

Effects of Injection Enhancement Carrageenan, Sea-salt, and Potassium Lactate on Beef *longissimus lumborum* Muscle Sensorial Characteristics and Color Stability

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Abstract

To determine the effects of injection ingredients and USDA quality grade response on meat color stability, beef strip loins representing two quality grades (USDA Choice and Select) were enhanced with either 0.25 CG [0.25% kappa-carrageenan + 1% sea salt + 0.3% sodium tripolyphosphate]; 0.50 CG [0.50% kappa-carrageenan + 1% sea salt + 0.3% sodium tripolyphosphate]; or 2.5 KL [2.5% potassium lactate + 1% sea salt + 0.3% sodium tripolyphosphate]; or NEC = non-enhanced control. Changes in surface color, visual appearance, discoloration, and metmyoglobin formation during a 7 d retail display at 2°C were evaluated. Enhancement with 0.50 CG and 2.5 KL affected ($P < 0.05$) display color properties and metmyoglobin reduction. Enhanced Choice steaks outperformed Select steaks in color stability and palatability characteristics and enhancement with 2.5 KL induced red color darkening in enhanced steaks. This study shows that kappa-carrageenan will effectively enhance color stability, improve expected eating quality, and minimize discoloration during retail display and storage.

Keyword: Beef; Meat color; Injection-enhancement; Carrageenan; Lactate; Sea-salt

Introduction

Meat color is an important quality attribute that consumers associate with freshness of retail products. Discoloration due to inconsistencies in quality and ineffective control of other influences on meat color cause billions of retail sales dollars lost each year. Discoloration alone leads to price discounts for about 15% of retail beef, for annual revenue losses of \$1 billion. Meeting consumer expectations for a consistent, high-quality meat product has been a challenge for the US beef industry. Consumers consider color and tenderness the most important purchasing criteria, so maintaining meat color during retail cold chain management requires a delicate balance of biochemical factors affecting meat color during retail sales.

Quality grades are a subjective quality assessment used in the beef industry to describe the expected eating quality of beef. The United States Department Agriculture (USDA) uses a measurable quality assessment criteria to reflect differences in expected eating quality among slaughter cattle's physiological maturity and marbling (the amount and distribution of intramuscular fat) to determine the USDA Quality Grades [1]. Changes in the skeletal characteristics with animal age is critical, however, differences in quality grades of beef do not follow a definitive pattern of meat quality degradation and differences in expected eating quality. Differences in quality grades of beef with inherent differences in intrinsic quality traits may affect meat color stability and other sensory characteristics.

Enhancement is the process of adding non-meat ingredients to fresh meats to improve the eating quality of the final processed product. In most cases, during enhancement, beef is injected with a variety of non-meat ingredients intended to enhance its texture, flavor, and consistency. The ingredients typically include salt, phosphate, antimicrobials, seasoning, and flavorings. Injecting meat with non-meat ingredients has been shown to improve beef color shelf-life [2-5], decrease purge loss and improve juiciness, flavor, taste, and overall tenderness [6-9].

Several researchers have reported that beef steaks with injected with salt, sodium tripolyphosphate, and potassium lactate were more

tender, juicy, and developed positive flavor notes than non-enhanced steaks. Applying carrageenan increases cook-yield and sliceability in roasted turkey breasts [10], improves water holding capacity in breakfast sausages [11], and increases cook-yield and bind strength of low-fat sausages [12]. Carrageenans are naturally-occurring hydrocolloids used primarily to enhance functional properties of meat. As a non-meat ingredient, carrageenan can increase processing yield and improve product functional properties.

Hsu and Chung reported that kappa-carrageenan (κ -Carr) improved the textural profile of low fat meat balls. In a similar study, κ -Carr improved water retention in sausage [13], enhanced sensory properties of ham [14], and textural properties of beef patties [15-17]. Among several hydrocolloids used in meat, κ -Carr is the most widely used ingredient in the food industry in a broad range of products including canned meats, pet foods, and comminuted meat products [18].

Further research would help explain the biochemical interaction of meat proteins, like myoglobin with κ -Carr, as a way to achieve desirable quality characteristics in processed beef products. Therefore, the objective of this study was to evaluate the effects of injection-enhancement with κ -Carr, sodium tripolyphosphate, potassium lactate, and sea salt on beef strip loin muscle (USDA Choice and Select grades) color stability during retail display and storage.

Materials and Methods

Raw materials

Forty-eight boneless, beef strip loins (Institutional Meat Purchase

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Specification # 180) representing two quality grades [n = 24 USDA Select, and n = 24 USDA Choice) from A-maturity (9-30 months old cattle) carcasses were obtained from a local commercial abattoir at 10-d postmortem. US Department of Agriculture (USDA) uses quality grades for determining the expected eating characteristics (e.g. tenderness, juiciness, and flavor) by evaluating the amount of marbling (Prime = abundant to moderate; Choice = Modest to small; and Select = Slight to Traces) present is a particular carcass maturity group (A = 9-30 months; B = 30-42 months; C = 42-72 months; D = 72-96 months; and E = more than 96 months). A marbling score is used by the USDA to determine the quality grades for beef.

Chemicals

Sodium tripolyphosphate (STPP) was obtained from Sigma Chem. Co. (St. Louis, MO, USA). κ -Carrageenan (κ -Carr) was obtained from (S-100Fi, Ingredient Solutions Inc., Waldo, ME). Potassium lactate (KL) was obtained from PURAC America, Inc. (PURASAL HiPure P, 60% potassium lactate/40% water; Lincolnshire, IL, USA). Sea-salt (SS), a low sodium salt (Salona™, ICL Performance Products LP, St. Louis, MO), was used to reduce total sodium content in the finished product. Distilled water was used throughout the preparation of all treatment solutions.

Sampling and injection enhancement

Forty-eight beef strip loins (IMPS 180), representing two quality grades (24 U.S. Choice loins and 24 U.S. Select loins), were obtained from a commercial beef purveyor. Six loins of each grade were cut into halves and randomly assigned to four injection enhancement treatments. The anterior cut portion served as non-enhanced (untreated) control (NEC), and the posterior half portion was weighed (raw product weight) and injection enhanced (Schroder Injector/marinator, model N50, Wolf-Tec Inc., Kingston, NY) with either 0.25 CG [0.25% κ -Carr + 1% sea salt (SS) + 0.3% sodium tripolyphosphate (STPP)]; 0.50 CG [0.50% κ -Carr + 1% SS + 0.3% STPP; or 2.5 KL [2.5% potassium lactate (KL) + 1% SS + 0.3% STPP]. Injected cuts were allowed to drain and were re-injected to targeted percentages (110 ± 2% of the green weight). Following a 2 min rest period, injected loins were reweighed to ensure brine was assimilated to achieve minimum 110% of the original weight. All κ -Carr, phosphate, sea-salt, and/or lactate injection solutions were formulated to yield enhanced final product with 0.25% κ -Carr, 0.3% STPP, 1.0% SS, and 2.5% KL.

