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Palatability of Beef Strip Loin Steaks Following Variable Length High-Concentrate Diet Exposure Prior to Pasture-Finishing

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Abstract: Proximate composition, Warner-Bratzler shear force (WBSF), consumer sensory traits, fatty acid composition, and volatile flavor compounds were assessed on steaks from USDA Select strip loins (n = 40; 8/treatment) representing grass-fed beef sourced from New Zealand (NZ) with marbling consistent with USDA Select along with strip loins from four feeding treatments designed to evaluate the effects of early exposure to grain-based diets for 0 d (0D), 40 d (40D), 80 d (80D), or 120 d (120D) prior to pasture-finishing on meat quality and composition. Percent fat, moisture, and protein and WBSF did not differ ($P > 0.05$), but percent ash was decreased in 120D samples compared to those from NZ, 0D, and 40D ($P < 0.05$). Consumer scores for all traits differed among samples from the treatments ($P < 0.05$), with steaks from NZ receiving greater scores for flavor liking than those from 0D, 40D, and 80D ($P < 0.05$). Consumers also rated NZ and 120D samples greatest for overall liking ($P < 0.05$). Saturated fatty acids were decreased, and monounsaturated fatty acids were increased in NZ samples compared to samples from all other treatments ($P < 0.05$), and conjugated linoleic acid was least in samples from NZ ($P < 0.05$). The ratio of omega-6 to omega-3 fatty acids was greater in 80D and 120D samples than those from all other treatments ($P < 0.05$). Non-enzymatic browning-derived ketones and 2-pentylfuran were increased in samples from NZ compared to those from all other treatments ($P < 0.05$), and differences among treatments in lipid-derived compounds were primarily of alcohols and aldehydes. Early exposure to grain-based diets for 120 d prior to pasture-finishing produces beef that is comparable to grass-fed beef from New Zealand in palatability but differs in chemical composition.

Keywords: beef, grass-fed, high-concentrate exposure, palatability, pasture-finished
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Introduction

Increased consumer interest in pasture-fed beef has led to a need to revisit cattle-finishing systems and the effects of finishing diet on meat quality. Seasonality and resultant fluctuations in forage-quality, as well as diversity of forage types based on geographical region cause difficulty in producing consistent beef on pastures alone in the United States (Leheska et al., 2008). Thus, most of the pasture-finished beef marketed in the United States is imported from South America and other countries including Mexico, Australia, and New Zealand where high-quality pastures are available nearly year-round with less seasonality (USDA-ERS, 2018).

Cattle diet and growth rate affect the palatability of beef. According to the most recent feedlot consulting nutritionist survey, cattle in the United States are finished for an average of 201 d on corn-based diets prior to slaughter to produce tender, sufficiently marbled carcasses that provide characteristic beef flavor (Samuelson et al., 2016). It has been reported that 80 to 120 d of exposure to a high-concentrate diet prior to harvest may be optimal for development of marbling and prevention of off-flavors (Dolezal et al., 1982; Miller et al., 1987; Duckett et al., 1993). Cattle growth rate impacts lipid development and deposition, and early exposure to a high plane of nutrition through grain-feeding may lead to metabolic chang-

es that increase intramuscular fat deposition through the animal's life (Smith et al., 1977; Duckett et al., 1993; Bruns et al., 2004; Moriel et al., 2014; Scheffler et al., 2014). In addition to amount of fat, diet also affects composition of fat. Grain-fed cattle tend to have fatty acid profiles containing increased concentrations of saturated and monounsaturated fatty acids, notably stearic (C18:0) and oleic acid (C18:1), while pasture-finished cattle typically retain intramuscular fatty acid profiles more similar to that of the pastures they have grazed, containing increased concentrations of polyunsaturated fatty acids (Daley et al., 2010; van Elswyk and McNeill, 2014; Scollan et al., 2014).

