-thick SM or TB steak (designated as steak #1) was cut and placed on a styrofoam tray (2S White L; Sealed Air Cryovac, Duncan, SC) with an absorbent pad (Dri-Loc Meat Pads; Sealed Air Cryovac). Three additional 2.54-cm-thick steaks were subsequently cut, with the fourth steak (designated as steak #2) being placed on a styrofoam tray with absorbent pad. A timer was started immediately after each steak was cut, and instrumental color of the SM and TB were measured on each steak at 10-min intervals (3 readings/steak) for 2 h in a 3°C cooler under 807 lux of incandescent lighting. Instrumental color (CIE L*, a*, and b* values), as well as the spectral reflectance from 400 to 700 nm, was measured with a Hunter MiniScan XE (Model 45/0-L, Hunter Associates Laboratory Inc., Reston, VA), with a 22-mm aperture, a 10° observer, and using Illuminant A. The spectrocolorimeter was calibrated daily against the black and white tiles before steak fabrication. Hue angle and chroma (C*) were calculated from the a* and b* values of each steak as: $\tan^{-1}$ (b* / a*) and $[a^{*2} + b^{*2}]^{1/2}$, respectively (AMSA, 2012), and total color change (ΔE) was calculated as:

$$\Delta E = \sqrt{(L_x^* - L_0^*)^2 + (a_x^* - a_0^*)^2 + (b_x^* - b_0^*)^2}$$

where x is a specific time interval and 0 is the value immediately after cutting (AMSA, 2012; Clydesdale, 1991). In addition, the reflectance data from 400 to 700 nm was recorded and used to calculate the proportions of deoxymyoglobin (DMb = {[1.395 – ({A572 – A700} / {A525 – A700})]} × 100), metmyoglobin (MMb = {2.375 × [1 – ({A473 – A700} / {A525 – A700})]} × 100), and oxymyoglobin (OMb = DMb - MMb), where A473, A525, A572, and A700 are the natural log of the reflectance values at 473, 525, 572, and 700 nm, respectively (AMSA, 2012).

Instrumental color data from the SM (Exp. 1) and TB (Exp. 2) were analyzed as a completely randomized design with repeated measures using the mixed models procedure of SAS (SAS Inst., Inc., Cary, NC), with individual steak as the experimental unit. Aging period, post-cutting (bloom) time, and aging period × bloom time were included in the model as the fixed effects, whereas the repeated measure of bloom time was tested using subprimal within aging period as the random effect. Least squares means were computed and statistically separated by pair-wise t tests (PDIFF option) when there was a significant ($P < 0.05$) F-test.

In addition, polynomial contrasts were used to test the linear and quadratic responses to the main effects of aging period and bloom time.

In an attempt to determine when bloom development plateaued (stabilized), instrumental color data (L*, a*, b*, hue angle, C*, ΔE, and calculated oxymyoglobin percentage) were fitted to the sigmoidal growth curve equation ($y = A - B_e^{(-k)}$), where y is the dependent variable (instrumental color measurement), A is the value where change in instrumental color plateaus (asymptotic point), t is time, B_e is the y-intercept value, and k is the rate of approach in the change in instrumental color of the equation (Brody, 1945). The nonlinear procedure of SAS was used to solve for A, and individual values were then analyzed using the mixed model procedure of SAS, with wet-aging period as the lone fixed effect in the model. Again, least squares means were statistically separated using the PDIFF option, and polynomial contrasts were included in the analysis to discern linear and quadratic effects of wet-aging duration on asymptotic points.

Results and Discussion

There were no aging period × post-cutting (bloom) time interactions on any instrumental color characteristics (L*, a*, b*, C*, hue angles, ΔE, or oxymyoglobin and deoxymyoglobin percentages) of the SM ($P \geq 0.88$). There were significant aging period × bloom time interactions ($P \leq 0.001$) for hue angle and the percentages of deoxy- and oxymyoglobin, but differences among interactive least squares means were largely attributed to the main effect of bloom time; otherwise, there were no ($P \geq 0.52$) interactive effects on L*, a*, b*, C*, or metmyoglobin percentage of TB steaks.

Main effect of wet-aging on beef color

Lightness (L*) values increased (linear, $P = 0.016$), and yellowness (b*) values decreased (linear, $P = 0.002$), in SM steaks as the duration of wet-aging increased from 0 to 35 d (Table 1). In addition, both measures of SM steak redness (a* values and hue angles) decreased

Table 1. Influence of wet-aging period on instrumental color of fresh beef *semimembranosus* and *triceps brachii* steaks

	Wet-aging duration, d							*P*-values		
Color measure	0	7	14	21	28	35	SE	Aging	Linear	Quadratic
Semimembranosus										
Lightness (L*)[1]	41.08	41.22	42.11	43.96	42.71	43.32	0.834	0.113	0.016	0.418
Redness (a*)[1]	33.04	32.93	32.32	32.36	32.21	32.01	0.269	0.056	0.002	0.575
Yellowness (b*)[1]	26.19	26.06	25.66	25.55	25.03	24.97	0.335	0.062	0.002	0.956
Hue angle, °[2]	38.10	38.08	38.16	38.01	37.59	37.72	0.209	0.301	0.050	0.497
Chroma (C*)[3]	42.19[a]	42.02[a]	41.30[ab]	41.26[ab]	40.83[b]	40.62[b]	0.404	0.049	0.001	0.792
ΔE[4]	16.21	16.07	16.00	15.63	15.54	15.25	0.273	0.118	0.004	0.749
OMb, %[5]	74.70	75.37	75.99	75.07	74.00	74.85	0.782	0.580	0.511	0.393
DMb, %[5]	10.24	9.16	8.42	9.31	10.83	10.05	0.811	0.309	0.459	0.135
MMb, %[5]	15.03	15.43	15.69	15.34	14.89	15.14	0.353	0.366	0.554	0.132
Triceps brachii										
Lightness (L*)[1]	40.26	38.90	40.63	41.36	39.62	41.57	0.871	0.127	0.164	0.703
Redness (a*)[1]	31.26	31.34	31.51	31.44	31.88	31.67	0.316	0.660	0.129	0.878
Yellowness (b*)[1]	23.37	23.43	23.69	23.63	23.90	23.85	0.378	0.813	0.169	0.849
Hue angle, °[2]	36.50	36.54	36.71	36.66	36.60	36.75	0.199	0.893	0.363	0.811
Chroma (C*)[3]	39.06	39.16	39.45	39.36	39.87	39.67	0.475	0.740	0.143	0.868
ΔE[4]	13.24[b]	14.13[ab]	14.01[ab]	13.46[b]	14.85[a]	14.10[ab]	0.362	0.043	0.054	0.499
OMb, %[5]	71.32	71.48	72.01	71.96	71.93	72.60	0.567	0.459	0.062	0.939
DMb, %[5]	12.99	12.45	11.99	12.99	12.65	11.85	0.698	0.514	0.365	0.855
MMb, %[5]	15.69	16.10	16.03	15.04	15.38	15.56	0.420	0.229	0.177	0.849

