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Topical Application of Acerola Cherry Powder in Combination With Rosemary Extract Extends the Shelf Life of Beef Chuck Roll and Bone-In Short Rib Steaks

Jessie B. Van Buren[1], Brianna J. Buseman[1], Tanya M. Weber[1], James A. Nasados[1], Jessica M. Lancaster[1], Jaxon H. Smart[1], James A. Church[2], William J. Price[3], Phillip D. Bass[1], and Michael J. Colle[1]*

[1]Department of Animal, Veterinary, and Food Sciences, University of Idaho, Moscow, ID 83844, USA
[2]University of Idaho Extension, University of Idaho, Grangeville, ID 83530, USA
[3]Statistical Programs, College of Agricultural and Life Sciences, University of Idaho, Moscow, ID 83844, USA
*Corresponding author. Email: mjcolle@uidaho.edu (Michael J. Colle)

Abstract: Improving the shelf life of steaks from beef chuck rolls and bone-in short ribs, items commonly exported, will increase the demand of beef in international markets. Our objectives were to determine the effect of topically applying combinations of acerola cherry powder and rosemary extract on steak color and lipid oxidation of beef chuck roll and bone-in short rib. USDA Choice beef chuck rolls (Institutional Meat Purchase Specifications [IMPS] 116A; $N = 9$) and bone-in short ribs (IMPS 123A; $N = 18$) were aged (0°C) 28 d and cut into 1.0 cm-thick steaks. Steak treatments included the following: untreated control (C) or topically sprayed (2 mL) with an acerola cherry powder solution (0.05% A), rosemary extract solution (0.10% R), or mixture of acerola cherry powder and rosemary extract (M1 = 0.05% A + 0.1% R; M2 = 0.1% A + 0.1% R; M3 = 0.05% A + 0.2% R; M4 = 0.1% A + 0.2% R). On day 0 of retail display, oxygen consumption, metmyoglobin-reducing activity, and lipid oxidation were measured. Lipid oxidation was evaluated again following 4 d of retail display. Chuck roll steak color was scored twice daily, whereas short rib lean and bone marrow color were scored once daily throughout 4 d of retail display. Treating chuck roll steaks with M2, M3, and M4 decreased lipid oxidation compared to C and A ($P = 0.004$). In short rib steaks, lipid oxidation remained constant from day 0 to 4 treated with M4 but increased for all other treatments ($P < 0.001$). Chuck roll steaks treated with A, M2, and M3 were redder than C steaks ($P = 0.001$). On days 0 and 4, untreated bone marrow was less red than all the antioxidant treated bone marrow ($P = 0.011$). Antioxidant treatment did not improve subjective lean color for the chuck roll ($P = 0.324$) or bone-in short rib ($P = 0.081$). Topical application of M4 (0.1% acerola cherry powder and 0.2% rosemary extract) reduced lipid oxidation in both chuck roll and bone-in short rib steaks. Additionally, antioxidants alone or in combination with one another improve objective redness scores by up to 2 points; however, the subjective color panel did not observe lean color improvement.

Key words: antioxidants, extended aging, shelf life, beef
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Introduction

In 2021, US beef exports contributed over $10.5 billion of revenue, which equates to $407.22 per head (USMEF, 2022). South Korea is the largest growing export market for US beef cuts, such as chuck rolls and short ribs (USDA FAS, 2020; USMEF, 2021, 2022). However, exporting beef to South Korea and other countries often takes a minimum of 28 d during which time beef metabolism continues, improving tenderness but reducing retail shelf life potential.

Improving color stability of US beef will allow for longer shelf life of beef products and thus improved demand both nationally and internationally. Recently, Van Buren et al. (2022) found that topical application of the natural antioxidants rosemary extract and acerola cherry powder may improve shelf

life of beef steaks (Van Buren et al., 2022). Additionally, they noted that the source (supplier) of the natural antioxidant influences its effectiveness in improving shelf life. These naturally derived antioxidants contain tocopherols and ascorbic acid. Utilizing them in combination would allow the ascorbic acid to regenerate tocopherol molecules thus increasing their effectiveness at reducing oxidation and improving shelf life (Murray et al., 2006). Therefore, using results from Van Buren et al. (2022), the goal of this research was to evaluate the use of rosemary extract and acerola cherry powder in combination with one another. Additionally, minimal research has looked at applying antioxidants to cuts from the chuck or plate primals, including those cuts containing bones.

Our objectives were to determine the effect of topically applying combinations of acerola cherry powder and rosemary extract on steak color and lipid oxidation of beef chuck roll and bone-in short rib.

Materials and Methods

These materials and methods were adapted from Van Buren et al. (2022).