Differences in palatability have also been reported. Pasture-fed beef has been cited as producing "grassy" and "gamey" off-flavors. Polyunsaturated fatty acids are more prone to lipid oxidation and may contribute to production of unfavorable volatile compounds during storage and cooking which do not contribute positively to the development of beef flavor (Calkins and Hodgen, 2007; Kerth and Miller, 2015). Claims of decreased tenderness in pasture-fed beef have also been made (Bowling et al., 1977; Sitz et al., 2005; Kerth et al., 2007). However, palatability studies of pasture- and grain-fed beef are often confounded by differences in age at finishing, growth rate, and/or amount of intramuscular fat (Muir et al., 1998). Therefore, the objective of this study was to determine if a system of early exposure to grain following weaning affects palatability and chemical composition of beef strip loin steaks from pasture-finished cattle when animals are finished to a similar final body weight and intramuscular fat level is held constant and to determine if this system could be used to produce pasture-finished beef of similar palatability to established grass-fed systems while maximizing utilization of available resources.

Materials and Methods

All procedures for use of human subjects in consumer sensory panel evaluations were reviewed and approved by the Texas Tech University Institutional Review Board (IRB2017–475), and all animal protocols were approved by the Clemson University Animal Care and Use Committee (2015–069).

Product background

Beef strip loins (n = 40, IMPS #180; NAMP, 2010) from carcasses representing 5 feeding treatments were selected for use in this study. Eight strip loins were selected from each treatment based on USDA marbling scores targeting the USDA Select quality grade (370 ± 33.1; Slight[37]–Small[3]) to assess differences in quality while limiting inherent differences in lipid content across quality grades. Strip loins representing 4 major treatment groups were sourced directly from treatment groups following a cattle-feeding trial at Clemson University (Clemson, SC). Treatments were as described by Koch (2017) and included: 0 d exposure to a high-concentrate diet prior to pasture finishing on high quality forage (n = 12; 0D), 40 d exposure to high-concentrate diet prior to pasture finishing (n = 12; 40D), 80 d exposure to high-concentrate diet prior to pasture-finishing (n = 11; 80D), 120 d exposure to high-concentrate diet prior to pasture finishing (n = 12; 120D). The high-concentrate diet was composed of 71.5% cracked corn, 20% corn gluten feed, 5% chopped hay, and 3.5% mineral premix. Diet dry matter formulation is as described in Koch (2017) and is reported in Table 1. All cattle were finished to an average target BW of 487 kg on mixed pastures (non-toxic tall fescue, rye/ryegrass, oats, alfalfa). Throughout the grazing period, steers were rotated through pastures to provide sufficient forages to maintain at least 0.62 kg/d ADG. Finished cattle were transported 145 km to a commercial slaughter facility on 1 of 2 occasions based on time to finishing. All cattle were on study for a total 308 or 354 d (high-concentrate period + pasture-finishing). Ranges for time on forage by treatment are provided in Table 2.

Carcass data were collected at 24 h postmortem by trained personnel, and loins were separated from the carcasses, vacuum packaged, and stored at 0 to 4°C for 21 d, then frozen for shipment to the Gordon W. Davis Meat Science Laboratory (Lubbock, TX). At d 2 postmortem, the ribeye rolls (IMPS #112A) were also collected and fabricated into 2.54-cm steaks and

Table 1. Dry matter formulation of high-concentrate based diets provided to steers on treatment for 40 d, 80 d, or 120 d prior to forage-finishing[1]

Ingredient, %	Starter	Finisher
Chopped hay	15.00	5.00
Cracked corn	56.50	71.50
Corn gluten feed	25.00	20.00
Mineral premix	3.50	3.50
NRC Nutrient Composition[2]		
NEm, MJ/kg	769.7	848.7
NEg, MJ/kg	502.6	556.0
CP, %	13.1	11.90
Crude fat, %	3.29	3.60
NDF, %	37.84	21.60
ADF, %	15.97	7.50

[1]Adapted from Koch (2017).

Table 2. Minimum and maximum days on feed, days on pasture, and total days on study for steers grazing mixed pastures or fed a high-concentrate diet for variable time periods prior to forage-finishing[1]

	Treatment[2]							
Days	0D		40D		80D		120D	
n	12		12		11		12	
	Min[3]	Max	Min	Max	Min	Max	Min	Max
Days on feed[4]	0	–	40	–	80	–	120	–
Days on pasture[5]	308	354	268	314	228	274	188	234
Total days on study	308	354	308	354	308	354	308	354

[1]Mixed pastures: non-toxic tall fescue, rye/ryegrass, oats, alfalfa; sufficient to maintain ≥ 0.62 kg/d ADG.