[a,b]Within a row, least squares means lacking a common superscripted letter differ, $P < 0.05$.

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

[2]Hue angle represents the change from the true red axis (larger values indicate a greater shift from red to yellow).

[3]C* = a measure of the total color/vividness of color (greater C* values indicate greater total color/a more vivid color).

[4]ΔE = change in total color (greater ΔE values indicate a greater color change).

[5]Calculated percentages of oxymyoglobin (OMb), deoxymyoglobin (DMb), and metmyoglobin (MMb).

(linear, $P \leq 0.050$) with increasing aging period, but the ranges in mean a* values and hue angles across all aging periods were only 1.03 units and 0.38°, respectively. On the other hand, vacuum-aging period had no effect on L* ($P \geq 0.127$), a* ($P \geq 0.129$), b* ($P \geq 0.169$), or hue angles ($P \geq 0.363$) values of TB steaks (Table 1).

As the duration of aging vacuum-packaged inside rounds increased from 0 to 35 d, vividness of color (C* values) decreased (linear, $P = 0.001$), with SM steaks from inside rounds aged 0 and 7 d having greater ($P < 0.05$) C* values than SM steaks from inside rounds vacuum-aged 28 and 35 d; however, duration of aging had no ($P \geq 0.143$) effect on C* values of TB steaks from vacuum-packaged shoulder clods (Table 1). Interestingly, ΔE values for SM steaks decreased (linear, $P = 0.004$) as duration of wet-aging increased, but ΔE values for TB steaks tended to increase (linear, $P = 0.054$) with increasing aging time, with greater ($P < 0.05$) total color change occurring in TB steaks from shoulder clods aged 28 than 0 d. Lastly, there was no effect of aging time of vacuum-packaged inside rounds and shoulder clods on calculated proportions of oxymyoglobin (OMb), deoxymyoglobin (DMb), and metmyoglobin (MMb) of SM ($P \geq 0.132$) or TB steaks ($P \geq 0.062$) across the 2-h observation period (Table 1).

Kirchofer et al. (2002) indicated that the redness (a* values) of beef *longissimus thoracis* (LT) increased with increasing chilling time (24 vs. 48 h), but there is very little information available concerning the effects of wet-aging on beef color development. In an experiment designed similarly to the present ones, Lee et al. (2008a) reported that wet-aging durations of 0 to 35 d did not affect the color characteristics (L*, a*, b*, hue angle, C*, and ΔE) or estimated OMb percentage of LT steaks over the first 2 h after steak fabrication and exposure to air. Moreover, even though L* and hue angles of *gluteus medius* (GM) steaks were not affected by postmortem aging of vacuum-packaged top sirloin butts, Lee et al. (2008b) found that a*, b*, and C* values, as well as the calculated OMb content, were greater in GM steaks from top sirloin butts wet-aged 7 d than those aged either 0 or 21 to 35 d.

Bloom development

Increases ($P < 0.05$) of 53.0 and 56.8% occurred in lightness (L*) values within the first 10 min after SM (Fig. 1A) and TB steaks (Fig. 1B) were exposed to air, respectively, and almost 90% of the increases in L* values was achieved 60 and 50 min after fabrication of SM and TB steaks, respectively. In addition, redness (a*) values increased 47.2 and 50.0% in SM (Fig. 2A) and TB steaks (Fig. 2B) within 10 min of fabrication, respectively, whereas a* values had increased ($P < 0.05$) 88.5 and 89.9% within an hour of SM and TB steaks being exposed to air, respectively. Similarly, yellowness (b*) values of SM (Fig. 3A) and TB steaks (Fig. 3B) increased ($P < 0.05$) 54.4 and 57.3%, respectively, during the first 10 min after cutting, and b* values increased ($P < 0.05$) 87.4 and 89.7% in SM and TB steaks, respectively, within 50 min of cutting.

Rentfrow et al. (2004), as well as Wulf and Wise (1999), indicated that L*, a*, and b* values of the LT did not change 12 min after beef carcasses were ribbed; however, Lee et al. (2008a) reported that L*, a*, and b* values of LT steaks increased between 43 and 54% during the first 10 min after fabrication of vacuum-aged ribeye rolls. In addition, between 50 and 60% of the increases in a* and b* values of GM steaks occurred within the first 10 min after exposure to air, but L* values of GM steaks had increased only 45% within 10 min of steak fabrication from wet-aged top sirloin butts (Lee et al., 2008b). When individual SM steaks were

