Meat and Muscle Biology™

Product Yield and Color of Striploin and Sirloin Cuts Transported at Different Refrigerated Temperatures

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Abstract: The objective of this study was to determine the impact of environmental temperature during subprimal transport on moisture loss, color, and tenderness. Cases of striploins ($n = 24$) and sirloins ($n = 24$) were placed on 2 pallets. Each pallet was loaded on a refrigerated truck prechilled to −2.2°C (−2.2FT) or 3.3°C (3.3FT) and transported for 12 h prior to arriving at the South Dakota State University (SDSU) Meat Laboratory. One subprimal was subset from each case for further analysis. Purge loss was measured prior to fabrication into eight 2.54-cm steaks. Steaks were overwrapped and packaged in modified atmosphere packaging prior to a second transport. Four steaks from each subprimal were placed on 1 of 2 pallets. Each pallet was placed on a prechilled refrigerated truck set at −2.2°C or 3.3°C. The steaks were transported for 12 h prior to returning to SDSU, subjected to case life analysis, and stored fresh or frozen. Steaks were evaluated for color, cook loss, purge loss, and Warner-Bratzler shear force. Data were analyzed as a split plot design with main effects of first transport temperature, second transport temperature, and aging day. Data from fresh and frozen product were analyzed separately. Purge loss was increased for 3.3FT sirloins compared with −2.2FT ($P = 0.0362$). L^* values for −2.2FT strip steaks were increased ($P < 0.0001$) and purge loss decreased ($P = 0.0188$) compared with 3.3FT steaks. L^* values and fresh steak purge loss for 3.3FT sirloins were increased ($P = 0.0356$ and $P = 0.0460$, respectively) compared with −2.2FT steaks. These data indicate varied responses to temperature differences based on subprimal. Thus, a universal recommendation for all meat products could not be made. Further investigation into the impacts of transportation temperatures on various meat products is vital to optimization of the meat supply chain.

Key words: beef, color, tenderness, transportation, temperature, purge
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Introduction

The impact of storage temperature on the ability of meat products to hold water has been regularly studied since the 1980s (O'Keeffe and Hood, 1981; Offer and Knight, 1988; Hertog-Meischke et al., 1998; Jeremiah and Gibson, 2001). Previous research has shown that storage temperature impacts beef color stability and water holding capacity ultimately impacting product yield and consumer appeal (Hertog-Meischke et al., 1998; Jeremiah and Gibson, 2001). Mancini and Ramanathan (2014) evaluated the impact of storage temperature on color and reported that steaks from cuts aged at 5°C had increased color intensity but less color stability compared with steaks aged at 0°C. Differences in color intensity and stability are important factors that contribute to a consumer's purchasing decisions. Beef consumers expect the beef they purchase at retail to be a bright, cherry-red color (Killinger et al., 2004). Products that are discolored or are darker in appearance will likely be passed over by consumers, resulting in increased food waste and lost revenue. An estimated 2.55% of beef in retail stores is discarded due to discoloration, resulting in approximately $3.73 billion in lost revenue for the beef industry annually (Ramanathan et al., 2022).

However, the length of time that products can be subjected to elevated storage temperatures before meat color is impacted is unknown. Alternatively, Calpain-1, the endogenous enzyme largely thought to be responsible for proteolysis or the postmortem tenderization of meat, becomes more active with increased temperature, resulting in improved tenderness (Geesink et al., 2000; Hwang et al., 2004). It is unclear whether the temperature differences during transportation would result in enough difference in product temperature to increase proteolysis. Moreover, it is well known that meat processing facilities need to maintain refrigerated temperatures throughout the entire cold chain system to be compliant with Hazard Analysis Critical Control Point (HACCP) plans. Temperature regulation is more consistent during storage, and transportation is one of the weakest points in the cold chain. Trucks are opened and closed often, making it harder to keep constant temperatures. Additionally, during warmer months, the refrigeration units on the trucks need to work harder to keep temperatures within the box at the set levels, which results in increased fuel costs for the company. At this time, there is no research known to the authors that justifies a specific refrigerated temperature during transport that is below standard HACCP regulations. It was the goal of this research to examine these quality attributes to determine if the transportation temperatures of beef products should be more closely monitored to preserve product yield and quality attributes. Thus, the objectives of this study were to (1) determine the influence of transportation temperature on purge loss of subprimal striploins and subprimal center-cut top sirloin butts; and (2) determine the influence of transportation temperature on moisture loss, color stability, and tenderness of fabricated striploin steaks and top sirloin steaks. The authors hypothesized the subprimal cuts and steaks transported at increased temperatures would exhibit increased moisture loss, decreased shear force values, and less desirable color than primal cuts and steaks transported at decreased temperatures.

Materials and Methods

Product selection and first transportation

Cases of commodity choice beef striploins (IMPS #180; $n = 24$; ∼34 kg/case) and center-cut top sirloin butts (IMPS #184E; $n = 24$; ∼36 kg/case) were chosen from a commercial packing facility from a single production day. The following day, the cases were equally divided between 2 pallets, and pallets were stacked with 5 cases of meat per layer for a total of 4 full layers and a partial top layer contained 4 boxes. Approximately equal numbers of striploin cases and sirloin cases were stacked in each layer. Temperature data loggers (ThermaData stainless steel USB temp data logger; ThermoWorks, American Fork, UT) were placed into each case to track case temperature during transport. Each pallet was loaded into prechilled refrigerated trucks at set temperatures of either 3.3°C (3.3°C First Transport [3.3FT]) or −2.2°C (−2.2°C First Transport [−2.2FT]). Each refrigerated truck was also loaded with 7 pallets, each containing four 30-gallon plastic barrels containing approximately 102 L of water. The pallets of water were used to simulate the thermodynamic mass of a fully loaded refrigerated truck.