[2]0D: cattle consuming only forage; 40D: high-concentrate diet for 40 d prior to pasture-finishing, 80D: high-concentrate diet for 80 d prior to pasture-finishing; 120D: high-concentrate diet for 120 d prior to pasture-finishing.

[3]Min and Max: minimum and maximum number of d steers spent grazing forage after exposure to a high-concentrate diet but prior to slaughter at one of two time periods based on final BW.

[4]Days on feed: days steers spent in confinement consuming high-concentrate diet.

[5]Days on pasture: number of days steers spent grazing high-quality pasture prior to slaughter.

the most posterior steaks (12th rib) from all ribeye rolls were individually vacuum packed and frozen and retained at Clemson for fatty acid analysis of the longissimus muscle (LM). At this point, strip loins (n = 8) were selected from each treatment based on marbling scores targeting the USDA Select quality grade (370 ± 33.1; Slight[37]–Small[3]). Further information regarding feeding and harvest protocols and additional data can be found in Koch (2017). A 5th treatment, process-verified New Zealand grass-fed strip loins (n = 8; NZ) was included as a control representative of traditional pasture-fed beef. Carcasses from NZ were from British-cross cattle and were less than 30 mo of age based on physiological maturity of carcasses. Commercially fabricated strip loins with marbling scores consistent with USDA Select were selected from a commercial packing plant in New Zealand and aged under vacuum for 21 d at 0 to 4°C then frozen for shipment to the Texas Tech University Gordon W. Davis Meat Science Laboratory (Lubbock, TX) where they remained frozen (–20°C) for fabrication.

Subprimal fabrication

All subprimals were fabricated frozen into 2.54 cm thick steaks and assigned to analyses from the anterior end to posterior end in the following order: fatty acid (NZ only; Clemson samples were derived from posterior-most steak of adjacent ribeye rolls), Warner-Bratzler shear force, consumer sensory evaluation (×7), volatile compound analysis, and proximate analysis. All steaks were labeled according to analyses, vacuum packaged (Cryovac barrier bag; moisture vapor transmission rate: 0.3 to 0.6 g/100 in^2/24 h; oxygen transmission rate: 1.5 to 3.5 cc/m^2/24 h; Sealed Air Food Care; Charlotte, NC) using a vacuum packager (Ultrasource; ProVac 1000; Kansas City, MO) and stored frozen (–20°C) until subsequent analyses.

Compositional analysis

Treatments were randomized, and the 11th steak from each strip loin was used to conduct proximate analysis. Steaks were thawed for 24 h at 2 to 4°C. Once thawed, all subcutaneous fat, intermuscular fat, and perimysial connective tissue were trimmed from raw steaks to ensure values were representative of only LM and intramuscular fat. Trimmed raw samples were sliced, frozen in liquid nitrogen, and homogenized. Homogenized samples were placed in bags (Whirl-Pak, Nasco; Fort Atkinson, WI) and stored at –80°C.

Moisture and ash analysis

Moisture and ash analyses were conducted in duplicate based on AOAC official protocols (950.46, 920.153, respectively; AOAC, 2006). Clean, dry crucibles were numbered and weighed. Frozen, homogenized samples (5 g ± 0.02) were weighed into the previously numbered and weighed crucibles, and gross weight was recorded. Samples were dried in a drying oven at least 24 h at 103°C then removed and placed in a desiccator to cool. Cooled crucibles were weighed and returned to the desiccator for use in ash analysis. Moisture content (%MC) was calculated by weight loss as

$$\%MC = \frac{\left(wet\ sample\ weight\ (g) - dry\ sample\ weight\ (g)\right)}{wet\ sample\ weight\ (g)} * 100\ .$$