Packaging and display

Two hours after enhancement, loins were cut into six 2.54 cm thick steaks. Three steaks were used for Metmyoglobin Reducing Activity (MRA) measurements: one for visual color, one for instrumental color measurement, and one for pH and proximate analysis. Steaks for the color measurements (visual and instrumental) were overwrapped with polyvinyl chloride film (PVC; MAPACL, 21,700 cc O₂/m²/24 hr at standard temperature (23°C) and pressure (760 mm Hg), Borden Packaging and Industrial Products, North Andover, MA, USA) on foam trays (polystyrene foam; 17S; McCune Paper Company, Salina, KS, USA) with a Dri-Loc soaker pad (AC-50; Sealed Air Corp, Duncan, SC, USA). Steaks were displayed at 2°C ± 1 for 7-d under 2150 ± 50 lux of continuous fluorescent lighting (bulb F32T8/ADV830, 3000 K, CRI = 86; Phillips, Bloomfield, NJ, USA) in an open-front refrigerated display case (Model: Hussmann M3X, self-contained, multi-deck, Supermarket Equipment Sales, Inc., Rutledge, GA, USA). Visual and instrumental color measurements were recorded at predetermined time intervals for 0, 1, 2, 3, 4, 5, 6 and 7-d of retail display. Packages

were rotated twice daily to obtain a random sample placement and to minimize display case location effects.

pH measurement

The pH measurements were recorded for all meat portions before and after injection using a pierce-probe pH meter (Model pH 77-SS, metal probe, IQ Scientific, HACH, Loveland, CO, USA). The pH was measured in triplicate at three different locations on the same loin and averaged for statistical analysis (Table 1).

Instrumental color measurement

Instrumental color measurements were recorded on each steak through the packaging film at three different locations (randomly selected) and averaged for statistical analysis. Color measurements were recorded using HunterLab MiniScan™ EZ Plus Spectrophotometer 45/0 LAV, 2.54-cm-diameter aperture, 10° standard observer (Hunter Associates Laboratory, Inc., Reston, VA, USA). Values for CIE L*, a*, and b* (Illuminant A) were collected, and Hue Angle (HA) ($\tan^{-1} b^*/a^*$) and Saturation Index (SI) or chroma [$(a^{*2} + b^{*2})^{1/2}$] were calculated from instrumental measurements according to American Meat Science Association, Meat Color Guidelines [19]. The spectrophotometer was standardized against a black and white glass tile at least once every day before taking the color measurements.

Metmyoglobin reducing activity

Metmyoglobin reducing activity (MRA) was measured on the top half portion of the steak that had been exposed to light [20]. A 3 cm×3 cm×2 cm portion was removed from the displayed surface of the steak with no visible fat or connective tissue. The portion was submerged in 0.3% sodium nitrite solution for 30 min at 20°C ± 2. The oxidized tissue sample was removed from the solution and blotted dry to remove excess nitrite solution from the surface. The sample was vacuum packaged scanned three times for reflectance from 400 nm to 700 nm randomly with HunterLab MiniScan™ EZ Plus Spectrophotometer and averaged for statistical analysis. The samples were then incubated at 30°C and rescanned after 2 hr to determine the remaining amount of metmyoglobin (MMb). Surface MMb was quantified using the equations provided in AMSA Meat Color Guidelines.

Visual color and discoloration score

Trained visual color panelists (n=10) evaluated visual display color appearance and surface discoloration once each day from d 0 through d 7 of display. All panelists attended the color orientation session to learn to evaluate the color of steaks. The panelists also were provided descriptive screening and training to obtain quantitative ratings (visual color score) of steak samples on an 8-point scale according to AMSA Meat Color Guidelines. The color of the steaks was visually evaluated on an 8-point scale using color standards (1 = extremely bright cherry-red or bright red; 2 = bright cherry-red or bright red; 3 = moderately bright cherry-red or bright red; 4 = slightly bright cherry-red or bright red; 5 = slightly dark cherry-red or bright red; 6 = moderately dark red; 7 = dark red; 8 = extremely dark red). The displayed steaks were also evaluated for percent of surface discoloration. The discoloration scores were assigned using 7-point scale: [1 = no discoloration (0%); 2 = slight discoloration (1 to 19%); 3 = small discoloration (20 to 39%); 4 = modest discoloration (40 to 59%); 5 = moderate discoloration (60 to 79%); 6 = extensive discoloration (80 to 99%); and 7 = total discoloration (100%)]. For all displayed steaks, surface discoloration was estimated as a percentage of surface and sub-metmyoglobin formation. Color scales were used to half-point increments, and discoloration was scored

Quality Grade	Treatments ^ε	pH	
		Non-enhanced	Enhanced
Choice	NEC	5.6 ^a	---
	0.25 CG	5.7 ^{abm}	6.1 ^{an}
	0.50 CG	5.8 ^{bm}	6.1 ^{an}
	2.5 KL	5.9 ^{bm}	6.2 ^{an}
Select	NEC	5.7 ^b	---
	0.25 CG	5.6 ^{abm}	6.1 ^{an}
	0.50 CG	5.5 ^{am}	6.2 ^{an}
	2.5 KL	5.7 ^{bm}	6.4 ^{bn}

^εNEC = Non-enhanced Control; 0.25 CG = 0.25% κ-Carrageenan + 1% Sea salt + 0.3% Sodium tripolyphosphate; 0.50 CG = 0.50% κ-Carrageenan + 1% Sea salt + 0.3% Sodium tripolyphosphate; 2.5 KL = 2.5% Potassium lactate + 1% Sea salt + 0.3% Sodium tripolyphosphate.

^{a,b} Means within a row with different superscript letters differ ($P < 0.05$).

^{m,n} Means within a row with different superscript letters differ ($P < 0.05$).

^ε ±SE = 0.12.

Table 1: pH muscle × quality grade × treatment means and SE^ε for steaks

to whole-point increments.

Cooking procedure

The procedure for cooking was based on American Meat Science Association - Meat Cookery and Sensory Guidelines [21]. Enhanced Choice and Select beef steaks were weighed before cooking and a thermocouple wire (30-gauge, copper-constantan; Omega Engineering, Stamford, CT) was inserted at the geometric center of each steak. Enhanced Choice and Select beef steaks were cooked in a forced-air convection oven (Blodgett, model DFG-102 CH3, G.S. Blodgett Co., Burlington, VT) set at 163°C. Steaks were turned at an internal temperature of 40°C and cooked to an internal temperature of 70°C, and the temperature was monitored with copper-constantan thermocouples in the approximate geometric center of each steak. Steaks were cooled to room temperature and reweighed for determine the cook yield.

Warner-Bratzler shear force

The procedure for WBSF was based on American Meat Science Association - Meat Cookery and Sensory Guidelines. Both Choice and Select steaks from all enhancement treatments were cooked, cooled to room temperature, and stored at 2°C overnight. Shear force and the work of shearing were determined using a Texture Analyzer (Model TA-XT2i Texture Analyzer; Texture Tech. Corp., Scarsdale, NY) with a 25-kg load cell using a shearing blade (TA 7 – WB blade). As described above, six cooked steaks (1.9 cm wide) were removed parallel to the muscle fiber orientation with a 1.27 cm corer (G-R Manufacturing Co., Manhattan, KS) attached to an electric drill (Craftsman 3/8" Electric Drill, Sears, Hoffman Estates, IL).