The loaded trucks were driven 965 km on interstate roadways over the course of 12 h to mimic transportation of subprimal products from a harvest plant to a case-ready plant. Upon completion of the first transportation period, both pallets were placed in a holding cooler with an average temperature of 1.4°C ± 1.4°C until product reached 9 d postfabrication to mimic aging requirements for a case-ready plant. Products were subsampled by removing one piece from the approximate middle of each case for further analysis.

Subprimal purge loss

Each subsampled piece was weighed (Weigh-Tronix QC-3265, Weigh-Tronix Inc., Fairmont, MN) prior to opening the vacuum seal package. The package was then opened and the subprimal was lightly dried with a paper towel and then reweighed. The packaging was wiped dry and reweighed. Subprimal purge loss was calculated by subtracting subprimal weight and package weight from the weight of the packaged product and dividing that by the difference between subprimal weight and package weight.

Steak fabrication

Top sirloin butts were fabricated by facing the anterior end to create a uniform cut surface. Then, four 2.54 cm steaks were removed from the subprimal. Each steak was cut in half between the dorsal and ventral sides of the subprimal to create 2 steaks per slice. Steaks fabricated from the first slice were designated as either steak number 1 or 2. Steaks from the second slice were designated as steaks number 3 or 4 and so on. Striploins were faced on the anterior end to create a uniform cut surface prior to cutting eight 2.54 cm steaks. Based on fabrication order, the steaks were assigned to a second transport temperature (3.3°C Second

Transport [3.3ST] or −2.2°C Second Transport [−2.2ST]), steak aging day group (Day 0 or 5 of case life), and shear force storage method (immediately frozen upon reaching designated aging day [frozen] or analyzed for shear force immediately [fresh]; see Table 1). Steaks were then placed in black 21.6 × 16.5 × 2.5 cm polystyrene trays (Dyne-A-Pak, Quebec, Canada) with oxygen permeable polyvinyl chloride (15,500 to 16,275 $cm^3/m^2/24$ h oxygen transmission rate). The overwrapped trays were then placed into vacuum seal bags (denoted as mother bags) and gas flushed with a tri-gas mix of 0.4% CO, 30% CO_2, and 69.6% N_2. The mother bags were placed in industry standard steak transport trays and stacked on pallets with 4 trays per level and 12 levels per pallet, one pallet per truck. Each level contained 2 trays of strip steaks and 2 trays of sirloin steaks in an alternating fashion. A temperature data logger was placed on each tray to monitor temperature around each mother bag. An additional data logger was fixed to the outside of the tray that would be placed closest to the middle of the inside of the truck during the second transportation to monitor truck ambient temperature.

Second transport

Steaks were stored in their mother bags for 5 d at 1.4°C ± 1.4°C prior to undergoing a second transportation. Similar to the first transport, one pallet was placed in each prechilled refrigerated truck and the remainder of the space in the truck was filled with pallets of water barrels. One truck was set to hold at 3.3°C (3.3°C Second Transport [3.3ST]) and the other was set at −2.2°C (−2.2°C Second Transport [−2.2ST]). The trucks travelled approximately 1,030 km over the course of 12 h to mimic transport from a case-ready plant to a distribution center. Upon completion of the second transport, the pallets were again placed into a holding cooler with an average temperature of 1.4°C ± 1.4°C for 10 d.

Table 1. Fabrication order and designated temperature for the second transport (−2.2°C or 3.3°C), case life aging day, and storage method at the end of aging (Fresh or Frozen)

Steak number	Second transport temperature	Aging day	Storage method
1	3.3°C	Day 0	Fresh
2	−2.2°C	Day 0	Fresh
3	3.3°C	Day 0	Frozen
4	−2.2°C	Day 0	Frozen
5	3.3°C	Day 5	Fresh
6	−2.2°C	Day 5	Fresh
7	3.3°C	Day 5	Frozen
8	−2.2°C	Day 5	Frozen

Steak experimental design

Steaks were analyzed for purge loss, cook loss, and Warner-Bratzler shear force (WBSF) separately based on storage method (evaluated fresh, stored at 1.4°C ± 1.4°C vs. evaluated after being frozen and thawed). Additionally, striploin and sirloin steaks were analyzed separately to better evaluate the impacts of transport temperatures and case life days on each type of steak.

Steak case life and instrumental color

Once mother bags were opened, the steaks were allocated into their predetermined treatment groups. Treatment groups were Day 0 of case life fresh, Day 0 of case life frozen, Day 5 of case life fresh, and Day 5 of case life frozen. The Day 5 fresh steaks were also used for case life instrumental color analysis. The steaks were placed on tables under fluorescent lighting (F32 T8, 2975 lumens, 2.54-cm-diameter fluorescent bulbs; General Electric, Boston, MA). Average light intensity across the case life area was approximately 1,600 lux, and temperature of the cooler was 3.3°C ± 1.4°C. Steaks were rotated daily to eliminate a location effect on steak color. Two L^*, a^*, and b^* measurements were recorded (Illuminant D65, 5-cm-diameter aperture, 0° standard observer; Chroma Meter CR-410; Konica Minolta, Inc., Osaka, Japan) on each steak daily at approximately 1,600 h. The 2 color measurements recorded each day were averaged and measurements were taken from Day 0 of case life to Day 5.