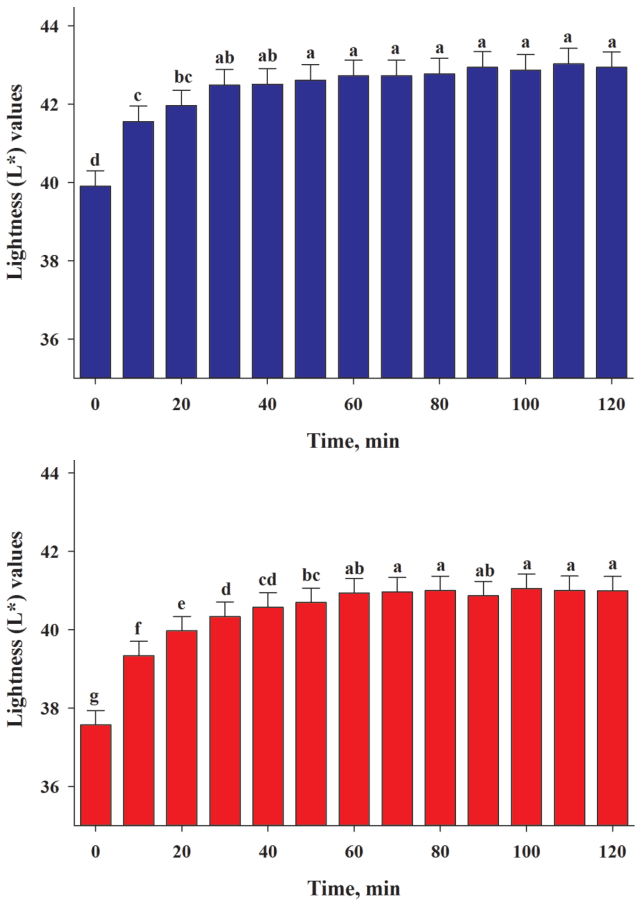

Figure 1. Influence of bloom development time on lightness (L*) values of beef (A) semimembranosus ($P < 0.001$) and (B) triceps brachii ($P < 0.001$) steaks. Columns lacking common letters differ, $P < 0.05$.

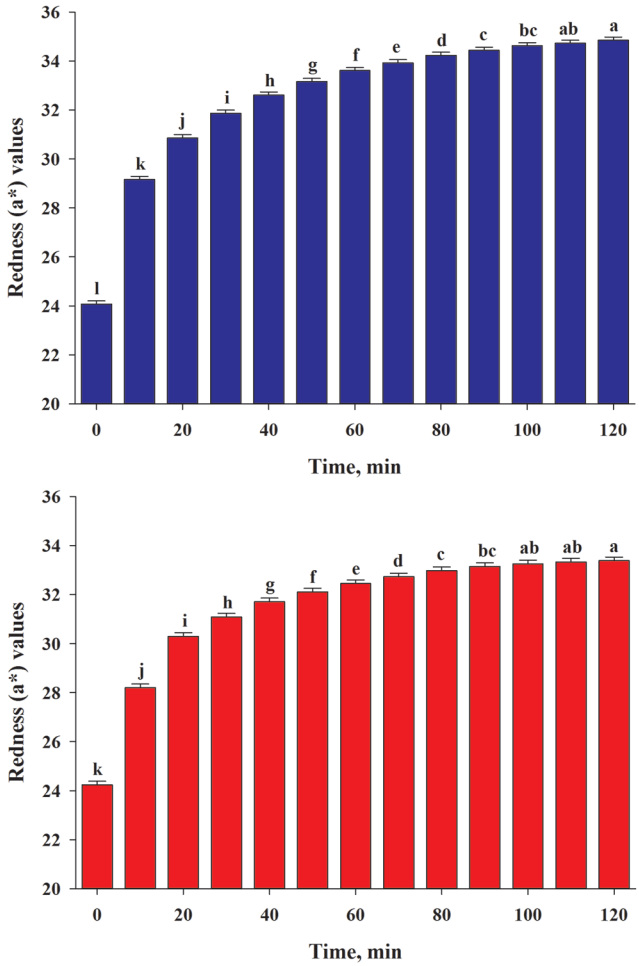

Figure 2. Influence of bloom development time on redness (a*) values of beef (A) semimembranosus (P < 0.001) and (B) triceps brachii (P < 0.001) steaks. Columns lacking common letters differ, P < 0.05.

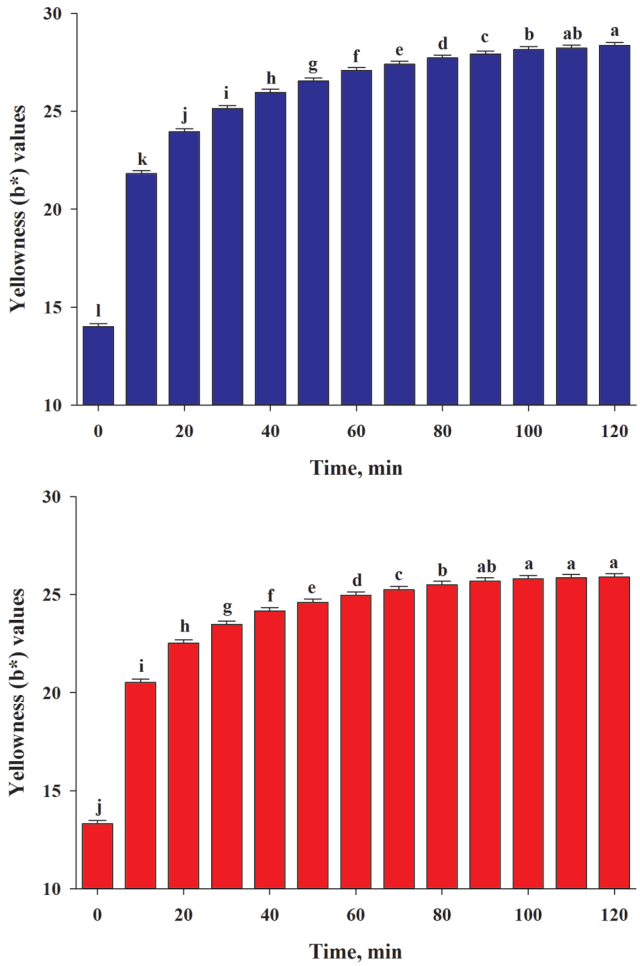

Figure 3. Influence of bloom development time on yellowness (b*) values of beef (A) semimembranosus (P < 0.001) and (B) triceps brachii (P < 0.001) steaks. Columns lacking common letters differ, P < 0.05.

vacuum-aged only 1 d, Wyrwisz et al. (2016) reported that L* and a* values were similar for the first 30 and 35 min, respectively, after exposure to air, but b* values increased almost 95% within 10 min of air exposure; however, when SM steaks were individually wet-aged for 28 d, 63.4 and 76.1% of the increases in L* and a* values occurred within 15 min of exposure to air, respectively, but approximately 54% of the increase in b* did not occur until 30 min after exposure to air.