Samples were placed on a slotted plate which was installed into a heavy-duty platform (TA 90). Platform was adjustable to allow the blade to pass through the slotted plate. Crosshead speed of the blade was set at 10 mm/sec, and the test was triggered by a 0.05 N contact force. Meanwhile preset and posttest speed was set to 5 mm/sec. Shear force and the work of shearing was calculated as area under the force deformation curve by the texture analyzer. Shear value was reported as mean of six replicates for each treatment.

Cook yield

Cook-yield was determined based on the original weight (green weight) of fresh steak. As described above, cooked meat was cooled

down at room temperature and weighed. Cook-yield was calculated as follows:

$$\% \text{ Cook yield} = (W_{\text{cooked}} / W_{\text{initial}}) \times 100$$

Moisture content

Moisture content (MC, %) of cooked steaks was determined in duplicate according to the Association of Official Analytical Chemists method (AOAC Official Method 990.03; Thiex, 2009). Approximately, 3 - 3.5 g sample was removed and ground. The ground sample was weighed and placed in appropriate pre-dried aluminum pans (Fisher Scientific, Cat. No. 08-732-101) and then vacuum dried in a vacuum oven (Cole-Parmer Instrument Comp., Vernon Hills, IL) overnight 100°C. The MC (%) was calculated using following:

$$MC, \% = \frac{W_2 - W_3}{W_2 - W_1} \times 100$$

where,

W_1 = weight of dry aluminum pan.

W_2 = weight of wet sample and dry aluminum pan.

W_3 = weight of dry sample and dry aluminum pan.

Expressible moisture

Expressible Moisture (EM, %) was determined in duplicate using a briefly modified procedure [22,23]. Samples having fixed diameter and 300 ± 10 mg weight were obtained from cooked steaks. A 2×2 cm² piece of steak muscle was cut for the EM determination. A #12 brass corn borer was used to fix the diameter of samples. Cooked steaks were compressed between two parallel plates. A 1.0 kg load cell was allowed to compress the sample that was placed on a pre-weighed Whatmann filter paper (#1, 9 cm) in between two Plexiglass plates for 60s. The moisture soaked filter paper was then weighed to determine the released moisture from the sample. The difference of the muscle weight before and after the compression was calculated. The EM (%) was calculated as percentage of the uncompressed weight:

$$EM, \% = 100 \times (W_{\text{final}} - W_{\text{initial}}) / \text{sample weight}$$

where, W_{final} = weight of filter paper after compression

W_{initial} = initial weight of filter paper

Statistical analysis

The data were analyzed using Mixed Procedure of SAS [24]. The experimental design was a randomized complete block with repeated measurements, and each experiment was replicated six times. Color measurements were repeat measurements of the same experimental unit during the retail display period. Triplicate color measurements taken on the same experimental unit were averaged for statistical analysis. The statistical model included the fixed effects of grade (Select and Choice), treatments, display time, and their interaction. Data for all injected strip loin sections were analyzed to permit comparisons among injection treatments. Type-3 tests of fixed effects for changes in L^* , a^* , and b^* and MMb formation during retail display were evaluated using the Mixed Procedure of SAS. Means were separated using Fisher's protected LSD with Prasad-Rao-Jeske-Kackar-Harville standard errors and the Kenward-Roger degrees of freedom. Highest order interactions were reported when they were significant, or main effects were reported when no interactions were significant. Significance was determined at probability values of ($P < 0.05$).

Results

pH measurement

There was a muscle \times quality grade \times enhancement treatment interaction ($P < 0.05$) for pH (Table 1). The mean pH range for the non-enhanced Choice grade steaks ranged between 5.6 and 5.9 and for the Select grade steaks between 5.5 and 5.7. After injection enhancement, mean pH for both Choice and Select grade steaks varied between 6.1 and 6.4. Enhanced Choice and Select grade steaks had a higher ($P < 0.05$) pH than non-enhanced steaks.

Instrumental color properties

Effects of enhancement treatment \times quality grade: In the present experiment, quality grade interacted with treatments and affected instrumental color properties (L^* , a^* , b^* , Hue angle, and SI). Least-square means for quality grade \times enhancement treatment interaction effect for CIE L^* , a^* , b^* , HA, and SI - values for both Choice and Select steaks across the 7 d of retail display are presented in Table 2. The L^* - values for the Choice steaks enhanced with 0.50 CG (0.50% κ -Carr) were lighter (higher L^* - values; $P < 0.05$) than 0.25 CG (0.25% κ -Carr) and NEC (non-enhanced control). A numerical increase in L^* - value for the Choice steaks enhanced with 0.25 CG was observed as compared to NEC (Table 2). Choice steaks injected with 2.5 KL (2.5% potassium lactate) exhibited higher lightness appearance ($P < 0.05$) than all other treatments.

Comparatively, the L^* - values for the Select steaks enhanced with 0.25 and 0.50 CG were observed lighter ($P < 0.05$) than Select steaks enhanced with 2.5% KL. Enhancement treatment of Select steaks with 2.5 KL was darker in appearance in Select than Choice steaks. Select steaks enhanced with 2.5 KL had the lowest L^* - value ($P < 0.05$) and was darkest among all enhancement treatments (Table 2) and NEC.

Choice steaks enhanced with 0.25 CG and 0.50 CG were more red (higher a^* - value; $P < 0.05$) as compared with 2.5 KL and NEC (Table 2). Injection enhancement of Choice steaks with 0.50 CG showed increased ($P < 0.05$) redness in appearance than those enhanced with 0.25 CG and 2.5 KL. Select steaks injected with 2.5 KL exhibited darkening of red color appearance than Choice steaks. Among enhancement treatments, 2.5 KL treatment caused the most darkening of red color in Select steaks. Select steaks enhanced with 0.25 CG and 0.50 CG treatments were also darker red than Choice.

Choice steaks enhanced with 0.25 CG, 0.50 CG, and 2.5 KL were more yellowish (higher b^* ; $P < 0.05$) than NEC steaks. Select steaks from the 0.25 CG, 0.50 CG, and 2.5 KL treatments were comparable to Choice steaks in b^* - values.

Intensity of red color appearance of Choice and Select steaks is provided in Table 2. Injected Choice steaks with 2.5 KL treatment displayed increased red color intensity (higher SI - value) than those treated with 0.25 CG and 0.50 CG treatments. Comparatively, Select steaks enhanced with 0.50 CG revealed higher ($P < 0.05$) red color saturation than 0.25 CG and 2.5 KL treatments. Results show (Table 2) that enhancement with 2.5 KL improved redness intensity in Choice steaks than the Select steaks. The redness intensity was observed to be higher for the Choice steaks than the Select among all enhancement treatment groups.

Injection enhancement of the Choice steaks with treatment 2.5 KL showed higher ($P < 0.05$) hue angle and was different ($P < 0.05$) from the 0.25 and 0.50 CG treatments. Enhancement of the Select steaks with treatment 0.25 CG exhibited higher ($P < 0.05$) hue angle values than

those with 0.50 CG and 2.5 KL (Table 2). Hue angle values for the steaks enhanced with 0.50 CG treatment were comparable, and not different ($P > 0.05$).