Warner-Bratzler shear force and cook loss

The steaks that were frozen and designated for WBSF were thawed for 24 h at 4.4°C. Prior to cooking, all steaks were weighed (Model MWP, CAS, East Rutherford, NJ) and initial weight was recorded for cook loss. WBSF was conducted as described by Bakker et al. (2021). Steaks were cooked to a target internal temperature of 71°C using an electric clam shell grill (George Foreman, Model GR2144P, Middleton, WI). Peak internal temperatures were recorded for each steak using a digital thermocouple (Atkins Aqua Tuff NSF Series, Cooper-Atkins Corporation, Middlefield, CT). Steaks were allowed to cool overnight at 4.4°C. Three hours prior to the commencement of WBSF analysis, the steaks were removed from the cooler and equilibrated to room temperature before they were weighed again to determine cook loss (Scale Model MWP, CAS). Five cores (1.27-cm diameter) were removed parallel to the muscle fiber direction. Cores were sheared perpendicular to the direction of the muscle fibers using a texture analyzer (EZ-SX, Shimadzu Corporation, Kyoto, Japan) fitted with a WBSF head with a crosshead speed of 20 cm/min. Peak force was recorded for each core, and shear force value was determined by averaging the peak force values for all 5 cores for each steak.

Steak moisture loss calculations

Purge loss was determined by weighing (Model MWP, CAS) each individual steak at the time of fabrication (initial weight). Steaks were weighed again prior to cooking for shear force (raw weight). Purge loss was calculated by dividing the difference between initial and raw weight by initial weight. Cook loss was determined by dividing the difference between raw and cooked weight by the raw weight.

Statistical analysis

Data were analyzed as a split plot design using the Mixed procedure of SAS 9.4 (SAS Institute Inc., Cary, NC) with fixed effects of first transport temperature, second transport temperature, and aging day, where applicable. Data for sirloins and striploins were analyzed independently. Additionally, independent comparisons were made for steaks stored fresh versus frozen. For subprimal purge loss, subprimal piece was considered the experimental unit; for all other data, steak was considered the experimental unit. Cook loss, WBSF, and case life color measurements were analyzed as repeated measures. Peak internal temperature was used as a covariate for WBSF and cook loss using a Toeplitz covariance structure. Significance was declared at $P < 0.05$. First transport temperature, second transport temperature, and day of case life interactions were evaluated where appropriate and are reported when significant.

Table 2. Least square means for subprimal purge loss of striploins and sirloins transported at −2.2°C or 3.3°C for 12 h

Subprimal cut	−2.2°C	3.3°C	SEM[1]	*P* value
Striploin purge loss, %	2.70	3.41	0.79	0.3717
Sirloin purge loss, %	0.83	1.46	0.28	0.0362

[1]SEM = standard error of means.

Results

Subprimal purge loss

Subprimal striploin purge loss was not impacted by truck temperature during the first transport ($P = 0.3717$; Table 2). However, purge loss for subprimal center-cut top sirloin butts was increased for 3.3FT pieces compared with −2.2FT ($P = 0.0362$; Table 2).

Instrumental color

A case life day effect was observed for L^* values of strip steaks ($P < 0.0001$; Table 3). The L^* value on Day 0 was increased compared with Days 1 through 5 ($P < 0.0001$). Day 1 had an increased value compared with Days 2 through 5 ($P < 0.001$). Days 2 and 3 had similar values ($P = 0.9329$) but were increased compared with Day 4 ($P = 0.0371$ and $P = 0.0209$, respectively). Days 4 and 5 had similar L^* values ($P = 0.5159$). Generally, as the case life study progressed, L^* value decreased, indicating that steaks became darker.

Table 3. Least square means for day effect of fresh steak case life instrumental color

Variable	0[1]	1[1]	2[1]	3[1]	4[1]	5[1]	SEM[1]	*P* value
Strip steak								
L*	50.67[a]	49.85[b]	49.56[c]	49.57[c]	49.36[d]	49.42[cd]	0.20	< 0.0001
a*	20.73[a]	19.63[b]	18.40[c]	17.35[d]	15.57[f]	15.90[e]	0.34	< 0.0001
b*	7.69[a]	7.68[a]	7.26[b]	6.90[c]	6.70[d]	6.51[e]	0.12	< 0.0001
Sirloin steak								
L*	48.52[a]	47.73[b]	47.46[c]	47.48[c]	47.29[c]	47.32[c]	0.35	< 0.0001
b*	7.64[bc]	7.81[a]	7.69[b]	7.59[c]	7.50[cd]	7.42[d]	0.11	< 0.0001

[1]Day of case life.

[2]SEM = standard error of means.

[a–e]Rows lacking common superscripts differ ($P < 0.05$).

There was an effect of first transport temperature on L^* with −2.2FT strip steaks having increased L^* values compared with 3.3FT strip steaks (50.59 ± 0.26 vs. 48.89 ± 0.26; $P < 0.0001$; Table 4). No effect of second transport temperature was observed ($P = 0.2151$; Table 4) for L^*.

No effects of first transport temperature ($P = 0.1201$; Table 4) or second transport temperature ($P = 0.5305$; Table 4) were observed for strip steak a^* values. However, a day effect was observed ($P < 0.0001$; Table 3) with the general trend of a decreasing a^* value across the duration of the case life evaluation. Redness values decreased from Day 0 to 1, Day 1 to 2, Day 2 to 3, and Day 3 to 4 and 5 ($P < 0.0001$). An increase in a^* values was observed from Day 4 to 5 ($P < 0.0001$).