Product preparation

Nine USDA Choice beef chuck rolls (IMPS 116A) and 18 bone-in short ribs (IMPS 123A) were purchased from a commercial harvest facility and transported for 4 h at 4°C to the University of Idaho Meat Laboratory. Subprimals were wet-aged (0°C) for 28 d post-fabrication before being cut into 1.0 cm-thick steaks ($N = 126$ chuck roll steaks and $N = 126$ short rib steaks; Butcher Boy SA20, Butcher Boy, Selmer, TN). Steaks were systematically assigned to one of 7 treatment groups. For example, steak 1 from rib 1, steak 2 from rib 2, steak 3 from rib 3, etc. were assigned to the control treatment to prevent a location bias. Treatments included the following: untreated control (C), acerola cherry powder solution (0.05% A; Acerola Cherry Powder, Pure, American Fork, UT) (Van Buren et al., 2022), rosemary extract solution (0.10% R; GUARDIAN Rosemary Extract 08, Danisco, Madison, WI) (Van Buren et al., 2022), or mixture of acerola cherry powder and rosemary extract (M1 = 0.05% A + 0.1% R; M2 = 0.1% A + 0.1% R; M3 = 0.05% A + 0.2% R; M4 = 0.1% A + 0.2% R) (Colle et al., 2019). Steaks were sprayed with 2 mL of the respective treatment. Nine steaks per treatment were assigned to day 0 oxygen consumption (OC) rate, metmyoglobin-reducing activity (MRA), and lipid oxidation. The remaining 9 steaks per treatment were used for a 4 d retail display. These steaks were then sampled for lipid oxidation on day 4. Retail display steaks were overwrapped with an oxygen-permeable PVC film (Koch Industries, Inc. #7500-3815; Wichita, KS) and placed in a retail display room that was set at 2°C. The display room had 4000 W natural white lights (Fisherbrand Traceable Dual-Range Light Meter, Fisher Scientific, Waltham, MA). The lights had an average intensity of 849 lux. Steaks were rotated daily to avoid any effects caused by retail display location.

Retail fluid loss

After treatment on day 0, retail display steaks were weighed. They were then packaged using white foam trays (CKF Inc. #88142, Langley, BC, Canada) with an oxygen-permeable polyvinyl chloride film overwrap (Koch Industries, Inc., #7500-3815, Wichita, KS). Steaks were reweighed after 4 d of retail display, and percentage retail fluid loss was calculated using this equation:

$$\%\,Fluid\ Loss = \frac{Initial\ Weight - Final\ Weight}{Initial\ Weight} \times 100\%$$

Retail color

Steaks were bloomed for at least 60 min; subsequently, 2 objective color measurements per steak were obtained on the *Serratus ventralis* (SV) muscle of both the chuck roll and short rib steaks, and 2 color measurements were taken on the bone marrow of the short rib steaks using a Nix Pro 2 Color Sensor (Nix Sensor Ltd., Hamilton, ON, Canada). The Nix Pro 2 Color Sensor had a 14 mm-diameter measuring area and a 2° standard observer. The instrument was set to Illuminant D_{65}, and Commission Internationale de l'Eclairage L^* (lightness), a^* (redness), and b^* (yellowness) values were recorded. Oxygenated lean color, discoloration, surface discoloration, bone marrow color, color uniformity, and amount of browning were scored by 5 evaluators following American Meat Science Association Guidelines for Meat Color Measurement (King et al., 2023). Evaluators were not color blind and were between 18 and 59 years old. After screening, to standardize evaluators, evaluators were trained with picture examples, color tiles, and in-person steaks. Color was evaluated on short rib steaks once daily throughout the 4 d retail display. After the initial chuck roll steak readings at 1 h of retail display, subsequent chuck roll color measurements were taken in

the morning and evening on days 1, 2, and 3, and only in the morning on day 4.

Metmyoglobin-reducing activity

Nitric oxide MRA of the SV muscle of both the chuck roll and short rib steaks was evaluated on day 0 of retail display after treatment (King et al., 2023). Using a HunterLab MiniScan EZ (Reston, VA), duplicate readings were captured. The instrument had a 10° standard observer and a 25-mm-diameter measuring area. Furthermore, Illuminant A was used, and reflectance (400 to 700 nm) was recorded. Prior to measurement, the MiniScan was calibrated by measuring against black and white tiles. Percentage of metmyoglobin (MMb) was determined following King et al. (2023).

$$MRA = \left[\frac{Initial\,\%\,MMb - Final\,\%\,MMb}{Initial\,\%\,MMb}\right] \times 100$$

Oxygen consumption

Oxygen consumption of the SV muscle of both the chuck roll and short rib steaks were evaluated on day 0 of retail display after treatment (King et al., 2023). Color measurements were taken as described earlier. The oxymyoglobin (OMb) percentage was determined following King et al. (2023).

$$OC = \left[\frac{Initial\,\%\,OMb - Final\,\%\,OMb}{Initial\,\%\,OMb}\right] \times 100$$

Lipid oxidation

Thiobarbituric acid reactive substances (TBARS) were evaluated on day 0 after treatment in duplicate and on day 4 of retail display (King et al., 2023). Samples weighed 1 g and were cut from the SV muscle of both the chuck roll and short rib steaks. The steak edge was avoided along with large pieces of fat and connective tissue.

Statistical analysis

Data were analyzed using mixed model analysis of variance. Antioxidant treatments, retail display time, and their interaction were assumed as fixed effects. Retail display time was considered a repeated measure modeled as a compound symmetric correlation structure in a split-plot in time design using subprimal and steak location within subprimal as random effects. Lipid oxidation was evaluated twice during retail display (day 0 and day 4), while color was analyzed at 5 or 8 time points. Prior to analysis, subjective color score was averaged across trained evaluators. Treatment least-square means differences were assessed through pair-wise comparisons for significant effects. Significance was determined at $P < 0.05$. All statistical analyses were conducted using SAS v. 9.4 (SAS Inc., Cary, NC).