Effects of quality grade \times display days: Both a^* and saturation index (SI) showed a quality grade \times display days interaction ($P < 0.05$; Table 3). The redness (a^*) values decreased ($P < 0.05$) progressively during each day of retail display for both Choice and Select steaks. Decreasing redness was as expected for typical meat color deterioration during retail display. However, Choice steaks provided higher ($P < 0.05$) redness (a^*) values than Select steaks from d 0 through 7 of the retail display.

The SI values (Table 3) followed similar trend as redness for both Choice and Select steaks. The SI values decreased over time with advancement of the display days for the first 5 d of the retail display for both Choice and Select steaks (Table 3). The SI values of the Choice steaks were higher than the Select throughout the retail display except for the d 5 and d 6 when it was lower.

Effects of enhancement treatment \times display days: Instrumental color properties for a^* and saturation index also showed an enhancement treatment \times display day interaction (Table 4). On d 0, the a^* values for both Choice and Select steaks injected with treatments (0.25 CG, 0.50 CG, and 2.5 KL) did not differ from the non-enhanced steaks. On d 1, steaks (both Choice and Select) enhanced with 0.50 CG and 2.5 KL were more red than 0.15 CG and NEC. Steaks enhanced with 0.50 CG and 2.5 KL treatments exhibited a similar pattern of red color deterioration from d 1 to d 7 of retail display. Treatment with 0.50 CG and 2.5 KL demonstrated increased display color stability over 0.25 CG and NEC. Enhanced and non-enhanced steaks (both Choice and Select) showed a similar trend of red color intensity (SI) deterioration over the display time. Enhanced Choice and Select steaks treated with 0.50 CG and 2.5 KL had improved and stabilized redness (a^* values) and redness intensity (SI), unlike steaks treated with 0.25 CG and NEC during 7 d display.

Visual color evaluation: Visual color evaluation scores for both Choice and Select steaks showed a quality grade \times enhancement treatment \times display days interaction (Table 5) during retail display. Visual color panelists noted that enhanced and non-enhanced Choice steaks were bright cherry red or bright red on d 0, 1, and 2 of retail display except Choice steaks enhanced with 2.5 KL was perceived to be slight ($P < 0.05$) bright red in appearance on d 2. On display d 2, Choice steaks enhanced with 0.50 CG tended to appear moderately bright red in color than 0.25 CG and 2.5 L treatments (Table 5). As display day advanced from d 3 through d 5 of retail display, NEC Choice steaks demonstrated a slight to modest dark red color appearance [higher visual color scores; ($P < 0.05$)] than the enhanced steaks with 0.25 CG, 0.50 CG, and 2.5 KL treatments. Choice steaks enhanced with 0.25 CG followed a similar trend of red color darkening with advancement of display days from d 3 to d 7. Visual color panelists scored enhanced Choice steaks with 0.25 CG higher ($P < 0.05$) than 0.50 CG and 2.5 KL equivalents. In general, color panelists scored enhancement treatment 0.50 CG very similarly to 2.5 KL. Choice steaks enhanced with 0.25 CG were comparable to the Non-Enhanced Control (NEC) and appeared to exhibit similar darkening patterns throughout the display period.

On d 0 of retail display, enhanced and non-enhanced Select steaks received the same ($P > 0.05$) visual color scores (Table 5). On display d 2, Select steaks enhanced with 0.25 CG and 2.5 KL received higher ($P < 0.05$) visual scores by the panelists than 0.50 CG enhanced Select steaks (Table 5). On d 3, 4, and 5 of retail display, NEC and 0.25 CG

Quality Grade	Treatment	Instrumental color properties				
		L*	a*	b*	Hue angle	Saturation Index
Choice	NEC	45.4 ^{as}	21.0 ^{af}	16.6 ^{af}	44.3 ^{bf}	33.7 ^{af}
	0.25 CG	46.7 ^{bs}	24.3 ^{bf}	17.7 ^{bs}	44.1 ^{bs}	35.4 ^{bf}
	0.50 CG	49.2 ^{cs}	27.7 ^{df}	18.9 ^{cf}	44.4 ^{bs}	36.9 ^{cs}
	2.5 KL	51.6 ^{df}	25.6 ^{cf}	19.0 ^{cs}	41.3 ^{bs}	38.6 ^{ds}
Select	NEC	44.9 ^{bs}	19.6 ^{bs}	14.9 ^{bs}	39.8 ^{bs}	31.1 ^{bs}
	0.25 CG	48.6 ^{cf}	22.7 ^{bs}	18.1 ^{bs}	47.0 ^{cf}	33.1 ^{bs}
	0.50 CG	50.8 ^{df}	26.0 ^{ds}	17.7 ^{bs}	44.5 ^{bs}	37.2 ^{cs}
	2.5 KL	42.5 ^{bs}	23.8 ^{cs}	21.3 ^{cf}	41.2 ^{bs}	37.7 ^{cs}

^ε NEC = Non-enhanced Control; 0.25 CG = 0.25% κ-Carrageenan + 1% Sea salt + 0.3% Sodium tripolyphosphate; 0.50 CG = 0.50% κ-Carrageenan + 1% Sea salt + 0.3% Sodium tripolyphosphate; 2.5 KL = 2.5% Potassium lactate + 1% Sea salt + 0.3% Sodium tripolyphosphate.

^{a, b, c, d} Means with different superscript within a column and within each quality grade (Choice vs Select) differ ($P < 0.05$).

^{s, t} Means with different superscript within a column and within the treatment among quality grades differ ($P < 0.05$).

±SE for L* = 0.46; a* = 0.29; b* = 0.23; hue angle = 0.21; and Saturation Index = 0.57

Table 2: LS Means for quality grade × treatment interaction for instrumental color properties (L*, a*, b*, Hue angle and Saturation index) for beef strip loins enhanced with different treatments^ε.

Color Properties	Quality Grade	Display Days							
		0	1	2	3	4	5	6	7
a*	Choice	29.7 ^{br}	27.4 ^{bq}	24.8 ^{bp}	20.3 ^{bo}	19.6 ^{bo}	16.2 ^{bn}	15.7 ^{bn}	11.3 ^{am}
	Select	26.2 ^{ar}	25.8 ^{ar}	21.5 ^{aq}	18.1 ^{ap}	17.6 ^{ap}	14.7 ^{ao}	12.8 ^{an}	10.8 ^{am}
Saturation Index	Choice	37.4 ^{bq}	34.2 ^{bp}	32.9 ^{bp}	27.1 ^{bo}	23.1 ^{bn}	20.0 ^{am}	19.8 ^{am}	19.9 ^{bm}
	Select	34.8 ^{aq}	30.4 ^{ap}	29.3 ^{ap}	24.7 ^{ao}	20.7 ^{an}	19.4 ^{am}	18.6 ^{am}	17.8 ^{am}

^ε NEC = Non-enhanced Control; 0.25 CG = 0.25% κ-Carrageenan + 1% Sea salt + 0.3% Sodium tripolyphosphate; 0.50 CG = 0.50% κ-Carrageenan + 1% Sea salt + 0.3% Sodium tripolyphosphate; 2.5 KL = 2.5% Potassium lactate + 1% Sea salt + 0.3% Sodium tripolyphosphate.