Yellowness (b^*) values of −2.2FT strip steaks were increased compared with 3.3FT steaks ($P = 0.0005$; Table 4). No treatment effect was observed for the second transport temperature ($P = 0.5927$; Table 4). A day effect for b^* was observed ($P < 0.0001$; Table 3). Yellowness values for Day 0 and 1 were similar but increased compared with Day 2, Day 2 was increased compared with Day 3, Day 3 was increased compared with Day 4, and Day 4 was increased compared with Day 5 ($P < 0.0001$).

Contrary to strip steaks, the L^* values of sirloin steaks were increased for 3.3FT steaks compared with −2.2FT steaks (48.37 ± 0.48 vs. 46.89 ± 0.48; $P = 0.0356$; Table 5). No treatment effect was observed for the temperature during the second transport ($P = 0.1086$; Table 5). A day effect was observed ($P < 0.0001$; Table 3) as Day 0 had an increased L^* value compared with Day 1 ($P < 0.0001$) and Day 1 had an increase value compared with Days 2, 3, 4, and 5 ($P < 0.04$). Days 2, 3, 4, and 5 were similar ($P > 0.05$), indicating that L^* values decreased for the first 2 d of case life but were maintained for the remainder of the case life evaluation.

A first transport by day interaction was observed for sirloin steak a^* values ($P = 0.0060$; Figure 1). The −2.2FT steaks were more red on Day 0 compared with the 3.3FT steaks on Day 0 ($P = 0.0002$). The steaks from both first transport temperature groups appeared to decrease in a^* value in similar increments, remaining different ($P < 0.05$), from Day 0 to 4 before steaks from both first transport temperature groups became similar on Day 5 ($P = 0.1484$). Additionally, −2.2ST sirloin steaks tended to have increased redness values compared with 3.3ST steaks ($P = 0.0696$; Table 5).

No treatment effects were observed for b^* values for first transport ($P = 0.8924$; Table 5) or second transport ($P = 0.5436$; Table 5) of sirloin steaks. A day effect was observed for yellowness ($P < 0.0001$; Table 3) with Day 1 having an increased b^* value compared with all other days ($P < 0.01$). Day 2 was similar to Day 0 ($P = 0.3592$). Day 0 was similar to Day 3 and 4 ($P > 0.05$), and Day 4 was similar to Day 5 ($P = 0.0946$).

Table 4. Least square means for fresh strip steak instrumental color, purge loss, and Warner-Bratzler shear force (WBSF) data for steaks transported at −2.2°C or 3.3°C for the first or second transport

Variable	−2.2°C	3.3°C	SEM[1]	*P* value
Color				
***L** First transport**	50.59	48.89	0.26	< 0.0001
***L** Second transport**	49.97	49.51	0.26	0.2151
***a** First transport**	18.62	17.58	0.47	0.1201
***a** Second transport**	17.89	18.31	0.47	0.5305
***b** First transport**	7.56	6.70	0.17	0.0005
***b** Second transport**	7.06	7.19	0.17	0.5927
Purge loss, %				
First transport	1.47	1.78	0.09	0.0188
WBSF, kg				
Second transport	4.15	3.97	0.18	0.4834

[1]SEM = standard error of means.

Table 5. Least square means for fresh sirloin steak instrumental color, purge loss, cook loss, and Warner-Bratzler shear force (WBSF) data for steaks transported at −2.2°C or 3.3°C for the first or second transport

Variable	−2.2°C	3.3°C	SEM[1]	*P* value
Color				
***L** First transport**	46.89	48.37	0.48	0.0356
***L** Second transport**	47.07	48.19	0.48	0.1086
***a** Second transport**	16.18	15.37	0.31	0.0696
***b** First transport**	7.62	7.59	0.15	0.8924
***b** Second transport**	7.67	7.54	0.15	0.5436
Purge loss, %				
First transport	3.45	4.84	0.48	0.0460
Second transport	3.75	4.55	0.48	0.2470
Cook loss, %				
First transport	22.31	23.09	0.34	0.1152
Second transport	23.10	22.31	0.34	0.1096
WBSF, kg				
First transport	4.77	5.02	0.14	0.2239
Second transport	4.90	4.89	0.14	0.9759

[1]SEM = standard error of means.

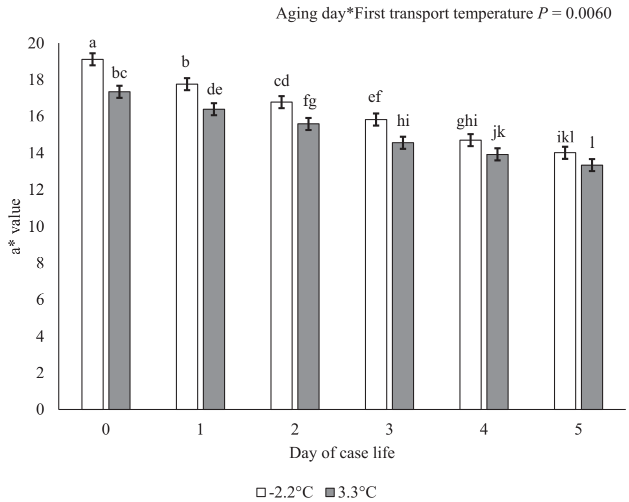

Figure 1. Redness (a^*) values of fresh sirloin steaks during case life where $+a^*$ = more red and $-a^*$ = more green. −2.2°C or 3.3°C = ambient temperature of the refrigerated truck during the first transport. [a–l]Bars lacking common superscripts differ ($P < 0.05$)

Fresh steak purge loss

Purge loss for 3.3FT strip steaks was increased compared with −2.2FT ($P = 0.0188$; Table 4). A second transport by day interaction was observed ($P = 0.0460$; Figure 2). Purge loss for −2.2ST strip steaks was similar on Day 0 and 5 ($P = 0.8077$). Additionally, 3.3ST strip steaks aged for 5 d had similar purge loss to −2.2ST steak aged for 0 or 5 d ($P = 0.2037$ and $P = 0.1316$, respectively). However, 3.3ST steaks aged for 0 d experienced the least amount of purge loss compared with all other steaks ($P < 0.03$).