Results and Discussion

Retail fluid loss

No differences in fluid loss between chuck roll steak treatments were observed ($P = 0.316$; Table 1). However, differences in fluid loss were observed between short rib steak treatments ($P = 0.034$; Table 2). Treated steaks, M1, M3, and M4 had a lower amount of fluid loss than M2, while M4 had less fluid loss than R. Fluid loss causes products to be drier when cooked by the consumer (Pietrasik and Janz, 2009). Retail fluid loss is unavoidable, and losses under 2% are considered acceptable (Johnson, 1974). The current results are similar to previous research, in which antioxidants did not impact chuck roll steak fluid loss but did impact short rib steak fluid loss (Van Buren et al., 2022). Even though there were differences in the short rib steaks, only M2 and R had a fluid loss of greater than 2%.

Retail objective color

When evaluating the chuck roll steaks, an interaction was not observed between treatment and retail display time for L^*, a^*, or b^* ($P = 0.587$, $P = 0.898$, and $P = 0.335$, respectively). However, there was a treatment difference for L^*, a^*, and b^* ($P = 0.012$, $P = 0.001$, and $P = 0.034$, respectively; Table 1). Even though there were L^* differences among treatments, none of the antioxidant treatments differed in lightness from the C steaks. Steaks treated with A, M2, and M3 were redder (higher a^*) than C steaks and R treated steaks. This was expected based on previous research of ascorbic acid in ground beef (Ismail et al., 2009). The active ingredient in acerola cherry powder, ascorbic acid, delays myoglobin oxidation by donating electrons to the iron of the myoglobin molecules (Buettner and Jurkiewicz, 1996). This converts the iron from an oxidized (Fe^{3+}) state to a reduced (Fe^{2+}) state, subsequently changing the color of meat from brown to red. Holman et al. (2017) noted that an a^* value of 14.5 is the consumers' threshold for redness acceptability.

Table 1. Estimated mean effects of topical antioxidant treatment on chuck roll steak fluid loss, color, metmyoglobin reducing activity, oxygen consumption, and lipid oxidation ($N = 63$)

			Topical Antioxidant Treatment[1]						
Trait	Control	A	M1	M2	M3	M4	R	*P* value	SEM
Retail fluid loss, %	1.96	3.63	4.97	1.88	2.14	1.83	3.99	0.316	1.15
*L**	38.10^{abc}	38.25^{ab}	38.31^{ab}	37.59^{bc}	37.27^{c}	38.82^{a}	38.23^{ab}	0.012	0.59
*a**	19.99^{b}	20.83^{a}	20.38^{ab}	20.78^{a}	21.26^{a}	20.27^{ab}	19.99^{b}	0.001	0.35
*b**	14.06^{bc}	14.81^{a}	14.26^{abc}	13.95^{c}	14.59^{ab}	14.10^{bc}	14.08^{bc}	0.034	0.23
Oxygenated lean color[2]	4.9	5.0	4.8	4.8	4.8	4.7	4.8	0.324	0.1
Amount of browning[3]	2.7	2.8	2.7	2.6	2.6	2.6	2.7	0.096	0.2
Discoloration[4]	2.3^{ab}	2.4^{a}	2.3^{ab}	2.3^{b}	2.2^{b}	2.2^{b}	2.3^{ab}	0.024	0.1
Surface discoloration[5]	2.5	2.6	2.4	2.4	2.4	2.4	2.5	0.557	0.1
Color uniformity[6]	2.6	2.8	2.7	2.6	2.6	2.6	2.7	0.267	0.1
Metmyoglobin reducing activity, %	17.04	15.07	15.84	15.29	15.30	17.76	13.66	0.134	1.89
Oxygen consumption, %	50.88^{bc}	60.62^{ab}	52.46^{bc}	53.75^{bc}	47.16^{c}	57.24^{ab}	65.47^{a}	0.007	4.00
Lipid oxidation[7]	0.85^{a}	0.86^{a}	0.76^{ab}	0.71^{b}	0.67^{b}	0.72^{b}	0.77^{ab}	0.004	0.07

$^{a–c}$Within a row, means without a common superscript differ ($P < 0.05$).

[1]Treatments included the following: an untreated control, topically sprayed (2 mL) with a 0.05% acerola cherry powder solution (A), topically sprayed (2 mL) with a 0.10% rosemary extract solution (R), or topically sprayed (2 mL) with a mixture of the acerola cherry powder and rosemary extract (M1 = 0.05% A + 0.1% R; M2 = 0.1% A + 0.1% R; M3 = 0.05% A + 0.2% R; M4 = 0.1% A + 0.2% R).

[2]Oxygenated lean color scale: 1 = extremely bright cherry-red, 8 = extremely dark red.

[3]Amount of browning scale: 1 = no evidence of browning, 6 = dark brown.

[4]Discoloration scale: 1 = none, 5 = extreme.

[5]Surface discoloration scale: 1 = no discoloration (0%), 6 = extensive discoloration (81%–100%).

[6]Color uniformity scale: 1 = uniform no two-toning, 5 = extreme two-toning.

[7]mg malondialdehyde/kg meat.