^{a, b} Means with different superscripts within a column for a particular color trait are different ($P < 0.05$).

^{m, n, o, p, q, r} Means with different superscripts within a row are different ($P < 0.05$).

±SE for a* = 0.67; Saturation Index = 0.64

Table 3: LSMeans for quality grade × display days interaction for instrumental color properties (a* and Saturation Index) for the raw beef strip loins enhanced with different treatment^ε

enhanced Select steaks had higher ($P < 0.05$) visual scores than 0.50 CG, and 2.5 KL steaks. As display days advanced, enhanced Select steaks with 2.5 KL were scored lower ($P < 0.05$) than 0.25 CG, 0.50 CG and NEC. Enhancement of Select steaks with 0.25 CG was comparable to NEC and tended to exhibit a similar darkening pattern throughout the display.

Discoloration scores: Discoloration scores (Table 6) for both Choice and Select steaks showed a quality grade × treatment × display days interaction. Visual color panelists found that non-enhanced Choice steaks exhibited surface discoloration at a relatively rapid rate than enhanced steaks over 7 d of retail display and storage. Injection enhancement of Choice steaks with 2.5 KL displayed improved color stability with little or no surface ($P < 0.05$) discoloration as compared with those enhanced with 0.25 CG and 0.50 CG respectively. Choice steaks enhanced with 0.50 CG discolored at much slower rate ($P < 0.05$) than 0.25 CG and NEC treatments.

A similar trend was observed for Select steaks. However, Choice steaks enhanced with 2.5 KL outperformed all Select steaks (Table 6). Choice and Select steaks enhanced with 0.50 CG showed almost no differences. On display d 2, Select steaks enhanced with 0.25 CG

received same discoloration scores as NEC. On d 3 through d 7 of retail display, Select steaks enhanced with 0.25 CG were comparable to NEC Select steaks and discolored more rapidly than steaks enhanced with 0.50 CG and 2.5 KL. The rate of discoloration was relatively similar between 0.50 CG and 2.5 KL treatments.

Impact of enhancement treatments on metmyoglobin reducing activity: Results from nitric oxide metmyoglobin reducing assays during display and storage are presented in Figure 1. A higher reduction of MMB represents higher reducing activity and greater color stability. On d 1 and 2 of retail display, Choice steaks injected with 0.25 CG (0.25% κ-Carr) and 0.50 CG (0.50% κ-Carr) enhancement solutions reduced more ($P < 0.05$) MMB and displayed higher reducing activity than 2.5 KL enhanced Choice steaks and NEC (Figure 1A). Enhancement treatments 0.25 CG, 0.50 CG, and 2.5 KL demonstrated higher reducing activity (higher MRA) and reduced more than 70% of MMB as compared to NEC. There was a concentration-dependent effect of κ-Carr on MMB reducing activity of Choice steaks enhanced with 0.25 CG and 0.50 CG on d 5 and 7 of retail display. Enhancement of Choice steak with 2.5 KL was found to have persistently higher ($P < 0.05$) reducing activity and higher MMB reduction as compared with 0.25 CG, 0.50 CG, and NEC on d 2 and d 7 of retail display (Figure 1A and 1B). Comparatively, enhanced Choice steaks with 0.25 CG and 0.50 CG presented a decreasing trend of MRAs on d 5 and d 7 of retail display. Enhancement of Choice steaks with 0.50 CG had higher reducing activity than 0.25 CG and NEC.

A similar trend was observed for Select steaks enhanced with 0.25 CG, 0.50 CG, and 2.5 KL. Injection enhancement of Select steaks with 0.25 CG and 2.5 KL displayed higher ($P < 0.05$) reducing activity and < 65 % MMB reduction on d 1 of retail display than 0.50 CG and NEC (Figure 1B and 1D). As display days advanced, enhanced Select steaks with 2.5 KL outperformed enhancement treatments 0.25 CG and 0.50 CG and were found to have higher percentages of MMB reduction on display days 1 through 7. However, Select steaks enhanced with 0.50 CG performed relatively better than 0.25 CG in reduction MMB on display d 5 and 7. In general, both Choice and Select steaks enhanced with 0.50 CG and 2.5 KL greater MRA and presented higher MMB reducing ability than 0.25 and NEC treatments (Figure 1).

Oxidation of myoglobin to MMB is an indicator of meat discoloration and, in some cases, spoilage. Results (Figure 1C and 1D) provide an overview of how enhancement treatments influenced nitric oxide induced myoglobin oxidation and MMB formation during retail display over 7 days. Most notably, 2.5 KL enhancement outperformed 0.25 CG and 0.50 CG in their abilities to reduce MMB. Although, enhancement with 0.50 CG exhibited higher MMB reducing activity, it was also associated with a continuous decline in reducing capacity as display day advanced from d 1 through d 7.

Impact of enhancement treatments on cooked product sensory characteristics

Cook yield: The cooked product sensory characteristics (cook yield, expressible moisture, and moisture content) for both Choice and Select steaks are provided in Table 7. Choice steaks enhanced with treatment 0.5% CG revealed a greater cook yield compared with enhancement treatments 0.25 CG, 2.5PL, and NEC respectively. Enhancement of Choice steaks with 2.5 PL increased ($P < 0.05$) the cook yield to 72.6% as compared to NEC at 67.8%. A similar trend was observed for the Select steaks. However, cook yield for the enhanced Select steaks with 0.5 CG demonstrated a higher cook yield than the Choice steak. Enhancement treatment of the Select steaks with 0.25 and 0.5 CG exhibited greater

Color Properties	Treatment	Display Days							
		0	1	2	3	4	5	6	7
a*	NEC	26.8 ^{as}	25.1 ^{ar}	21.3 ^{aq}	17.2 ^{ap}	13.7 ^{ao}	12.8 ^{ano}	11.4 ^{amn}	10.7 ^{am}
	0.25 CG	27.3 ^{ar}	26.2 ^{abr}	22.2 ^{aq}	17.4 ^{ap}	15.2 ^{ao}	13.5 ^{ano}	10.9 ^{am}	12.3 ^{amn}
	0.50 CG	26.5 ^{ap}	27.3 ^{acp}	27.6 ^{bp}	24.6 ^{co}	23.2 ^{bo}	19.0 ^{bn}	16.0 ^{bm}	15.2 ^{cm}
	2.5 KL	27.2 ^{ap}	28.8 ^{cpq}	26.5 ^{bp}	22.7 ^{bo}	22.9 ^{bo}	19.8 ^{bn}	18.9 ^{cmn}	17.5 ^{dm}
Saturation Index	NEC	35.4 ^{ap}	28.2 ^{ao}	27.5 ^{ao}	21.4 ^{an}	15.4 ^{am}	16.6 ^{am}	16.2 ^{am}	15.8 ^{am}
	0.25 CG	38.2 ^{bpq}	31.0 ^{bp}	29.2 ^{bo}	24.6 ^{bn}	19.9 ^{bm}	19.3 ^{bm}	19.2 ^{bm}	20.3 ^{bm}
	0.50 CG	37.5 ^{bp}	36.7 ^{dp}	35.9 ^{dp}	28.2 ^{co}	27.5 ^{do}	24.8 ^{dn}	19.7 ^{bm}	19.9 ^{bm}
	2.5 KL	37.3 ^{br}	33.3 ^{cq}	33.8 ^{cq}	30.3 ^{bp}	25.2 ^{co}	21.9 ^{cn}	16.8 ^{am}	16.4 ^{am}

[†] NEC = Non-enhanced Control; 0.25 CG = 0.25% κ-Carrageenan + 1% Sea salt + 0.3% Sodium tripolyphosphate; 0.50 CG = 0.50% κ-Carrageenan + 1% Sea salt + 0.3% Sodium tripolyphosphate; 2.5 KL = 2.5% Potassium lactate + 1% Sea salt + 0.3% Sodium tripolyphosphate.