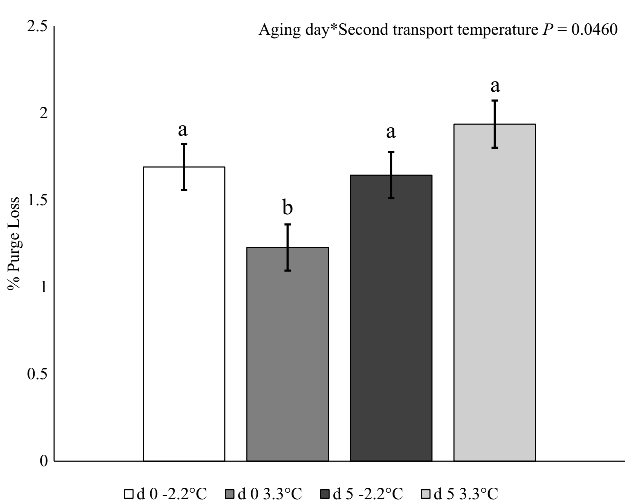

Figure 2. Percent purge loss of fresh strip steaks where Day 0 = evaluated on Day 0 of case life, Day 5 = evaluated on Day 5 of case life, and −2.2°C or 3.3°C = ambient temperature of the refrigerated truck during the second transport. [ab]Bars lacking common superscripts differ ($P < 0.05$)

No day effect ($P = 0.9261$; Table 6) or second transport temperature effect ($P = 0.2470$; Table 5) was observed for fresh sirloin steak purge loss. Purge loss was increased for 3.3FT sirloin steaks compared with −2.2FT sirloin steaks ($P = 0.0460$; Table 5).

Fresh steak cook loss

A first transport by second transport by aging day interaction was observed for fresh strip steak cook loss ($P = 0.0369$; Figure 5). Strip steaks aged for 0 d and transported at −2.2FT and −2.2ST had less cook loss than strip steaks aged for 0 d and transported at 3.3FT and −2.2ST ($P = 0.0147$). Strip steaks aged for 0 d and transported at 3.3FT and 3.3ST and steaks aged for 0 d and transported at −2.2FT and 3.3ST had similar cook loss to all other strip steaks aged for 0 d ($P > 0.05$). Strip steaks aged for 0 d and transported at −2.2FT and 3.3ST, strip steaks aged for 0 d and transported at 3.3FT and −2.2ST, and strip steaks aged for 5 d and transported at 3.3FT and −2.2ST had similar cook loss values ($P > 0.05$). All fresh strip steaks aged for 5 d had similar cook loss values ($P > 0.05$).

Fresh sirloin steaks did not experience an effect of first ($P = 0.1152$; Table 5) or second ($P = 0.1096$; Table 5) transport for cook loss. However, a day effect was observed, with steaks aged until Day 5 showing an increase in cook loss compared with Day 0 ($P < 0.0001$; Table 6).

Frozen steak purge loss

Frozen strip steak purge loss was not impacted by aging day ($P = 0.3099$; Table 6), first transport

Table 6. Least square means for cook loss, purge loss, and Warner-Bratzler shear force (WBSF) data for steaks aged for 0 or 5 d of case life

Variable	Day 0	Day 5	SEM[1]	P value
Frozen strip steak				
Purge loss, %	3.05	2.84	0.16	0.3099
Cook loss, %	16.71	17.96	0.45	0.0528
WBSF, kg	3.10	3.51	0.12	0.0002
Fresh sirloin steak				
Purge loss, %	4.12	4.18	0.45	0.9261
Cook loss, %	20.24	25.16	0.45	< 0.0001
WBSF, kg	4.71	5.08	0.13	0.0374
Frozen sirloin steak				
Purge loss, %	5.98	5.77	0.18	0.3467
Cook loss, %	22.88	23.30	0.44	0.5180

[1]SEM = standard error of means.

temperature ($P = 0.2722$; Table 7), or second transport temperature ($P = 0.8493$; Table 7). Similarly, frozen sirloin steak purge loss was not impacted by aging day ($P = 0.3467$; Table 6), first transport temperature ($P = 0.3302$; Table 8), or second transport temperature ($P = 0.8462$; Table 8).

Frozen steak cook loss

Frozen strip steak cook loss tended to be increased for steaks aged for 5 d compared with 0 d ($P = 0.0528$; Table 6). First transport temperature did not impact frozen strip steak cook loss ($P = 0.2309$; Table 7). Cook loss for −2.2ST strip steaks was increased compared with 3.3ST steaks ($P = 0.0478$; Table 7).

There was no effect of aging day ($P = 0.5180$; Table 6), first transport temperature, ($P = 0.1330$; Table 8), or second transport temperature ($P = 0.8849$; Table 8) for frozen sirloin steak cook loss.