Table 2. Estimated mean effects of topical antioxidant treatment on bone-in short rib steak fluid loss, color, metmyoglobin reducing activity, and oxygen consumption ($N = 63$)

		Topical Antioxidant Treatment[1]							
Trait	Control	A	M1	M2	M3	M4	R	*P* value	SEM
Retail fluid loss, %	1.50^{abc}	1.52^{abc}	0.43^{bc}	2.58^{a}	0.46^{bc}	−0.08^{c}	2.10^{ab}	0.034	0.70
Bone marrow *b**	11.00	10.88	11.83	11.92	12.35	11.62	13.06	0.065	0.65
Lean *L**	39.08	38.28	38.74	38.78	38.51	38.27	37.94	0.409	0.74
Lean *b**	14.80	14.62	14.85	14.80	15.75	15.17	15.35	0.214	0.39
Oxygenated lean color[2]	4.6	4.2	4.3	4.2	4.1	4.1	4.2	0.081	0.2
Amount of browning[3]	1.6	1.6	1.7	1.5	1.6	1.5	1.6	0.198	0.1
Discoloration[4]	1.5	1.5	1.5	1.4	1.4	1.4	1.5	0.411	0.1
Surface discoloration[5]	1.5	1.5	1.5	1.4	1.4	1.4	1.5	0.123	0.1
Color uniformity[6]	1.7	1.7	1.6	1.7	1.6	1.6	1.7	0.952	0.1
Metmyoglobin reducing activity, %	15.49	16.57	17.57	17.65	16.22	18.35	14.57	0.315	0.80
Oxygen consumption, %	70.06	65.68	64.01	65.82	67.11	67.97	63.39	0.570	3.20

$^{a–c}$Within a row, means without a common superscript differ ($P < 0.05$).

[1]Treatments included the following: an untreated control (C), topically sprayed (2 mL) with a 0.05% acerola cherry powder solution (A), topically sprayed (2 mL) with a 0.10% rosemary extract solution (R), or topically sprayed (2 mL) with a mixture of the acerola cherry powder and rosemary extract (M1 = 0.05% A + 0.1% R; M2 = 0.1% A + 0.1% R; M3 = 0.05% A + 0.2% R; M4 = 0.1% A + 0.2% R).

[2]Oxygenated lean color scale: 1 = extremely bright cherry-red, 8 = extremely dark red.

[3]Amount of browning scale: 1 = no evidence of browning, 6 = dark brown.

[4]Discoloration scale: 1 = none, 5 = extreme.

[5]Surface discoloration scale: 1 = no discoloration (0%), 6 = extensive discoloration (81%–100%).

[6]Color uniformity scale: 1 = uniform no two-toning, 5 = extreme two-toning.

All treatments in the current study resulted in steaks with a redness value (a^*) greater than 14.5. Lastly, chuck roll steaks treated with A had higher b^* values, or were more yellow, than the untreated C steaks as well as the M2, M4, and R treated steaks.

An interaction between retail display time and treatment was observed for short rib lean a^* measurements ($P = 0.009$; Table 3). On day 0, there was not a difference in redness between treatments. Throughout retail display, all treatments decreased in redness except for M3, which had the highest redness on day 4. Previously, Colle et al. (2015) noted aged steaks decreased in redness during retail display. The untreated control steaks and steaks treated with M4 were consistently two of the reddest steaks each day of retail. All treatments had redness values greater than the consumer acceptability threshold throughout retail display (14.5; Holman et al., 2017). Interactions were not observed for L^* or b^* between retail display time and treatment ($P = 0.932$ and $P = 0.574$, respectively). Furthermore, a difference in L^* or b^* between treatments was not observed ($P = 0.409$ and $P = 0.214$, respectively; Table 2).

For bone marrow L^*, there was an interaction between treatment and retail display time among bone-in short ribs ($P = 0.038$; Table 3). Untreated bone marrow did not change in lightness from day 0 to day 4. All antioxidant treated bone marrow were darkest on day 4. Untreated bone marrow was similar in lightness to A and M3 treated bone marrow throughout the entire retail display. However, on day 4, untreated bone marrow was lighter than bone marrow of steaks treated with M1, M2, M4, and R. Previous research found rosemary extract can cause darker bone marrow when compared to a control (Van Buren et al., 2022). Low L^* values may be due to higher redness values in rosemary treated marrow.

For bone marrow a^*, an interaction between treatment and retail display time was observed ($P = 0.011$; Table 3). Across all treatments, bone marrow was the reddest on day 0. Antioxidant treatments A, M2, and M3 resulted in more red bone marrow on day 4 versus

Table 3. Estimated mean effects of topical antioxidant treatment and retail display time on bone-in short rib steak color