^{a, b, c, d} Means with different superscripts within a column and within the same quality grade are different (P<0.05).

^{m, n, o, p, q, r, s} Means with different superscripts within a row are different (P<0.05).

±SE for a* = 0.79; Saturation Index = 0.77

Table 4: LSM means for treatment × display days interaction for instrumental color properties (a* and Saturation Index) for raw beef strip loins enhanced with different treatments[†].

Quality grade	Treatment	Display Days							
		0	1	2	3	4	5	6	7
Choice	NEC	2.4 ^{amx}	2.9 ^{bnx}	2.8 ^{bnx}	5.4 ^{cox}	6.1 ^{dpv}	6.9 ^{eqx}	7.1 ^{eqx}	7.0 ^{fax}
	0.25 CG	2.8 ^{cmx}	2.9 ^{abmx}	3.1 ^{bnx}	4.8 ^{cnx}	5.6 ^{dox}	6.1 ^{epx}	7.5 ^{fax}	7.4 ^{fax}
	0.50 CG	2.6 ^{bnx}	2.3 ^{abmx}	2.2 ^{amx}	3.3 ^{cnx}	4.1 ^{dox}	4.8 ^{epx}	5.3 ^{fax}	6.5 ^{grx}
	2.5 KL	2.3 ^{amx}	2.9 ^{bnx}	4.2 ^{copx}	4.4 ^{cpdx}	4.6 ^{depv}	4.8 ^{efpax}	5.2 ^{gax}	5.1 ^{frx}
Select	NEC	2.8 ^{amy}	3.5 ^{bny}	3.9 ^{bny}	5.5 ^{cox}	6.9 ^{dpv}	7.2 ^{epy}	7.7 ^{fax}	7.6 ^{fax}
	0.25 CG	2.5 ^{amy}	3.3 ^{bny}	4.0 ^{coy}	5.2 ^{dpv}	6.1 ^{eqy}	6.4 ^{eqx}	6.9 ^{fix}	7.4 ^{gsx}
	0.50 CG	2.4 ^{amy}	2.7 ^{any}	2.8 ^{bny}	3.8 ^{coy}	4.0 ^{cpv}	5.7 ^{dqy}	5.9 ^{drx}	6.8 ^{erx}
	2.5 KL	2.6 ^{amx}	3.1 ^{bnx}	3.9 ^{cox}	4.5 ^{dpv}	4.5 ^{dpv}	4.7 ^{dpv}	4.6 ^{dpv}	5.2 ^{eqx}

[†] NEC = Non-enhanced Control; 0.25 CG = 0.25% κ-Carrageenan + 1% Sea salt + 0.3% Sodium tripolyphosphate; 0.50 CG = 0.50% κ-Carrageenan + 1% Sea salt + 0.3% Sodium tripolyphosphate; 2.5 KL = 2.5% Potassium lactate + 1% Sea salt + 0.3% Sodium tripolyphosphate.

^{a, b, c, d} Means with different superscripts within a row are different (P<0.05).

^{x, y} Means with different superscripts within a row and within the same treatment and among the quality grades are different (P<0.05).

^{m, n, o, p, q, r, s} Means with different superscripts within a column and within same quality grade are different (P<0.05).

Table 5: LSM means for quality grade × treatment × display days interaction for visual color evaluation for beef strip loins enhanced with different treatments[†]. ±SE for visual color score = 0.17.

Quality grade	Treatment	Display Days							
		0	1	2	3	4	5	6	7
Choice	NEC	1.1 ^{amx}	1.5 ^{abnx}	1.8 ^{bnx}	3.2 ^{cox}	6.1 ^{dpv}	6.3 ^{dpv}	6.9 ^{eqx}	6.9 ^{erx}
	0.25 CG	1.1 ^{amx}	1.3 ^{amx}	1.2 ^{amx}	2.2 ^{bnx}	4.9 ^{cox}	6.3 ^{dpv}	6.6 ^{dpqx}	6.7 ^{dqx}
	0.50 CG	2.1 ^{amy}	2.2 ^{amy}	2.1 ^{amy}	2.8 ^{bny}	4.1 ^{cox}	5.2 ^{dpv}	5.4 ^{dpv}	6.1 ^{eqx}
	2.5 KL	2.2 ^{amy}	2.2 ^{amy}	3.2 ^{bny}	3.4 ^{bny}	3.5 ^{bcnx}	3.9 ^{cox}	4.9 ^{dpv}	4.8 ^{dqx}
Select	NEC	1.1 ^{amx}	1.4 ^{amy}	2.3 ^{bny}	3.8 ^{cox}	5.7 ^{dpv}	6.2 ^{cox}	6.7 ^{fpv}	6.9 ^{fpv}
	0.25 CG	2.1 ^{amy}	2.2 ^{amy}	2.3 ^{amy}	4.2 ^{bny}	5.9 ^{coy}	6.3 ^{cdpv}	6.6 ^{deqx}	6.8 ^{eqx}
	0.50 CG	1.8 ^{abmx}	1.5 ^{amx}	1.7 ^{amx}	2.2 ^{bny}	4.8 ^{coy}	5.2 ^{cdpv}	5.6 ^{deqx}	5.9 ^{erx}
	2.5 KL	1.3 ^{amx}	1.5 ^{amx}	2.1 ^{bnx}	2.6 ^{cox}	3.4 ^{dpv}	4.8 ^{eqy}	5.8 ^{frv}	5.7 ^{frv}

[†] NEC = Non-enhanced Control; 0.25 CG = 0.25% κ-Carrageenan + 1% Sea salt + 0.3% Sodium tripolyphosphate; 0.50 CG = 0.50% κ-Carrageenan + 1% Sea salt + 0.3% Sodium tripolyphosphate; 2.5 KL = 2.5% Potassium lactate + 1% Sea salt + 0.3% Sodium tripolyphosphate.

^{a, b, c, d} Means with different superscripts within a row are different (P<0.05).

^{x, y} Means with different superscripts within a row and within the same treatment and among the quality grades are different (P<0.05).