Haas and Bratzler (1965) reported that instrumental color, specifically redness (Gardner a_l) values, of beef LT continued to change 180 min after cutting and exposure to air, but Wulf and Wise (1999) demonstrated that L* values of the beef LT stabilized long before a* and b* values when exposed to air. Similarly, Lee et al. (2008a, 2008b) noted that greater than 80% of the increases in L* values of LT and GM steaks occurred within 30 min of steak fabrication and exposure to air, whereas a* and b* values of LT and GM steaks had increased almost 90% within an hour of steak fabrication. Results from the current study concur that, although instrumental color values – in particular a* and b* values – increased over the 120-min observation period, beef color of the SM and TB steaks began to stabilize around 90 min post-cutting.

Even though there is debate concerning the ability of hue angles to measure bloom development in beef (Beggan et al., 2006), 74.0% of the increase ($P < 0.05$) in hue angles was observed during the first 10 min after SM and TB steak fabrication (Fig. 4). Moreover, greater than 90% of the increases ($P < 0.05$) in hue angles occurred within 30 min of exposing SM and TB steaks to air. Similar to the present results, Lee et al. (2008a, 2008b) reported that hue angles of LT and GM steaks stabilized within 60 min of cutting. Conversely, Rentfrow et al. (2004) reported that hue angles of the beef LT stabilized within 10 min of carcass ribbing, whereas hue angles of beef SM steaks (Wyrwisz et al., 2016) actually decrease during the first 30 min following exposure to air. Škrlep and Čandek-Potokar (2007)

reported that changes in hue angle had the greatest association with bloom development in pork LT chops, and Wyrwisz et al. (2016) reported a strong, positive correlation between hue angle and oxymyoglobin percentage in beef SM steaks. Yet, the inconsistent ability of hue angles to monitor bloom development is likely due to differences in the illuminant used to measure a* and b* values (Yancey and Kropf, 2008). In the current study, as well as those of Lee et al. (2008a, 2008b), where results question the reliance of hue angles to measure bloom development, instrumental color was collected using illuminant A; however, in previous studies where hue angles were used to measure bloom development in beef, illuminant D65 was the light source used to measure a* and b* values (Wyrwisz et al., 2016; Beggan et al., 2006; Rentfrow et al., 2004).

Because chroma (C*) is calculated with a* and b* values, it was not surprising that over 50% of the increase ($P < 0.05$) in C* values had occurred within the first 10 min after cutting SM (Fig. 5A) and TB (Fig. 5B) steaks. Furthermore, almost 90% of the increases ($P < 0.05$) in C* values had transpired within 60 min of cutting SM steaks (Fig. 5A), whereas more than 75% of the increase in C* values had occurred within 30 min of TB steak fabrication (Fig. 5B). Rentfrow et al. (2004) reported an increase in C* values in beef LT for the first 9 min after carcass ribbing, and C* values stabilized within 12 min of exposure to air. In agreement with the present study, greater than 45 and 55% of the increase in C* values occurred within 10 min of cutting in LT and GM steaks, respectively, and more than 87 and 90% of the change in C* values of LT and GM steaks, respectively, occurred within 60 min of air exposure (Lee et al., 2008a, 2008b).

Between 52.2 and 55.3% of the total color change (ΔE) occurred ($P < 0.05$) within the first 10 min post-cutting of the SM (Fig. 6A) and TB (Fig. 6B) steaks, respectively, whereas 90.2 and 92.4% of the increase ($P < 0.05$) in ΔE values transpired within 60 min of

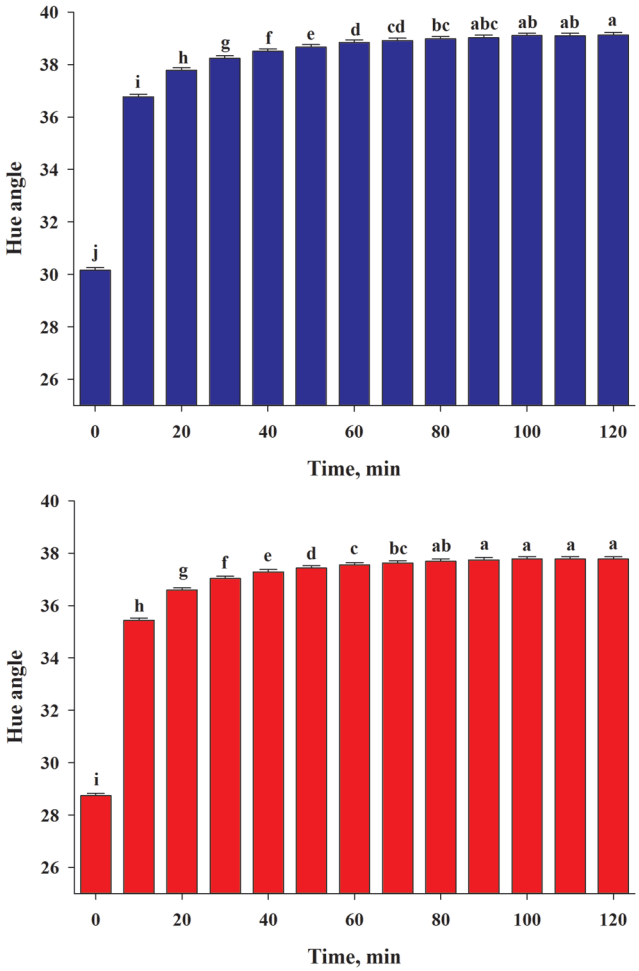

Figure 4. Influence of bloom development time on hue angles of beef (A) semimembranosus (P < 0.001) and (B) triceps brachii (P < 0.001) steaks. Columns lacking common letters differ, P < 0.05.