			Topical Antioxidant Treatment[1]							
Trait	Day of Display	Control	A	M1	M2	M3	M4	R	*P* value	SEM
Bone marrow *L**	0	$44.47^{ab,w}$	$43.47^{b,wx}$	$46.09^{a,w}$	$45.13^{ab,w}$	$43.77^{ab,w}$	$43.60^{ab,w}$	$43.22^{b,w}$	0.038	1.15
	1	$45.30^{a,w}$	$45.51^{a,w}$	$43.42^{ab,x}$	$42.40^{b,x}$	$45.01^{ab,w}$	$43.03^{ab,w}$	$44.05^{ab,w}$		
	2	$45.58^{ab,w}$	$43.89^{abc,wx}$	$42.00^{c,xy}$	$44.63^{abc,wx}$	$45.76^{a,w}$	$42.89^{bc,w}$	$45.56^{ab,w}$		
	3	$45.11^{a,w}$	$44.27^{ab,wx}$	$43.17^{ab,xy}$	$45.05^{a,wx}$	$44.28^{ab,w}$	$42.08^{b,w}$	$44.59^{ab,w}$		
	4	$43.64^{a,w}$	$41.81^{ab,x}$	$40.72^{bc,y}$	$38.86^{c,y}$	$41.12^{a,x}$	$38.98^{c,x}$	$38.88^{c,x}$		
Bone marrow *a**	0	$16.23^{c,w}$	$17.97^{b,w}$	$18.26^{b,w}$	$19.98^{a,w}$	$20.04^{a,w}$	$18.99^{ab,w}$	$19.28^{ab,w}$	0.011	0.58
	1	$13.28^{b,xy}$	$13.30^{b,xy}$	$15.19^{a,x}$	$16.08^{a,x}$	$15.11^{a,x}$	$15.61^{a,x}$	$15.56^{a,x}$		
	2	$13.68^{ab,w}$	$12.26^{b,y}$	$13.81^{a,xy}$	$14.24^{a,y}$	$13.85^{a,x}$	$13.81^{ab,y}$	$13.77^{ab,yz}$		
	3	$13.92^{a,w}$	$12.91^{a,xy}$	$13.38^{a,y}$	$14.40^{a,y}$	$13.81^{a,x}$	$13.90^{a,y}$	$12.96^{a,z}$		
	4	$11.97^{c,y}$	$14.24^{b,x}$	$14.56^{b,xy}$	$16.21^{a,x}$	$13.87^{b,x}$	$15.08^{ab,xy}$	$14.79^{ab,xy}$		
Lean *a**	0	$22.86^{a,wxy}$	$23.38^{a,w}$	$22.50^{a,w}$	$22.04^{a,w}$	$23.91^{a,w}$	$24.24^{a,w}$	$22.55^{a,w}$	0.009	0.93
	1	$23.84^{a,w}$	$22.20^{ab,wx}$	$23.06^{ab,w}$	$21.36^{b,w}$	$22.68^{ab,w}$	$24.04^{a,wx}$	$23.68^{ab,w}$		
	2	$23.02^{ab,wx}$	$20.90^{b,xy}$	$22.37^{b,w}$	$21.97^{b,w}$	$22.59^{b,w}$	$24.88^{a,w}$	$22.03^{b,w}$		
	3	$20.65^{a,y}$	$21.81^{a,wxy}$	$22.56^{a,w}$	$22.97^{a,w}$	$21.84^{a,w}$	$21.12^{a,y}$	$22.36^{a,w}$		
	4	$21.54^{ab,xy}$	$19.70^{bc,y}$	$19.55^{bc,x}$	$19.04^{c,x}$	$23.50^{a,w}$	$21.74^{ab,xy}$	$18.16^{c,x}$		
Bone marrow color[2]	0	$2.8^{a,z}$	$2.3^{b,z}$	$2.0^{c,z}$	$2.1^{bc,z}$	$2.0^{c,z}$	$2.0^{bc,z}$	$2.1^{bc,z}$	0.011	0.1
	1	$3.5^{a,y}$	$3.5^{ab,y}$	$3.3^{ab,y}$	$3.2^{b,y}$	$3.2^{b,y}$	$3.4^{ab,y}$	$3.6^{a,y}$		
	2	$3.7^{ab,y}$	$4.0^{a,x}$	$3.7^{ab,x}$	$3.5^{b,x}$	$3.6^{b,x}$	$3.8^{a,x}$	$3.7^{ab,xy}$		
	3	$3.7^{a,y}$	$3.8^{a,x}$	$3.6^{a,x}$	$3.6^{a,x}$	$3.6^{a,wx}$	$3.8^{a,x}$	$3.7^{a,xy}$		
	4	$4.1^{a,x}$	$4.1^{ab,x}$	$3.8^{b,x}$	$3.8^{b,x}$	$3.9^{ab,w}$	$4.1^{ab,x}$	$4.0^{ab,x}$		

[a–c]Within a trait and day, means without a common superscript differ ($P < 0.05$).

[w–z]Within a trait and treatment, means without a common superscript differ ($P < 0.05$).

[1]Treatments included the following: an untreated control (C), topically sprayed (2 mL) with a 0.05% acerola cherry powder solution (A), topically sprayed (2 mL) with a 0.10% rosemary extract solution (R), or topically sprayed (2 mL) with a mixture of the acerola cherry powder and rosemary extract (M1 = 0.05% A + 0.1% R; M2 = 0.1% A + 0.1% R; M3 = 0.05% A + 0.2% R; M4 = 0.1% A + 0.2% R).

[2]Bone marrow color scale: 1 = bright reddish-pink to red, 7 = black.

the bone marrow of untreated steaks. Bone marrow treated with M2 was consistently one of the reddest treatments every day of retail display. This treatment contained 0.10% acerola cherry powder. In previous research, ascorbic acid topically applied to vertebrae improved redness (Mancini et al., 2004). Additionally, higher concentrations of acerola cherry powder were more effective in this study as hypothesized in previous research (Van Buren et al., 2022). Buettner and Jurkiewicz (1996) noted low concentrations of ascorbic acid can act as a pro-oxidant in meat.