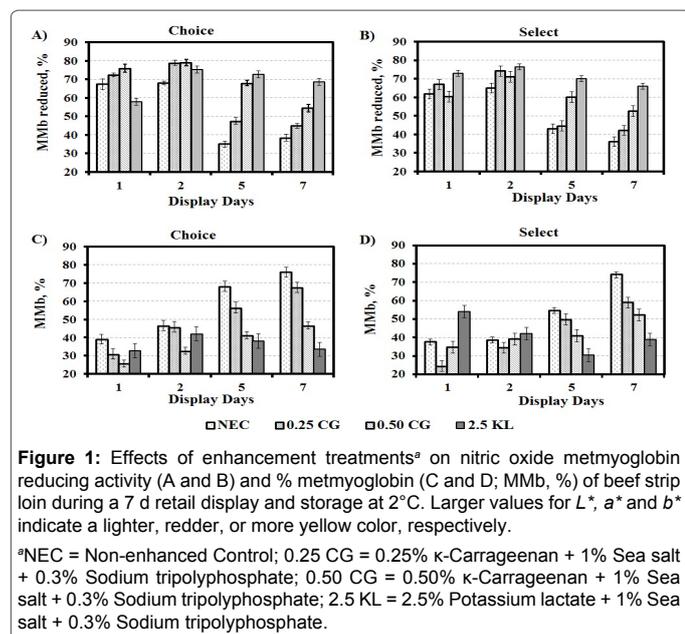
^{m, n, o, p, q, r} Means with different superscripts within a column and within a quality grade (within Choice or within Select) are different (P<0.05).

Table 6: LSM means for quality grade × treatment × display days interaction for discoloration scores for beef strip loins enhanced with different treatments[†]. ±SE for discoloration score = 0.19.

(P<0.05) cook yield as compared with 2.5 PL and NEC. As compared to NEC with 63.1% cook yield, 2.5% PL treatment showed a higher ((P < 0.05)) cook yield of 66.4%.

Expressible moisture: Results obtained in this study shows that there was grade specific differences in expressible moisture between Choice and Select steaks enhanced with treatments 0.25 CG and 0.5 CG.

In general, Choice grade steaks exhibited higher expressible moisture than the Select steaks. Expressible moisture for Choice steaks enhanced with 0.25 CG and 0.5 CG had higher amount of expressible moisture and were significantly different (P<0.05) from all other treatments. Enhancement of both Choice and Select steaks demonstrated higher expressible moisture than NEC.



Moisture content: Experimental outcomes of this study indicate that Choice quality grade steaks had moisture content than the Select grade steaks. Enhancement treatment with 0.25 CG, 0.5 CG, and 2.5 PL did not show grade and treatment specific differences in moisture content. However, Choice steaks exhibited a trend of higher moisture content than the Select steaks.

Warner-Bratzler shear force: The results for Warner-Bratzler Shear Force (WBSF) values are provided in Table 7. Enhancement treatments used in this study indicate a grade specific tenderness response for both Choice and Select steaks. Enhancement of Choice steaks with 0.50 CG resulted in being tenderer than those enhanced with 0.25 CG or 2.5 PL. There were no differences ($P>0.05$) in WBSF for enhanced Choice steaks with 0.25 CG or NEC. Conversely, Choice steaks enhanced with 2.5 PL were less tender ($P<0.05$) than other treatments including non-enhanced steaks.

Select steaks enhanced with 0.25 CG or 0.50 treatments more tender than steaks enhanced with 2.5 PL or NEC. The results show distinct grade specific differences in tenderness due to enhancement treatments. Enhancement of Select steaks with 0.50 CG resulted in being tenderer than those enhanced with 0.25 CG or 2.5 PL. The WBSF results showed differences ($P<0.05$) for 2.5 PL enhanced Select steaks as compared to NEC.

Discussion

A continuous challenge in the meat industry is to provide consumers with a consistent, high quality product that meets their expectations. The current industry practices of using the same enhancement strategy on different USDA beef quality grade may not be either economical or necessary. We hypothesized that color stability and sensory characteristics of enhanced beef is influenced by ingredients functionality and USDA quality grade specific. The main objective of this study was to evaluate the effects of injection enhancement with solutions containing κ -Carr, sodium tripolyphosphate, potassium lactate, and sea salt retail display attributes and color stability traits of both Choice and Select strip loins. The results of this study suggest that an enhancement strategy for beef is both ingredient and quality grade

specific, and therefore, the meat industry should consider optimizing their approach to meat enhancement strategy based on current usage of meat quality grades. We observed that the increased concentration of enhancement solutions containing κ -Carr from 0.25 to 0.50% in the finished product influenced color stability of both Choice and Select grade beef used in this study. Overall, results clearly indicate that that USDA beef quality grading system can positively influence quality characteristics and beef color stability.

Differences in muscle composition, distribution of inter- and intramuscular fats and inherent metabolic characteristics should be considered critical to optimizing beef enhancement strategy. Differences in color stability between the Choice and Select steaks has been described [25,26] to be attributed to their intrinsic muscle composition properties influencing MMB reducing activity and endogenous enzyme activity. Thus, the effects of non-meat ingredients on enhanced beef color stability and sensory characteristics may be quality grade specific.

In the literature, variation in quality grades affecting quality traits are often measured using multiple sensory traits describing juiciness, tenderness, and flavor. Measurement of color variables shows that differences in color traits arise because of variations in quality grades; inherent biochemical traits like myoglobin oxidation and reducing capacity are often ignored [27]. Our study shows that differences in quality grades of beef do not follow a definitive pattern of meat color degradation. However, these quality traits (instrumental color and color stability) may vary because of differences in the inherent reducing capacity of muscles or differences in reducing capacity. To design strategies to reduce variation in color-life of a given muscle from different quality grades requires more information on what causes those variations. Thus, we addressed the question of whether color variations at the end of display and color stability change during display may be due to differences in beef quality grades. Differences in the inherent reducing capacity of muscle and the biochemical processes that affect meat color stability should be investigated further to explain this variation.

Results of previous studies [28] suggest that certain postmortem biochemical phenomena (oxygen consumption, metmyoglobin formation, and NADH content) affects beef color stability.

Knock et al. reported that steaks from muscles injected with potassium lactate, with or without sodium acetate, had increased color stability, but were darker than non-enhanced control steaks. Lawrence et al. reported an improvement in display color stability with enhancements. In their study, enhancing of USDA Select strip loins with 2% κ -Carr resulted in redder steaks (higher *a** - value) than those enhanced with 1% κ -Carr; enhancement with only sodium phosphate plus salt solution reduced color stability.