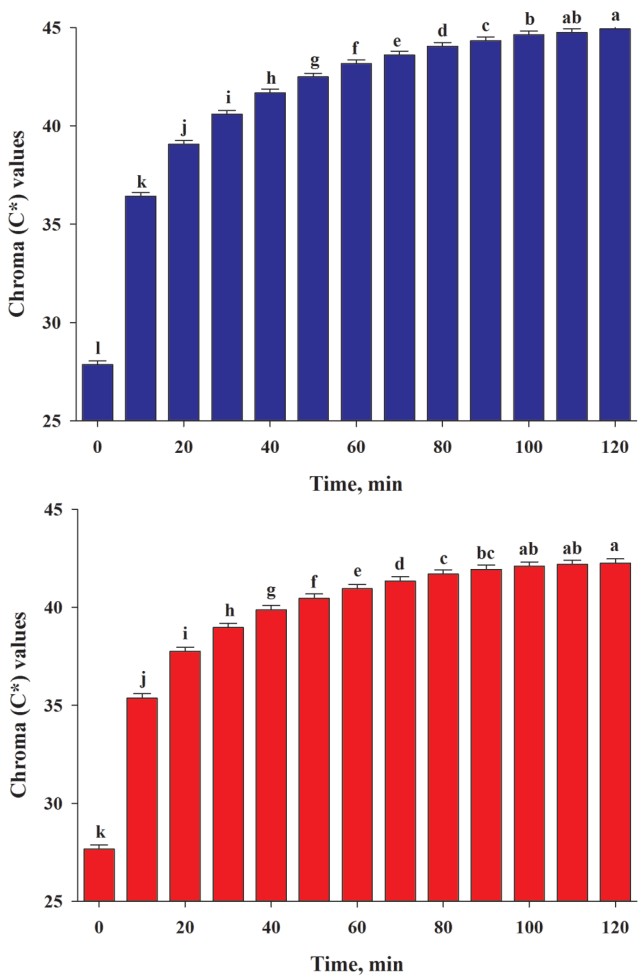

Figure 5. Influence of bloom development time on chroma (C*) values of beef (A) semimembranosus (P < 0.001) and (B) triceps brachii (P < 0.001) steaks. Columns lacking common letters differ, P < 0.05.

SM and TB steak fabrication, respectively. Similarly, Lee et al. (2008b) noted that greater than 50 and 80% of the increase in ΔE values of GM steaks occurred within 30 and 60 min of steak fabrication, respectively, whereas Lee et al. (2008a) reported that 45, 75, and 90% of the increase in ΔE values occurred 30, 60, and 90 min after LT steak fabrication, respectively. Haas and Bratzler (1965) reported that ΔE values decreased as oxygenation increased in beef LT; however, Moore et al. (2003) reported that ΔE values increased over time in beef *semitendinosus* steaks similar to the present results observed in the SM and TB.

The calculated proportion of OMb increased ($P < 0.05$) 78.1 and 76.7%, and the proportion of DMb decreased ($P < 0.05$) 77.0 and 74.7%, during the first 10 min after SM (Fig. 7A) and TB (Fig. 7B) steak fabrication and exposure to air, respectively. Moreover, 94% of the increase ($P < 0.05$) in calculated OMb percentages had occurred after 30 min post-cutting, and greater than 99% of the proportion of OMb had occurred within 70 min of steak fabrication, in both SM and TB steaks. In agreement, Lee et al. (2008a, 2008b) reported that calculated OMb percentages doubled within the first 10 min of LT and GM steak fabrication, and between 90 and 91% of the increase in the proportion of OMb in LT and GM steaks occurred within 1 h of cutting steaks from wet-aged ribeye rolls and top sirloin butts, respectively. Even though Wyrwisz et al. (2016) reported that calculated OMb percentage increased between 12.0 and 29.0% during the first 10 min after vacuum-packaged beef SM steaks were exposed to air, nearly 100% of the increase in the percent of OMb was achieved within 60 min of steak removal from vacuum-packages and exposure to air.

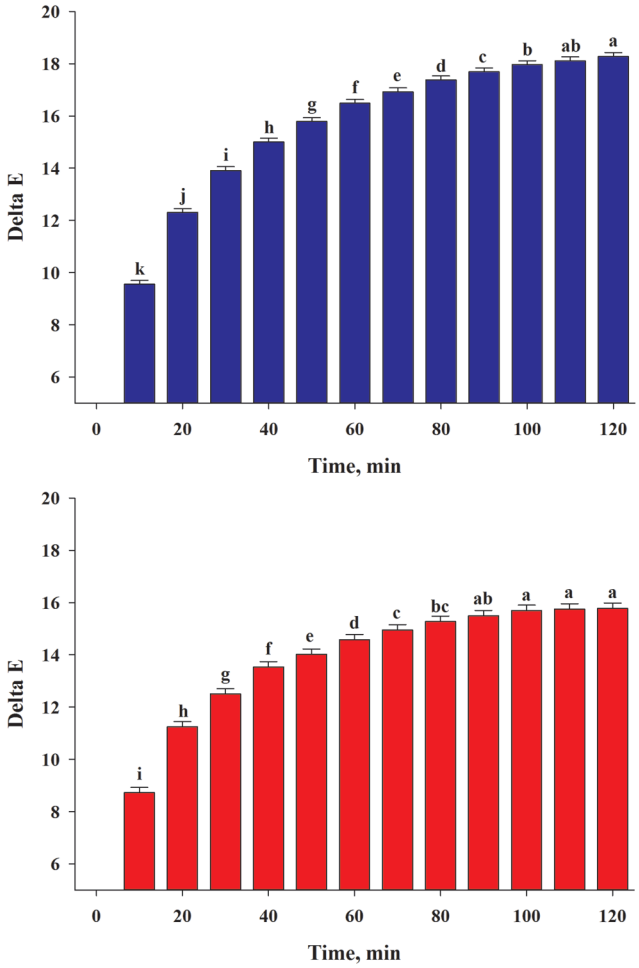

Figure 6. Influence of bloom development time on calculated ΔE (total change in color from initial cutting) values of beef (A) semimembranosus ($P < 0.001$) and (B) triceps brachii ($P < 0.001$) steaks. Columns lacking common letters differ, $P < 0.05$.