No interaction was observed between retail display time and treatment for bone marrow b^* measurements ($P = 0.232$). Additionally, antioxidant treatments did not differ in b^* measurements ($P = 0.065$; Table 2).

Retail subjective color

In the chuck rolls, there was not an interaction between antioxidant treatment and day of retail display for oxygenated lean color, amount of browning, discoloration, surface discoloration, or color uniformity ($P = 0.087$, $P = 0.974$, $P = 0.657$, $P = 0.502$, $P = 0.234$, respectively). Antioxidant treated steaks did not differ in discoloration from the untreated control steaks, but M2, M3, and M4 treated steaks statistically exhibited less discoloration than A treated steaks ($P = 0.024$; Table 1), although the small numerical difference is likely not biologically important. This does not support the findings that ascorbic acid prevents steak discoloration (Buettner and Jurkiewicz, 1996). However, the results do support more recent research suggesting antioxidants in combination work better than individual antioxidants (Murray et al., 2006). Antioxidants did not impact oxygenated lean color, amount of browning, surface discoloration, or color uniformity ($P = 0.324$, $P = 0.149$, $P = 0.531$, $P = 0.061$, respectively; Table 1). Based on significant differences in objective color, subjective color differences would have been expected. The lack of subjective color differences, specifically in oxygenated lean color, could indicate that although objective color differences were noted, they may be too small to influence a consumer's perception of steak color.

When evaluating the short rib steaks, there was an interaction observed between antioxidant treatment and day of retail display for bone marrow color ($P = 0.011$; Table 3). On day 0 of retail display, untreated bone marrow had significantly more discoloration than bone marrow of the antioxidant treated steaks. Additionally, marrow treated with a M1 or M3 was less discolored than marrow treated with A on day 0. On day 1, untreated bone marrow and R treated bone marrow had more discoloration than M2 and M3 treated bone marrow. On day 2, M2 and M3 treated bone marrow had less discoloration than A and M4 treated bone marrow. Lastly, on day 4, M1 and M2 treated bone marrow had less discoloration than untreated bone marrow. Overall, bone marrow treated with a combination of the antioxidants tended to be more effective in delaying discoloration as hypothesized based on previous research (Murray et al., 2006).

No interaction was observed between antioxidant treatment and day of retail display for short rib steaks with regard to oxygenated lean color, amount of browning, discoloration, surface discoloration, or color uniformity ($P = 0.829$, $P = 0.462$, $P = 0.630$, $P = 0.869$, $P = 0.977$, respectively). Additionally, there were no differences in oxygenated lean color, amount of browning, discoloration, surface discoloration, or color uniformity ($P = 0.081$, $P = 0.198$, $P = 0.411$, $P = 0.123$, $P = 0.952$, respectively; Table 2). Given the improvements of short rib bone marrow objective and subjective redness as well as chuck roll objective redness score, it is interesting that antioxidant treatment did not improve either subjective or objective short rib redness scores. In both the chuck roll and short ribs, the SV was the muscle evaluated. The portion of the SV in the short ribs may be more consistent than the portion in the chuck roll because it is used less in that location, and it is smaller in size.

Metmyoglobin-reducing activity

Treatments did not differ in MRA in short rib steaks ($P = 0.060$; Table 2) or chuck roll steaks ($P = 0.134$; Table 1) on day 0 of retail display. This is likely due to the small amount of MMb formation on day 0. Further analysis of steaks with longer retail display times may show differences between treatments. Increasing MRA improves meat color stability by delaying browning. This happens through inherent enzymes reducing MMb to OMb (Sammel et al., 2002).

Oxygen consumption

The OC was observed to be highest in chuck roll steaks treated with R ($P = 0.007$; Table 1). Moderate OC rates during initial bloom time could stabilize color by leading regeneration of NADH which would be used for MRA (Sammel et al., 2002). OC did not differ between treatments in the short rib steaks ($P = 0.570$; Table 2), which is like previous antioxidant research (Colle et al., 2019; Van Buren et al., 2022).

Lipid oxidation

No interaction was observed among chuck roll steaks between day of retail display and antioxidant treatment for lipid oxidation ($P = 0.572$). However, treating chuck roll steaks with M2, M3, and M4 decreased lipid oxidation ($P = 0.004$; Table 1). Combinations of antioxidants likely allowed the ascorbic acid to regenerate tocopherol molecules, thus reducing oxidation to a greater extent than individual antioxidants (Murray et al., 2006). The ability to control lipid oxidation prevents myoglobin oxidation and, thus, steak discoloration (Mancini and Hunt, 2005). Other previous research mixing antioxidants into a ground product has shown a delay in lipid oxidation (Ismail et al., 2009; Kim et al., 2013; Gómez et al., 2016; Zhang et al., 2016). However, when ascorbic acid and rosemary extract were topically applied to the *semimembranosus* and *longissimus lumborum*, lipid oxidation did not change (Colle et al., 2019). The difference between studies may be due to the use of higher concentrations (0.1% acerola cherry powder and 0.2% rosemary extract vs. 0.05% and 0.1%, respectively) of antioxidants in the present experiment.