After drying, samples were placed in a muffle furnace. A gradual temperature ramp was used to reach a temperature of 550°C. Samples were sustained at 550°C for 24 h until white ash was achieved. The muffle furnace was allowed to cool to 100°C, then samples were removed and placed in a desiccator to cool (30 min). Following cooling, crucibles were weighed and ash content (%Ash) was calculated using the following equation:

$$\%Ash = \frac{ashed\ sample\ weight}{wet\ sample\ weight} \times 100\ .$$

Protein analysis

Protein analysis was conducted in duplicate using a LECO TruMacN (LECO Corporation, Saint Joseph, MI) based on AOAC method 992.15 (AOAC, 2006). Prior to analyzing samples, the instrument was calibrated using blanks followed by ethylenediaminetetraacetic acid (EDTA; 0.3 g ± 0.02). Following calibration, frozen, homogenized samples (0.3 g ± 0.02) were weighed into ceramic boats and loaded into the machine carousel. Sample weights and identification were recorded and inputted into LECO TruMacN software (LECO Corporation, Saint Joseph, MI). Percent protein was calculated from nitrogen using a protein conversion factor of 6.25.

Total fat analysis

Total fat analysis was conducted in duplicate using a USDA approved chloroform-methanol extraction method (AOAC 983.23) modified from the methods of Folch et al. (1957) and Bligh and Dyer (1959). Frozen, homogenized samples (1.00 g ± 0.02) were weighed into labeled polypropylene tubes and lipid was extracted using chloroform (8 mL) and methanol (8 mL). Samples were centrifuged for 10 min at 1643 × *g*, then extract was filtered through medium porosity and medium flow rate quantitative filter paper (Q5 filter paper; Fisher Scientific, Hampton, NH) into pre-labeled and dried borosilicate tubes. Extracts were heated to dryness on a heating block, then dried in a drying oven at 101°C until a constant weight was obtained (24 h). Tubes were removed from the oven and placed into desiccators to cool. Cooled tubes were weighed to obtain a gross extract weight. Percent fat was calculated as:

$$\%Fat = \frac{residue\ weight\ after\ drying\,(g)}{wet\ sample\ weight\,(g)} \times 100\,.$$

Cooked product preparation

For evaluations requiring cooking (i.e., Warner-Bratzler shear force, volatile flavor compounds analysis, consumer sensory panels), steaks were prepared from the LM following a common cooking protocol outlined in the AMSA Sensory Guidelines (American Meat Science Association, 2015). Frozen steaks were thawed under refrigeration (2 to 4°C) for 24 h prior to cooking and were trimmed of subcutaneous and intermuscular fat. Three steaks were cooked at a time on an electric clamshell grill (Cuisinart Griddler Deluxe, Cuisinart, East Windsor, NJ) to a medium (71°C endpoint temperature; Thermapen, Classic Super-Fast, Thermoworks, American Fork, UT) degree of doneness. Rising peak temperature was recorded after removal from the grill. Steaks were weighed both raw and cooked for calculation of percentage cook loss using the following equation:

$$\%Cook\ Loss = \frac{\left[raw\ weight\,(g) - cooked\ weight\,(g)\right]}{raw\ weight\,(g)} \times 100\,.$$

Warner-Bratzler Shear Force

Warner-Bratzler shear force (WBSF) was used as a measure of instrumental tenderness following specifications outlined in AMSA Sensory Guidelines (American Meat Science Association, 2015). The second steak adjacent to the anterior end of each strip loin was prepared for WBSF according to the cooking protocol outlined above. Following cooking, steaks were placed on metal trays and covered with polyvinyl chloride film to be chilled under refrigeration (2 to 4°C) for 24 h. After chilling, six 1.27-cm diameter cores were removed from the steaks parallel to the muscle fiber orientation of the steak using a handheld cork borer. Cores were sheared in the center of the core perpendicular to the muscle fibers using a WBSF analyzer (G-R Elec. Mfg., Manhattan, KS) and measured in kg of force. Average WBSF was calculated for each steak for statistical analysis.