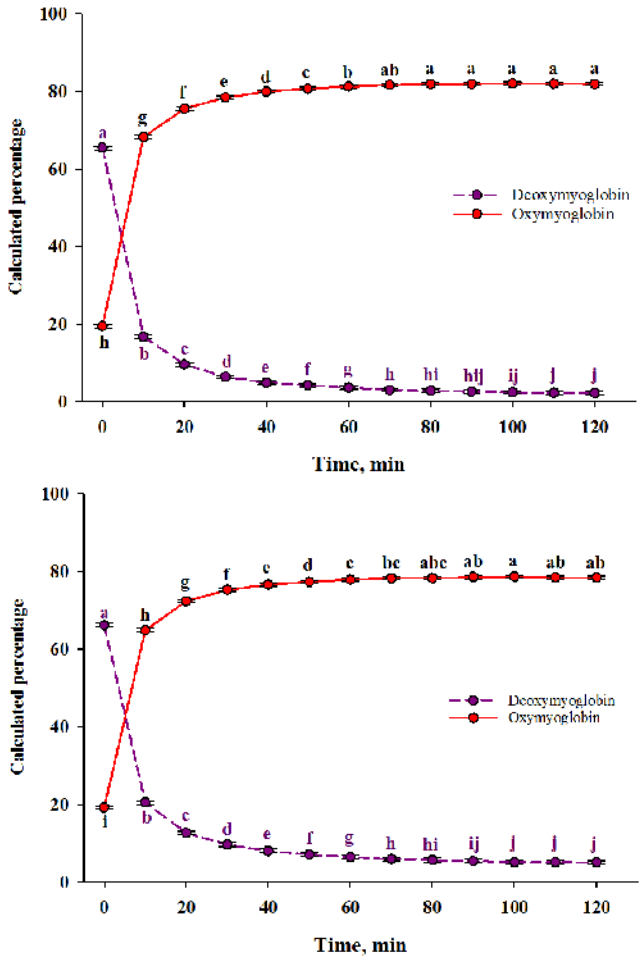

Figure 7. Influence of bloom development time on calculated deoxymyoglobin and oxymyoglobin percentages of beef (A) semimembranosus ($P < 0.001$) and (B) triceps brachii ($P < 0.001$) steaks. Within a line, datum points lacking common letters differ, $P < 0.05$.

Asymptotic values for color development curves

When the instrumental color characteristics were fitted to a sigmoidal growth curve, the asymptote (*A*) of color development was calculated and represents the value at which the color variable plateaus. The asymptotic points for L* values of SM streaks increased (linear, $P = 0.007$) with increasing wet-aging duration, with SM steaks from inside rounds aged 21 and 35 d plateauing at greater ($P < 0.05$) L* values than SM steaks from vacuum-packaged inside rounds aged 0 and 7 d (Table 2). In addition, the lowest ($P < 0.05$) asymptotic point on the L* development curve was observed in TB steaks from shoulder clods wet-aged 7 d, and L* asymptotic points for TB steaks were greater ($P < 0.05$) when shoulder clods were aged 35 than 28 d. Asymptotic points for a* and b* values decreased (linear, $P < 0.001$) among SM steaks, with a* values of SM steaks from inside rounds aged 0 and 7 d plateauing at greater ($P < 0.05$) values than SM steaks from inside rounds aged 14 to 35 d. Similarly, b* values plateaued at the highest ($P < 0.05$) and lowest ($P < 0.05$) asymptotic points on the yellowness development curve for SM steaks from inside rounds aged 0 and 35 d, respectively. Conversely, asymptotic points for a* and b* values of TB streaks actually increased (linear, $P \leq 0.032$) as aging duration increased.

The hue angle development curve among SM steaks revealed that asymptotic points decreased (linear, $P < 0.001$) as the wet-aging period increased, with plateau points for SM steaks from inside rounds wet-aged 14 d, or less, being greater ($P < 0.05$) than SM steaks from inside rounds aged 28 and 35 d (Table 2). On the other hand, hue angle asymptotic points for TB streaks were not ($P \geq 0.181$) affected by the aging duration of vacuum-packaged shoulder clods. Asymptotic points on the C* development curve for SM steaks decreased (linear, $P < 0.001$) the longer inside rounds were aged, with the greatest ($P < 0.05$) and least ($P < 0.05$) asymptotic points for SM steaks

Table 2. Influence of wet-aging period on asymptotic[1] values for color development curves of fresh beef *semimembranosus* and *triceps brachii* steaks

	Wet-aging duration, days							*P*-values		
Color measure	0	7	14	21	28	35	SE	Aging	Linear	Quadratic
Semimembranosus										
Lightness (L*)[2]	41.55^{b}	41.91^{b}	43.24^{ab}	44.61^{a}	42.92^{ab}	44.11^{a}	0.771	0.024	0.007	0.222
Redness (a*)[2]	35.11^{a}	35.06^{a}	34.37^{b}	34.51^{b}	34.25^{b}	33.96^{b}	0.220	0.001	< 0.001	0.784
Yellowness (b*)[2]	28.55^{a}	28.49^{ab}	27.93^{abc}	27.85^{bc}	27.27^{cd}	27.10^{d}	0.266	< 0.001	< 0.001	0.782
Hue angle[3], °	39.13^{a}	39.12^{a}	39.08^{a}	38.94^{ab}	38.56^{c}	38.59^{bc}	0.150	0.005	< 0.001	0.333
Chroma (C*)[4]	45.27^{a}	45.18^{ab}	44.31^{cd}	44.35^{bc}	43.79^{cd}	43.47^{d}	0.330	< 0.001	< 0.001	0.981
ΔE[5]	18.80	18.85	18.78	18.69	18.41	17.85	0.315	0.105	0.012	0.114
OMb, %[6]	81.31	81.65	81.86	81.37	80.62	80.94	0.587	0.561	0.214	0.373
DMb, %[6]	3.66	2.88	2.37	3.12	4.30	3.76	0.595	0.134	0.214	0.088
Triceps brachii										
Lightness (L*)[2]	41.54^{ab}	39.68^{c}	41.65^{ab}	41.78^{ab}	40.40^{bc}	42.18^{a}	0.756	0.014	0.282	0.343
Redness (a*)[2]	32.69	33.02	33.19	33.08	33.68	33.41	0.290	0.103	0.008	0.541
Yellowness (b*)[2]	25.10	25.29	25.51	25.50	25.90	25.72	0.366	0.364	0.032	0.601
Hue angle[3], °	37.46	37.49	37.59	37.64	37.60	37.65	0.174	0.785	0.181	0.625
Chroma (C*)[4]	41.24	41.58	41.88	41.78	42.50	42.17	0.454	0.196	0.016	0.570
ΔE[5]	15.07^{c}	16.17^{b}	16.39^{ab}	16.13^{b}	17.09^{a}	16.28^{ab}	0.402	< 0.001	0.001	0.015
OMb, %[6]	77.04^{c}	77.53^{bc}	78.07^{ab}	78.14^{ab}	78.10^{ab}	78.45^{a}	0.409	0.022	0.001	0.259
DMb, %[6]	6.96^{a}	6.10^{abc}	5.59^{c}	6.52^{ab}	6.13^{abc}	5.68^{bc}	0.510	0.042	0.063	0.377

$^{a–d}$Within a row, least squares means lacking a common superscripted letter differ, $P < 0.05$.