Table 7. Least square means for frozen striploin steak purge loss, cook loss, and Warner-Bratzler shear force (WBSF) data for steaks transported at −2.2°C or 3.3°C for the first or second transport

Variable	−2.2°C	3.3°C	SEM[1]	*P* value
Purge loss, %				
First transport	2.81	3.08	0.17	0.2722
Second transport	2.97	2.92	0.17	0.8493
Cook loss, %				
First transport	17.72	16.95	0.45	0.2309
Second transport	17.98	16.68	0.45	0.0478
WBSF, kg				
First transport	3.52	3.09	0.16	0.0635
Second transport	3.26	3.35	0.16	0.7168

[1]SEM = standard error of means.

Table 8. Least square means for frozen sirloin steak purge loss, cook loss, and Warner-Bratzler shear force (WBSF) data for steaks transported at −2.2°C or 3.3°C for the first or second transport

Variable	−2.2°C	3.3°C	SEM[1]	*P* value
Purge loss, %				
First transport	5.73	6.02	0.21	0.3302
Second transport	5.84	5.90	0.21	0.8462
Cook loss, %				
First transport	22.63	23.55	0.42	0.1330
Second transport	23.05	23.13	0.42	0.8849
WBSF, kg				
First transport	4.02	4.39	0.15	0.0933

[1]SEM = standard error of means.

Fresh steak WBSF

An aging day by first transport temperature interaction was observed for strip steak fresh WBSF ($P = 0.0415$; Figure 4). Shear force values for −2.2FT strip steaks aged until Day 5 showed an increase in WBSF compared with 3.3FT steaks aged until Day 5 ($P = 0.0223$). Steaks aged for 0 d and transported at either temperature were intermediate and not different to the steaks aged for 5 d ($P > 0.05$). Second transport

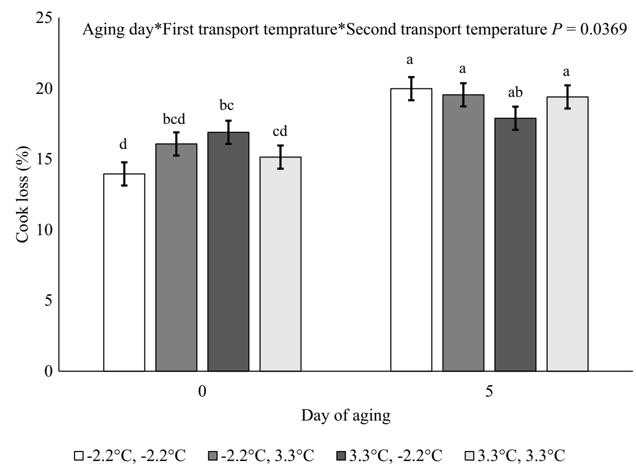

Figure 3. Percent cook loss of fresh strip steaks where Day 0 = evaluated on Day 0 of case life, Day 5 = evaluated on Day 5 of case life, and −2.2°C or 3.3°C = ambient temperature of the refrigerated truck during the first and second transport. [a–d]Bars lacking common superscripts differ ($P < 0.05$)

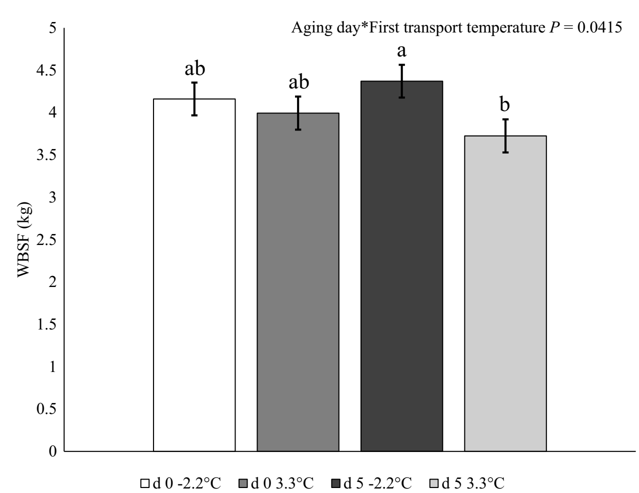

Figure 4. Warner-Bratzler shear force (WBSF) of fresh strip steaks where Day 0 = evaluated on Day 0 of case life, Day 5 = evaluated on Day 5 of case life, and −2.2°C or 3.3°C = ambient temperature of the refrigerated truck during the first transport. [ab]Bars lacking common superscripts differ ($P < 0.05$).

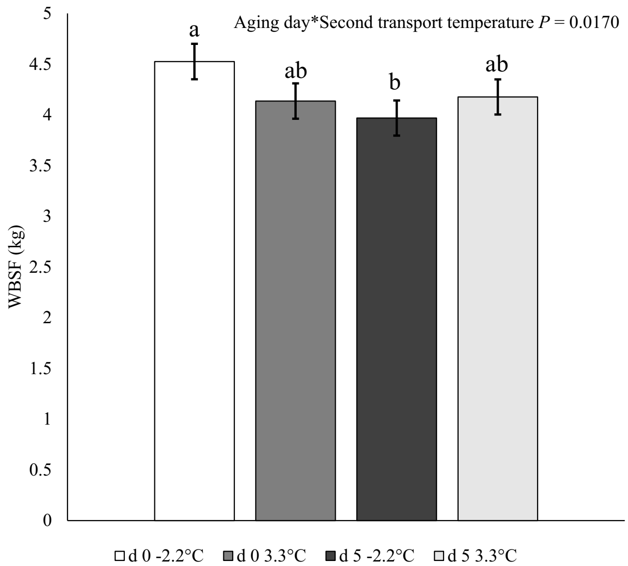

Figure 5. Warner-Bratzler shear force (WBSF) of frozen sirloin steaks where Day 0 = evaluated on Day 0 of case life, Day 5 = evaluated on Day 5 of case life, and −2.2°C or 3.3°C = ambient temperature of the refrigerated truck during the second transport. [ab]Bars lacking common superscripts differ ($P < 0.05$).

temperature did not impact striploin fresh steak WBSF ($P = 0.4834$; Table 4).