Fatty acid quantification

Samples for fatty acid analysis were retained at or shipped frozen to Clemson, SC for analysis. Samples were prepared for fatty acid analysis as described by Koch (2017). Steaks were trimmed of any adjacent muscles, subcutaneous fat, and intermuscular fat, then moisture content of the LM was determined by weight loss after drying, and remaining samples were frozen, lyophilized, and ground. Total lipid content was determined from prepared samples in duplicate using an Ankom XT15 extractor (Ankom Technology, Macedon, NY) and hexane as the solvent and used for calculations of fatty acids concentrations. Methods of Park and Goins (1994) were followed for transmethylation of freeze-dried samples. Fatty acid methyl esters were analyzed in duplicate using an Agilent 6850 gas chromatograph (Agilent, San Fernando, CA) and Agilent 7673A (Hewlett-Packard, San Fernando, CA) automatic sampler according to the methods outlined by Duckett et al. (2013). Samples were evaluated

twice, once with a split ratio of 100:1 for identification of trans-C18:1 and long-chain fatty acids and once with a split ratio of 10:1 for identification of conjugated linoleic acid (C18:2 cis-9 trans-11) and n-3 fatty acids. Fatty acids were separated using a Supelco 100-m SP2560 capillary column (0.25 mm i.d. and 0.20 µm film thickness; Sigma-Aldrich, St. Louis, MO). The column oven temperature increased from at a rate of 1°C per min from 150 to 160°C, at 0.2°C per min from 160 to 167°C, and at 1.5°C per min up to 225°C at which point it was maintained at 225°C for 16 min. The injector and detector were held at 250°C. Sample injection volume was 1 µL. Hydrogen was used as a carrier gas at a flow rate of 1 mL per min. Individual fatty acids were identified by comparison of ion fragmentation patterns to external standards (Sigma-Aldrich; Matreya, Pleasant Gap, PA). Methyl tricosanoic (C23:0) acid was incorporated into each sample as an internal standard for quantification of fatty acids. Fatty acids are expressed as a weight percentage of total fatty acids. Total fatty acids (g/100g) are reported as a sum of identified fatty acids for each treatment.

Volatile compound analysis

Volatile compound analysis was conducted on cooked samples from each strip loin prepared as previously described. Analysis of volatile compounds was accomplished using an Agilent 7890 gas chromatograph (Agilent Technologies, Santa Clara, CA) and 5977A mass selection detector (Agilent Technologies, Santa Clara, CA) equipped with a Gerstel automated sampler (MPS, Gerstel Inc., Linthicum, MD) following the methods outlined by Chail et al. (2017) and Gardner and Legako (2018). Immediately following cooking, six 1.27-cm diameter cores were removed from the steaks perpendicular to the cooked surface using a handheld cork borer and minced in a coffee grinder (Coffee grinder, Mr. Coffee, Cleveland, OH). Following mincing, 5 g of sample were weighed into 20 mL glass GC vials (Gerstel Inc., Linthicum, MD), an internal standard solution (10 µL, 1,2-dichlorobenzene; 2.5 µg/µL) was incorporated into each sample for quantification of volatile compounds, and vials were capped with polytetrafluoroethylene septa and screw caps (Gerstel Inc., Linthicum, MD). Samples were agitated at 65°C for a 5-min incubation period in the Gerstel agitator (500 rpm; Gerstel, Inc.). Volatile compounds were extracted from the headspace of samples via solid phase microextraction (SPME) during a 20 min extraction period using an 85 µm film thickness carboxen polydimethylsiloxane fiber (Stableflex 24 GA, Supelco, Belefonte, PA) then separated using a VF-5 ms capillary column (30 m × 0.25 mm × 1.00 µm; Agilent J&W GC Columns, Netherlands). Data were collected using selective ion monitoring in the scan mode, then identities of volatile compounds were validated by comparison of ion fragmentation patterns to external standards (Sigma-Aldrich). Data were quantitated using an internal standard calibration.

Consumer sensory panels

Consumer sensory panelists (n = 220) were recruited from Lubbock, TX, and the surrounding areas to participate in sensory evaluation of samples at the Texas Tech University Animal and Food Sciences Building. Eleven consumer panels were conducted over 4 nights. Each session consisted of 20 panelists and lasted approximately 1 h. Panelists were provided with an information sheet, a ballot (containing demographic questionnaire and 5 sample ballots), plastic utensils, a toothpick, a napkin, an expectorant cup, and palate cleansers (a cup of water, unsalted crackers, and a cup of diluted apple juice, approximately 1:10 apple juice to water) to be used between samples.