We did find a decrease of redness and red color intensity (*a** and SI) during retail display, but we also observed that Choice steaks deteriorated in red color more slowly than Select steaks. Typically, color stability is a relative term related to any of the color or color change variables when measured on d 6. Oxygen consumption, mitochondrial activity, NADH content, and reducing ability all affect meat color stability. Meat quality grade may affect the rate of oxygen consumption and how readily myoglobin binds with oxygen to create oxidative conditions that favor metmyoglobin formation. In the present experiment, although oxygen consumption was not measured, Choice steaks may have had lower oxygen consumption and more reducing activity than Select steaks. Some researchers [29] have suggested

Quality Grade	Treatment	Cooked steaks sensory characteristics			
		CY ^a , %	EM ^b , %	MC ^c , %	Shear Value (N)
Choice	NE	67.2 ^a	2.5 ^a	63.8 ^a	37.7 ^b
Choice	0.25 CG	76.7 ^c	3.1 ^b	64.0 ^a	36.6 ^b
Choice	0.5 CG	81.8 ^d	4.8 ^c	63.2 ^a	32.3 ^a
Choice	2.5 PL	71.3 ^b	2.7 ^a	62.1 ^b	40.2 ^c
Select	NE	63.1 ^a	2.1 ^a	61.1 ^a	46.4 ^c
Select	0.25 CG	69.3 ^b	7.7 ^c	59.3 ^a	38.5 ^b
Select	0.5 CG	86.2 ^d	8.6 ^d	58.8 ^a	25.8 ^a
Select	2.5 PL	66.4 ^c	2.8 ^b	60.1 ^a	43.6 ^a

^a Treatment NE = Non-enhanced; 0.25 CG = 0.25% Carrageenan + 1% Sea salt + 0.3% Sodium tripolyphosphate; 0.5 CG = 0.5% Carrageenan + 1% Sea Salt + 0.3% Sodium tripolyphosphate; 2.5PL = 2.5% Potassium lactate + 1% Sea Salt + 0.3% Sodium tripolyphosphate.

^y CY = expressible moisture

^y EM = expressible moisture

^z MC = moisture content

^{a, b, c, d} Means with different superscript letters within a column and within each quality grade differ ($P < 0.05$)

±SE = 1.88 for WBSF; 1.1 for CY; 0.73 for EM; and 0.91 for CY.

Table 7: Results summarizing the effects of injection enhancement of Choice and Select steaks on cook yield^a, expressible moisture^b, moisture content^c, and Warner-Bratzler shear force (WBSF)

that differences in inherent metabolic characteristics of postmortem muscles influence metabolic activity and thus become a limiting factor on meat color-life.

Color panelists observed that non-enhanced Choice and Select steaks darkened more rapidly than enhanced steaks. Among enhanced steaks, the higher level of enhancement ingredient κ -Carr (from 0.25% to 0.50%) showed greater color stability with lower visual color scores.

Incorporating non-meat ingredients often mitigates differences in color stability. Other researchers have reported higher visual and discoloration scores for steaks enhanced with potassium lactate, which caused a darker appearance. Inclusion of lactate in the enhancement solution increases color stability but also results in darker muscle color [30]. The increased loss of redness over the retail display time may be due to a decrease in metmyoglobin-reducing activity. The brownish color of metmyoglobin begins to appear on the surface of steaks as meat loses its ability to reduce metmyoglobin to oxymyoglobin and a^* - values decrease [31].

In general, Choice steaks enhanced with a solution containing 0.50 CG or 2.5 KL exhibited superior color stability and retail display properties and had less perceptible discoloration scores than the Select steaks or non-enhanced steaks. Regardless of quality grade differences, steaks enhanced with a solution containing 0.50 CG or 2.5 KL discolored at a relatively slower rate than 0.25 CG and non-enhanced steaks.

Injection enhanced beef Select and Choice steaks used in this study had an extended color shelf-life, especially with 0.50 CG solution. When 2.5 KL was used to enhance the steaks, color shelf-life was also extended, but most steaks, of both grades, were darker in color. Thus, using 0.50 CG has similar results on beef color and color stability but does not darken the color. Lawrence et al., evaluated enhancement of beef *longissimus* muscles and reported improved retail display properties and overall color stability.

The results of this study show differences in cook yield, expressible moisture, moisture content, and tenderness due to quality grades

assigned to similar enhancement strategies. Results suggest that similar enhancement strategy applied to Choice and Select steaks were quality grade specific. More specifically, enhancement treatments with 0.50 CG appeared to show distinct improvement in cook-yield, expressible moisture, and WBSF values. Other studies have found that injection-enhancement of beef muscles results in decreased shear force values compared to non-enhanced steaks. In a similar study, Lawrence et al., demonstrated that enhancement of beef *longissimus* muscles with a phosphate and salt solution or a calcium lactate plus beef broth or carrageenan with rosemary extract solution. These authors found no differences in WBSF among all treatments. Knock et al., reported that steaks enhanced with sodium acetate had lower shear force than control steaks or steaks enhanced with potassium lactate.

Trends from the results of this study indicate that sensory characteristics of the steaks was quality grade specific and that enhancement with 0.50 CG resulted in more tender and juicier steaks. In general, Choice steaks exhibited higher expressible moisture, cook yield, and tenderness than the Select steaks assigned to similar enhancement treatments. The non-enhanced steaks from Choice grade were higher in tenderness and were tenderer. This indicates that injection enhancement effects are muscle quality grade specific and that different muscle types and cuts may respond differently within a specific quality grades. This study showed that within a similar enhancement treatment, Choice steaks were tenderer and juicy as compared to Select steaks.

This study was designed to address an underlying issue that a similar enhancement strategy for processing beef muscles with different physiological make-up (Choice or Select) will offer consumers with inconsistent and undesirable processed product. In order to provide consumers with consistent and desirable products, it is necessary to fully understand the quality grade specific enhancement treatments effects. The processed product with similar treatment regimen on different quality grades will affect beef quality traits, including palatability factors differently. Providing consumers with a consistent and high quality beef is of utmost importance and in order to maintain customer satisfaction meat industry should focus on processing strategy that will allow for repeat purchases.

Tenderness is the most important palatability attribute [32]; however, there is huge variation in tenderness among different muscles and cuts. Quality grade specific tenderness issues exist in beef steaks purchased at the retail level [33]. Additionally, consumers have the ability to determine tenderness and many are willing to pay a premium for "guaranteed tender" steaks [34].

In summary, Choice steaks enhanced with 0.50 CG had improved color stability while 2.5 KL solution induced darkening in enhanced steaks. Enhanced Select steaks exhibited similar characteristics, but 2.5 KL solution caused more darkening. Choice steaks had superior color stability with lower perceptible discoloration scores than Select or non-enhanced steaks. Regardless of quality grade differences, steaks enhanced with solutions containing 0.50 CG or 2.5 KL discolored more slowly throughout 7 d of display than non-enhanced steaks. Thus, using a hydrocolloid solution, like the CG solution we used, may effectively maintain red color and reduce negative visual sensory attributes.

Conclusion

Our study showed using 0.50 CG in the enhancement formulation is effective in improving color and cooked product attributes while minimizing quality inconsistencies during retail merchandizing of

fresh beef. The effects on meat color stability of packaging, postmortem age, and display conditions during the cold chain management and retail distribution are pre-requisite to maintaining extended color shelf-life and color stability, but our results clearly show that using a hydrocolloid in the enhancement formulation, in combination with sodium tripolyphosphate and sea-salt, will stabilize color life and improve palatability characteristics. These results should provide the beef industry with new strategies for producing beef that meets consumer sensory expectations during retail purchasing and consistency in quality attributes that should, in turn, ensure repeat purchases and consumption of beef.

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