An aging day effect was observed for fresh sirloin steak WBSF with steaks aged 5 d showing an increased shear force value compared with steaks aged 0 d ($P = 0.0374$; Table 6). There was no effect of first transport temperature ($P = 0.2239$; Table 5) or second transport temperature ($P = 0.9759$; Table 5) for fresh sirloin steak WBSF.

Frozen steak WBSF

An aging day effect was observed for frozen strip steak WBSF as steaks aged for 5 d had increased WBSF values compared with steaks aged 0 d ($P = 0.0002$; Table 6). There was a tendency for −2.2FT steaks to have an increased shear force value compared with 3.3FT steaks ($P = 0.0635$; Table 7). Second transport temperature did not impact frozen strip steak WBSF ($P = 0.7168$; Table 7).

An aging day by second transport temperature interaction was observed for frozen sirloin steak WBSF ($P = 0.0170$; Figure 5). Shear force values for −2.2ST sirloin steaks aged for 0 d were increased compared with −2.2ST steaks aged for 5 d (4.53 ± 0.17 kg vs. 3.97 ± 0.17 kg; $P = 0.002$). Shear force values for 3.3ST sirloin steaks aged for 0 or 5 d were intermediate to the −2.2ST steaks ($P > 0.05$). First transport temperature tended to impact frozen sirloin steak shear force values, with 3.3FT sirloin steaks recording increased shear force values compared with −2.2FT sirloin steaks ($P = 0.0933$; Table 8).

Discussion

Instrumental color of fresh steaks

Instrumental L^* (lightness) values for both strip steaks and sirloin steaks in the current study decreased during the 6 d case life evaluation, indicating the steaks became darker as the case life evaluation progressed. Although both types of steak experienced a darkening in color during case life evaluation, L^* data evaluating color change over time is inconsistent between the cuts. However, previous studies have demonstrated that L^* values can be variable, with some studies finding that beef and lamb cuts experience a change in L^* values over time (Segers et al., 2011; Callejas-Cárdenas et al., 2014; Li et al., 2017), whereas others report no effect of day on L^* values (Sapp et al., 1999; Jeremiah and Gibson, 2001).

Strip steaks in the current study exhibited an increase in L^* value for the −2.2FT treatment compared with 3.3FT. Interestingly, these data are opposite from previous research that evaluated the aging of steaks at various temperatures. Li et al. (2017) observed a decrease in L^* value for lamb chops aged at −0.8°C during Day 2, 4, and 8 of case life evaluation compared with chops aged at 4°C. Additionally, Cassens et al. (2018) observed increased L^* values for strip steaks aged at 3.3°C compared with steaks aged at 0°C, and Choe et al. (2016) recorded increased L^* values for steaks aged at 3°C and 7°C compared with steaks aged at −1.5°C. The contrasting data in this study compared with previous work could be due to the differing study objectives. The current study focused on differing temperatures during the transport period only, whereas the other studies focused on longer product storage times at the varied temperatures. Limited data are available on the impacts of short-term temperature fluctuations on meat color.

Sirloin steaks behaved differently than strip steaks in the current study, with 3.3FT steaks displaying increased lightness values compared with −2.2FT steaks. In contrast, Cassens et al. (2018) did not observe a difference in L^* values for sirloin steaks held at 0°C or 3.3°C, nor were there differences when comparing the L^* value of 4 cuts (strip, sirloin, T-bone, and ribeye) aged at the 2 temperatures.

Strip steaks decreased in redness (a^*) throughout the case life evaluation. These data are supported by Sapp et al. (1999), who observed a decrease in redness over 10 d of retail display corresponding with a decrease in oxymyoglobin throughout the 10 d. Conversely, Li et al. (2017) observed stabilization of redness values of lamb loin chops from Day 2 to 10 of retail display. No impact of transportation temperature on strip steak a^* was observed in the current study. However, several authors noted an increase in redness of strip steaks aged at decreased temperatures (Jeremiah and Gibson, 2001; Choe et al., 2016; Cassens et al., 2018). Additionally, Wang et al. (2020) observed decreased a^* values for steaks that underwent greater freezer temperature variation. The lack of temperature effect on redness in the current study could be due to the short times the steaks were subjected to the varied temperatures (2 transports at 12 h each). However, the impact of short duration temperature changes on color is unknown at this time.

Strip steaks became less yellow during the case life evaluation of the current study. Yellowness (b^*) values have been shown to decrease as retail display time increases (Sapp et al., 1999; Choe et al., 2016). Additionally, −2.2FT strip steaks showed increased b^* values compared with 3.3FT steaks. These data are supported by Li et al. (2017), who observed greater b^* values for lamb chops aged at −0.8°C compared with chops aged at 4°C, and Jeremiah and Gibson (2001), who observed increased yellowness of strip steaks aged at −1.5°C compared with 5°C. Also, Wang et al. (2020) noted steaks that underwent more severe temperature fluctuations during freezing had increased b^* values compared with steaks with less fluctuation. This is contradictory to the present study because the holding cooler utilized in this study was set at 1.4°C. Thus, steaks transported at −2.2°C experienced greater temperature fluctuations than steaks transported at 3.3°C. However, as Wang et al. (2020) evaluated frozen product and the current project evaluated the color of fresh product, there could be a difference in b^* values due to the different temperatures and storage conditions at which the 2 projects were conducted.