In the short rib steaks, there was an interaction for lipid oxidation between day of retail display and treatment ($P < 0.001$; Figure 1). Treatments did not differ in TBARS values on day 0. Steaks treated with M4 did not increase in lipid oxidation from day 0 to day 4, whereas the remaining treatments did increase. On day 4, steaks treated with M1, M3, and M4 all had less lipid oxidation than the untreated control steaks. Steaks treated with A had greater lipid oxidation than the untreated control steaks. Although low concentrations (0.05%) of acerola cherry powder increased lipid oxidation in this study, when used with rosemary extract, ascorbic acid can reduce tocopherol radicals to be reused (Murray et al., 2006). All treatments were less than the lipid oxidation threshold on day 4 (Tarladgis et al., 1960; Greene and Cumuze, 1981). Previously, adding vitamin E, or tocopherols, to cattle diets decreased lipid oxidation in ground beef (Faustman et al., 1989). Applying antioxidant mixtures containing rosemary extract on steaks could delay the oxidation of lipids without changing current US feeding systems. Rosemary extract contains tocopherols and works to delay lipid oxidation by quenching free radicals created by oxidizing fatty acids (Murray et al., 2006).

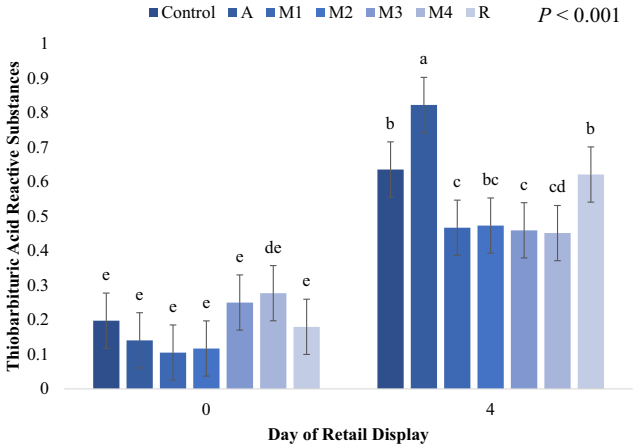

Figure 1. Thiobarbituric acid reactive substances (TBARS) values for antioxidant treatment by retail display time for bone-in short rib steaks ($N = 63$). Each steak was randomly assigned based on location to be an untreated control (C), topically sprayed (2 mL) with a 0.05% acerola cherry powder solution (A), topically sprayed (2 mL) with a 0.10% rosemary extract solution (R), or topically sprayed (2 mL) with a mixture of the acerola cherry powder and rosemary extract (M1 = 0.05% A + 0.1% R; M2 = 0.1% A + 0.1% R; M3 = 0.05% A + 0.2% R; M4 = 0.1% A + 0.2% R). Steaks were overwrapped with an oxygen-permeable PVC film and displayed in a retail display room at 2°C for 4 d. TBARS were measured on day 0 and day 4 of retail display for the control and each antioxidant treatment. Values are shown as least-square means ± SE. [a–e]Means without a common superscript differ ($P < 0.05$).

Conclusions

The antioxidant combination of 0.05% acerola cherry powder and 0.2% rosemary extract was effective at reducing lipid oxidation in both chuck roll and bone-in short rib steaks compared to the control and 0.05% acerola cherry powder treatment. This combination also resulted in improved redness of chuck roll steaks and bone marrow of short rib steaks. Overall, there was a lack of consistent improvement in color with the use of individual or combinations of antioxidants in the current study. Topical applications of antioxidants at the retail level following extended aging due to prolonged storage or transportation time has the potential to reduce lipid oxidation and improve redness. Combinations of antioxidants allow the ascorbic acid to regenerate tocopherol molecules, improving their efficacy. Further research is needed to identify the most effective antioxidant(s) and application method.

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Literature Cited

Buettner, G. R., and B. A. Jurkiewicz. 1996. Catalytic metals, ascorbate and free radicals: Combinations to avoid. J. Radiat. Res. 145:532–541. https://doi.org/10.2307/3579271

Colle, M. J., R. P. Richard, M. C. Colle, W. I. Loucks, G. K. Murdoch, P. D. Bass, C. J. Williams, and M. E. Doumit. 2019. Retail display properties and consumer perception of extended aged beef topically treated with ascorbic acid and rosemary extract. Meat Muscle Biol. 3:42–50. https://doi.org/10.22175/mmb2018.05.0011

Colle, M. C., R. P. Richard, K. M. Killinger, J. C. Bohlscheid, A. R. Gray, W. I. Loucks, R. N. Day, A. S. Cochran, J. A. Nasados, and M. E. Doumit. 2015. Influence of extended aging on beef quality characteristics and sensory perception of steaks from the *gluteus medius* and *longissimus lumborum*. Meat Sci. 110:32–39. https://doi.org/10.1016/j.meatsci.2015.06.013

Faustman, C., R. G. Cassens, D. M. Schaefer, D. R. Buege, S. N. Williams, and K. K. Scheller. 1989. Improvement of pigment and lipid stability in Holstein steer beef by dietary supplementation with vitamin E. J. Food Sci. 54:858–862. https://doi.org/10.1111/j.1365-2621.1989.tb07899.x