[1]Instrumental color data was fitted to the equation $y = A - B_e^{(-k)}$ (Brody, 1945), where *y* is the dependent variable (instrumental color measurement), *A* is the value where change in instrumental color plateaus (asymptotic point), *t* is time, *B* is the y-intercept value, *e* is the base of natural logarithms, and *k* is the rate of approach in the change in instrumental color.

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

[3]Hue angle represents the change from the true red axis (larger values indicate a greater shift from red to yellow).

[4]C* = a measure of the total color/vividness of color (greater C* values indicate greater total color/a more vivid color).

[5]ΔE = change in total color (greater ΔE values indicate a greater color change).

[6]Calculated percentages of oxymyoglobin (OMb), deoxymyoglobin (DMb), and metmyoglobin (MMb).

from inside rounds wet-aged 0 and 35 d, respectively. However, because C* is calculated from a* and b* values, it was no surprise that the plateau points for C* values of TB steaks actually increased (linear, $P = 0.016$) as wet-aging duration increased from 0 to 35 d, but, again, the C* asymptotic points only differed 1.26 units among all aging periods. Asymptotic points for ΔE decreased (linear, $P = 0.012$) in SM steaks as aging time of vacuum-packaged inside rounds increased, whereas plateau points for ΔE values of TB steaks increased (quadratic, $P = 0.015$) with increasing wet-aging duration, with the greatest ($P < 0.05$) and least ($P < 0.05$) ΔE plateau points for TB steaks from vacuum-packaged shoulder clods aged 28 and 0 d.

Asymptotic points for the proportions of OMb and DMb in SM steaks were similar ($P \geq 0.088$) across wet-aging periods (Table 2). However, asymptotic points for OMb percentage in TB steaks increased (linear, $P = 0.001$) as wet-aging duration increased, with the percentage of OMb in TB steaks from shoulder clods wet-aged 35 d plateauing at a greater ($P < 0.05$) value than TB steaks from vacuum-packaged clods aged 0 and 7 d. In addition, plateau points for DMb percentages were greater ($P < 0.05$) for TB steaks from shoulder clods wet-aged 0 d than those from shoulder clods wet-aged 14 and 35 d.

Consistent with the results observed in SM steaks, Lee et al. (2008a, 2008b) reported that asymptotic points for a* and b* values of GM steaks, as well as hue angles of LT steaks, were greater after wet-aging subprimals for 7 than 21 to 35 d; yet, asymptotic points for a*, b*, and C* values actually increased in TB steaks with longer wet-aging periods. Ledward (1992) reported that vacuum-aged meat blooms more rapidly than fresh meat when exposed to air, and the rapid bloom development was due to reductions in the activity of oxygen-utilizing enzymes (Ledward, 1992) and oxygen consumption rates (Zhu and Brewer, 1998). Conversely, McKenna et al. (2005) reported that resistance to induced MMb formation, nitric oxide MMb reducing ability, and oxygen consumption rate were similar among beef LT, SM, and TB, but beef TB, especially the long head, had greater myoglobin concentrations than either the LT or SM, which may explain some of the observed discrepancies in bloom patterns between TB and SM steaks in the current study.

Conclusions

Even though a number of researchers have shown that color development becomes stabilized sometime between 9 (Rentfrow et al., 2004) and 12 min (Wulf and Wise, 1999) in beef, results from the present study indicated that color development in both the SM and TB stabilized at approximately 90 min after cutting and exposure to air, and little to no change in instrumental color was observed thereafter. Moreover, extending the aging period to 21 d, or longer, may affect the degree to which color develops in the SM, and to a lesser extent in the TB; however, in contrast to the work of Ledward (1992), wet-aging inside rounds and shoulder clods up to 35 d had little to no impact on the rate of color development in either the SM or TB.

Literature Cited

AMSA. 2012. Meat Color Measurement Guidelines. American Meat Science Assoc., Champaign, IL.

Beggan, M., P. Allen, and F. Butler. 2006. Effect of oxygen concentrations on blooming ability of aged beef *longissimus lumborum* steaks following ultralow oxygen and vacuum storage. J. Muscle Foods 17:267–276. doi:10.1111/j.1745-4573.2006.00049.x

Brody, S. 1945. Bioenergetics and Growth. Reinhold Publishing Co., New York.

Carpenter, C. E., D. P. Cornforth, and D. Whittier. 2001. Consumer preferences for beef color and packaging did not affect eating satisfaction. Meat Sci. 57:359–363. doi:10.1016/S0309-1740(00)00111-X

Clydesdale, F. M. 1991. Color perception and food quality. J. Food Qual. 14:61–74. doi:10.1111/j.1745-4557.1991.tb00047.x

Denoyelle, C., and E. Lebihan. 2004. Intramuscular variation in beef tenderness. Meat Sci. 66:241–247. doi:10.1016/S0309-1740(03)00097-4

Gruber, S. L., J. D. Tatum, J. A. Scanga, P. L. Chapman, G. C. Smith, and K. E. Belk. 2006. Effects of postmortem aging and USDA quality grade on Warner-Bratzler shear force values of seventeen individual beef muscles. J. Anim. Sci. 84:3387–3396. doi:10.2527/jas.2006-194

Haas, M. C., and L. J. Bratzler. 1965. Determination of myoglobin oxygenation rates in pork, beef and lamb by Munsell and reflectance colorimetry. J. Food Sci. 30:64–68. doi:10.1111/j.1365-2621.1965.tb00264.x

Hood, D. E. 1980. Factors affecting the rate of metmyoglobin accumulation in pre-packaged beef. Meat Sci. 4:247–265. doi:10.1016/0309-1740(80)90026-1

Keith, F. K. M., D. L. De Vol, R. S. Miles, P. J. Bechtel, and T. R. Carr. 1985. Chemical and sensory properties of thirteen major beef muscles. J. Food Sci. 50:869–872. doi:10.1111/j.1365-2621.1985.tb12968.x

Kirchofer, K., C. Calkins, D. Burson, K. Eskridge, and D. Hanson. 2002. Factors influencing color development in beef. Nebraska Beef Report. http://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1267&context=animalscinbcr (accessed 20 November 2016).