Moisture loss

No treatment effect was observed for whole subprimal striploin purge loss. Interestingly, the treatment means for subprimal purge loss in the current study average approximately 3%, which is increased compared with data reported by Hergenreder et al. (2013), who reported average purge loss of 1.78% in striploin subprimals aged 14 d at refrigerated temperatures. It is unclear why such large differences in purge loss were observed between the 2 studies.

A treatment effect was observed for subprimal sirloin purge loss, with 3.3FT pieces showing increased purge loss compared with −2.2FT pieces. Offer and Knight (1988) suggested that increased temperatures can lower the viscosity of the water in the meat, resulting in increased drip loss; a theory echoed by Hertog-Meischke et al. (1998), who observed an increase in drip loss as storage temperature increased. Choe et al. (2016) and Wang et al. (2020) also observed a temperature dependent increase in drip loss for both fresh and frozen steaks, respectively.

When evaluating steak purge loss, both 3.3FT strip steaks and 3.3FT sirloin steaks experienced increased purge loss compared with their counterpart −2.2FT steaks. These data are supported by Pringle et al. (1996), who observed increased purge loss in sirloin steaks aged at 7°C compared with steaks aged at 5°C. However, others observed no differences in purge loss for strip steaks aged at different temperatures (Carpenter et al., 1976; Choe et al., 2016; Cassens et al., 2018). Interestingly, all observed differences in the purge loss of fresh steaks were no longer significant when steaks that had been frozen and thawed were evaluated. It is possible that the small differences observed in the fresh steaks were negated by the freezing process, which has been shown to damage the ultrastructure of meat, resulting in increased moisture loss (Sebranek, 1982).

Cook loss was not impacted by transportation treatment for fresh and frozen sirloins. However, a first transport temperature by second transport temperature by aging day interaction was observed for fresh strip steaks. Additionally, frozen strip steaks experienced increased cook loss for the −2.2ST treatment compared with the 3.3ST treatment. Alternatively, Choe et al. (2016) observed no difference in cook loss for steaks that were aged at −1.5°C, 3°C, or 7°C and then frozen prior to thawing and cooking for cook loss measurements. Additionally, King et al. (2009) did not observe a difference in cook loss for strip steaks aged for 12, 26, or 40 d at −0.5°C or 3.3°C. Interestingly, when evaluating sirloin steaks, King et al. (2009) observed an increase in cook loss for steaks aged at 3.3°C. Fresh sirloin and strip steaks as well as frozen strip steaks experienced an increase in cook loss from steaks aged until Day 5 of the case life evaluation versus steaks evaluated on Day 0. Data from King et al. (2009) agree with the current study as sirloin steaks aged 26 d showing an increased cook loss compared with steaks aged 12 d. This could be due to increased protein degradation through proteolytic enzyme systems resulting in decreased water holding capacity (Melody et al., 2004).

Additionally, the steaks utilized for Day 5 analysis were fabricated from a more posterior location in the subprimal than steaks utilized for Day 0 analysis. Rhee et al. (2004) evaluated meat quality characteristics of 11 muscles including the impact of location on cook loss, shear force, and desmin degradation and observed that steaks taken from more posterior portions of the *longissimus* muscle exhibited increased cook loss compared with steaks taken from the anterior portion of that muscle. The opposite was observed for the *gluteus medius*, with steaks from the anterior portion experiencing increased cook loss compared with steaks from the posterior portion.

Warner-Bratzler shear force

The temperature during the second product transport did not impact fresh sirloin or strip steak WBSF or frozen strip steak shear force. However, an aging day by second transport temperature interaction was observed for frozen sirloins as 3.3ST steaks did not differ by aging day, whereas −2.2ST steaks experienced improved shear force values from Day 0 to 5 as would normally be expected for postmortem aging of meat products. The temperature of the first transport did not impact WBSF values of fresh or frozen sirloin steaks or frozen strip steaks. An aging day by first transport temperature interaction was observed for fresh strip steaks with −2.2FT steaks aged 5 d recording increased shear force values compared with 3.3FT steaks aged 5 d. Although there was a statistically significant increase in shear force values for frozen strip steaks and fresh sirloin steaks aged 5 d compared with Day 0, the difference between the 2 aging days for both steaks was less than the 0.5 kg of force threshold indicated by Miller et al. (1995) as the required difference necessary for most consumers to notice a difference in tenderness. King et al. (2009) observed decreased slice shear force values for strip steaks and sirloin steaks aged at 3.3°C versus −0.5°C and cited an increase in degradation of the protein desmin as partially responsible for the results. However, others did not observe differences in shear force values for steaks aged at variable temperatures (Choe et al., 2016; Cassens et al., 2018).

Conclusions

These data highlight the importance of ambient temperature during the transport of meat products, especially the first time whole subprimals are transported. The increase in purge loss and subsequent yield of sirloins transported at elevated, yet still acceptable, temperatures has the potential to be an area of improvement for subprimal yields. However, these data indicate subprimal response to temperature variations is mixed. Thus, a universal recommendation for all meat products is not possible based on these data, and further investigation into the impacts of transportation temperatures on various meat products is vital to the optimization of the meat supply chain.

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