Gómez, I., M. J. Beriain, J. A. Mendizabal, C. Realini, and A. Purroy. 2016. Shelf life of ground beef enriched with omega-3 and/or conjugated linoleic acid and use of grape seed extract to inhibit lipid oxidation. Food Science & Nutrition 4:67–79. https://doi.org/10.1002/fsn3.251

Greene, B. E., and T. H. Cumuze. 1981. Relationship between TBA numbers and inexperienced panelists' assessment of oxidized flavor in cooked beef. J. Food Sci. 47:52–54, 58. https://doi.org/10.1111/j.1365-2621.1982.tb11025.x

Holman, B. W. B., R. J. van de Ven, Y. Mao, C. E. O. Coombs, and D. L. Hopkins. 2017. Using instrumental (CIE and reflectance) measures to predict consumers' acceptance of beef colour. Meat Sci. 127:57–62. https://doi.org/10.1016/j.meatsci.2017.01.005

Ismail, H. A., E. J. Lee, K. Y. Ko, H. D. Paik, and D. U. Ahn. 2009. Effect of antioxidant application methods on the color, lipid oxidation, and volatiles of irradiated ground beef. J. Food Sci. 74:25–32. https://doi.org/10.1111/j.1750-3841.2008.00991.x

Johnson, B. Y. 1974. Chilled vacuum-packed beef. C.S.I.R.O. Food Research 34:14–20.

Kim, S. J., S. C. Min, H. J. Shin, Y. J. Lee, A. R. Cho, S. Y. Kim, and J. Han. 2013. Evaluation of the antioxidant activities and nutritional properties of ten edible plant extracts and their application to fresh ground beef. Meat Sci. 93:715–722. https://doi.org/10.1016/j.meatsci.2012.11.029

King, D. A., M. C. Hunt, S. Barbut, J. R. Claus, D. P. Cornforth, P. Joseph, Y. H. Kim, G. Lindahl, R. A. Mancini, M. N. Nair, K. J. Merok, A. Milkowski, A. Mohan, F. Pohlman, R. Ramanathan, C. R. Raines, M. Seyfert, O. Sørheim, S. P. Suman, and M. Weber. 2023. American Meat Science Association Guidelines for Meat Color Measurement. Meat Muscle Biol. 6:12473, 1–81. https://doi.org/10.22175/mmb.12473

Mancini, R. A., and M. C. Hunt. 2005. Current research in meat color. Meat Sci. 71:100–121. https://doi.org/10.1016/j.meatsci.2005.03.003

Mancini, R. A., M. C. Hunt, K. A. Hachmeister, D. H. Kropf, and D. E. Johnson. 2004. Ascorbic acid minimizes vertebrae discoloration. Meat Sci. 68:339–345. https://doi.org/10.1016/j.meatsci.2004.03.017

Murray, R. K., D. K. Granner, and V. W. Rodwell. 2006. Harper's illustrated biochemistry. 27th ed. McGraw Hill, New York.

Pietrasik, Z., and J. A. M. Janz. 2009. Influence of freezing and thawing on the hydration characteristics, quality, and consumer acceptance of whole muscle bee injected with solutions of salt and phosphate. Meat Sci. 81:523–532. https://doi.org/10.1016/j.meatsci.2008.10.006

Sammel, L. M., M. C. Hunt, D. H. Kropf, K. A. Hachmeister, and D. E. Johnson. 2002. Comparison of assays for metmyoglobin reducing ability in beef inside and outside semimembranosus muscle. J. Food Sci. 67:978–984. https://doi.org/10.1111/j.1365-2621.2002.tb09439.x

Tarladgis, B. G., B. M. Watts, M. T. Younathan, and L. Dugan, Jr. 1960. A distillation method for the quantitative determination of malonaldehyde in rancid foods. J. Am. Oil Chem. Soc. 37:44–48. https://doi.org/10.1007/BF02630824

USDA FAS (United States Department of Agriculture Foreign Agricultural Service). 2020. South Korea 2019 export highlights. https://www.fas.usda.gov/south-korea-2019-export-highlights. (Accessed 4 January 2021).

USMEF (U.S. Meat Export Federation). 2021. U.S. Meat Export Federation annual report 2020. https://usmef.org/news/2020-usmef-annual-report-now-available. (Accessed 14 January 2021).

USMEF (U.S. Meat Export Federation). 2022. 2021 Beef exports shatter previous records: Pork export value also reaches new high. https://www.usmef.org/news-statistics/member-news-archive/2021-beef-exports-shatter-previous-records-pork-export-value-also-reaches-new-high/. (Accessed 1 April 2022).

Van Buren, J. B., B. J. Buseman, T. M. Weber, J. A. Nasados, J. M. Lancaster, J. H. Smart, P. D. Bass, and M. J. Colle. 2022. Extending the shelf life of beef steaks using acerola cherry powder and rosemary extract. Meat Muscle Biol. 6:1–10. https://doi.org/10.22175/mmb.13217

Zhang, X., D. Li, Q. Meng, C. He, and L. Ren. 2016. Effect of mulberry leaf extracts on color, lipid oxidation, antioxidant enzyme activities and oxidative breakdown products of raw ground beef during refrigerated storage. J. Food Quality 39:159–170. https://doi.org/10.1111/jfq.12187