Kropf, D. H. 1980. Effects of retail display conditions on meat color. Proc. 33rd Recipr. Meat Conf. 33:15-32.

Ledward, D. A. 1992. Color of raw and cooked meat. In: M. K. Knight and D. A. Ledward, editors, The Chemistry of Muscle-Based Foods, D. E., Johnston. Royal Society of Chemistry, London. p. 128–144.

Lee, M. S., J. K. Apple, J. W. S. Yancey, J. T. Sawyer, and Z. B. Johnson. 2008a. Influence of wet-aging on bloom development in the longissimus thoracis. Meat Sci. 80:703–707. doi:10.1016/j.meatsci.2008.03.013

Lee, M. S., J. K. Apple, J. W. S. Yancey, J. T. Sawyer, and Z. B. Johnson. 2008b. Influence of vacuum-aging period on bloom development of the beef *gluteus medius* from top sirloin butts. Meat Sci. 80:592–598. doi:10.1016/j.meatsci.2008.02.006

Lee, M. S., J. W. S. Yancey, J. K. Apple, J. T. Sawyer, and R. T. Baublits. 2008c. Within-muscle variation in color and pH of beef *semimembranosus*. J. Muscle Foods 19:62–73. doi:10.1111/j.1745-4573.2007.00100.x

McKenna, D. R., P. D. Mies, B. E. Baird, K. D. Pfeiffer, J. W. Ellebracht, and J. W. Savell. 2005. Biochemical and physical factors affecting discoloration characteristics of 19 bovine muscles. Meat Sci. 70:665–682. doi:10.1016/j.meatsci.2005.02.016

Moon, S. S., P.-N. Seong, and J. Y. Jeong. 2015. Evaluation of meat color and physiochemical characteristics in forequarter muscles of Holstein steers. Korean J. Food Sci. Anim. Res. 35:646–652. doi:10.5851/kosfa.2015.35.5.646

Moore, M. E., I. Y. Han, J. C. Acton, A. A. Ogale, C. R. Barmore, and P. L. Dawson. 2003. Effects of antioxidants in polyethylene film on fresh beef color. J. Food Sci. 68:99–104. doi:10.1111/j.1365-2621.2003.tb14122.x

O'Keeffe, M., and D. E. Hood. 1982. Biochemical factors influencing metmyoglobin formation on beef from muscles of differing color stability. Meat Sci. 7:209–228. doi:10.1016/0309-1740(82)90087-0

Rhee, M. S., T. L. Wheeler, S. D. Shackelford, and M. Koohmaraie. 2004. Variation in palatability and biochemical traits within and among eleven beef muscles. J. Anim. Sci. 82:534–550. doi:10.2527/2004.822534x

Rentfrow, G., M. L. Linville, C. A. Stahl, K. C. Olson, and E. P. Berg. 2004. The effects of the antioxidant lipoic acid on beef longissiumus bloom time. J. Anim. Sci. 82:3034–3037. doi:10.2527/2004.82103034x

Sammel, L. M., M. C. Hunt, D. H. Kropf, K. A. Hackmeister, C. L. Kastner, and D. E. Johnson. 2002. Influence of chemical characteristics of beef inside and outside *semimembranosus* on color traits. J. Food Sci. 67:1323–1330.

Sawyer, J. T., R. T. Baublits, J. K. Apple, J.-F. Meullenet, Z. B. Johnson, and T. K. Alpers. 2007. Lateral and longitudinal characterization of color stability, instrumental tenderness, and sensory characteristics in the beef *semimembranosus*. Meat Sci. 75:575–584. doi:10.1016/j.meatsci.2006.09.012

Searls, G. A., R. J. Maddock, and D. M. Wulf. 2005. Intramuscular tenderness variation within four muscles of the beef chuck. J. Anim. Sci. 83:2835–2842. doi:10.2527/2005.83122835x

Škrlep, M., and M. Čandek-Potokar. 2007. Pork color measurement as affected by bloom time and measurement location. J. Muscle Foods 18:78–87. doi:10.1111/j.1745-4573.2007.00067.x

Sullivan, G. A., and C. R. Calkins. 2011. Ranking beef muscles for Warner-Bratzler shear force and trained sensory panel ratings from published literature. J. Food Qual. 34:195–203. doi:10.1111/j.1745-4557.2011.00386.x

USDA. 2014. Institutional meat purchase specifications: Fresh beef series 100. https://ams.usda.gov/sites/default/files/media/IMPS_100_Fresh_Beef[1].pdf. (accessed 17 November 2016).

Von Seggern, D. D., C. R. Calkins, D. D. Johnson, J. E. Brickler, and B. L. Gwartney. 2005. Muscle profiling: Characterizing the muscles of the beef chuck and round. Meat Sci. 71:39–51. doi:10.1016/j.meatsci.2005.04.010

Wulf, D. M., and J. W. Wise. 1999. Measuring muscle color on beef carcasses using the L*a*b* color space. J. Anim. Sci. 77:2418–2427. doi:10.2527/1999.7792418x

Wyrwisz, J., M. Moczkowska, M. Kurek, A. Stelmasiak, A. Półtorak, and A. Wierzbicka. 2016. Influence of 21 days of vacuum-aging on color, bloom development, and WBSF of beef *semimembranosus*. Meat Sci. 122:48–54. doi:10.1016/j.meatsci.2016.07.018

Yancey, J. W. S., and D. H. Kropf. 2008. Instrumental reflectance values of fresh pork are dependent on aperture size. Meat Sci. 79:734–739. doi:10.1016/j.meatsci.2007.11.006

Zhu, L. G., and M. S. Brewer. 1998. Discoloration of fresh pork as related to muscle and display conditions. J. Food Sci. 63:763–767. doi:10.1111/j.1365-2621.1998.tb17895.x