Each consumer steak (n = 280) was randomly assigned to, and consumed by, 4 panelists based on a 10 × 10 Latin Square. Samples were prepared as previously described. Prepared steaks were portioned into 4 pieces (approximately 2 cm^3), avoiding connective tissue, and served warm to panelists. All samples were served in a pre-determined, randomized order. Panelists were served a total of 5 samples, which were rated for tenderness, juiciness, flavor liking, and overall liking using 100-mm verbally anchored line scales where 0 = not tender/juicy, dislike extremely and 100 = very tender/juicy, like extremely. Panelists were also asked to classify each sample as acceptable or unacceptable for each trait and to complete a demographic questionnaire. Panelists could only participate one time and were monetarily compensated for their participation.

Statistical analysis

All data were analyzed using procedures of SAS (SAS version 9.3, SAS Inst. Inc., Cary, NC). Treatment effects for all laboratory analyses (proximate composition, Warner-Bratzler shear force, fatty acid composition, and volatile fatty acids) were compared using PROC GLIMMIX as a completely randomized design with treatment as a fixed effect and $\alpha = 0.05$. For Warner-Bratzler shear force, percentage cook loss was included as a covariate ($P < 0.01$). For analysis of vola-

Table 3. Least squares means of carcass characteristics of steers grazing mixed pastures or fed a high-concentrate diet for variable time periods prior to forage-finishing and process-verified New Zealand grass-fed steers selected for use in the present study[1,2]

	Treatment[3]						*P*-
Variable[4]	NZ	0D	40D	80D	120D	SEM[5]	value[6]
n	8	8	8	8	8	–	–
Final body weight, kg	–	466	465	463	476	9.1	0.76
Hot carcass weight, kg	275	252	251	257	266	11.5	0.54
Dressing percent, %	–	54.11	54.23	55.52	56.08	0.838	0.28
Skeletal maturity	150.63	143.33	160.00	170.00	161.67	9.097	0.17
Marbling score	351.25	351.88	369.38	363.75	393.13	10.977	0.06
12th rib backfat, cm	0.35	0.44	0.41	0.47	0.57	0.061	0.15
Ribeye area, cm^2	79.25[a]	68.87[bc]	71.69[ab]	63.06[c]	74.91[ab]	2.894	<0.01
KPH, %	–	1.91	1.93	2.25	2.25	0.178	0.22
Yield grade	–	1.91	1.84	2.22	1.92	0.165	0.40

[a–c]Means within a row without a common superscript differ ($P < 0.05$).

[1]Based on data collected in Koch (2017).

[2]Mixed pastures: non-toxic tall fescue, rye/ryegrass, oats, alfalfa; sufficient to maintain ≥ 0.62 kg/d ADG.

[3]0D: cattle consuming only forage; 40D: high-concentrate diet for 40 d prior to pasture-finishing, 80D: high-concentrate diet for 80 d prior to pasture-finishing; 120D: high-concentrate diet for 120 d prior to pasture-finishing.

[4]Based on shrunk BW basis (4% shrink).

[5]Largest standard error of the least squares means.

[6]*P*- values < 0.05 considered significant.

tile compounds, endpoint temperature was included in the model when determined to be a significant covariate ($P < 0.05$). Consumer panel data were analyzed as a complete balanced block design. As recommended by the AMSA Sensory Guidelines, panel nested within night served as a block (American Meat Science Association, 2015). Acceptability data for each palatability trait were analyzed using a binomial error distribution. For all above analyses, denominator degrees of freedom were estimated using the Kenward-Roger adjustment. Treatment least squares means were separated using the PDIFF option ($P < 0.05$). Relationships between consumer palatability traits, proximate components, and shear force were assessed using PROC CORR to generate Pearson correlation coefficients ($\alpha = 0.05$). Consumer demographic and meat consumption preference data were summarized using PROC FREQ.

Results and Discussion

Carcass characteristics

Carcass data for cattle selected for use in this study are presented in Table 3 as a reference for the reader and are based on data collected by Koch (2017). Further evaluation of differences in animal and carcass performance among treatment groups can be found in Koch (2017). Differences in carcass characteristics in selected carcasses were present only for ribeye area ($P < 0.01$), with NZ carcasses having larger ($P < 0.05$) ribeye area than all other treatments except carcasses from 120D; 80D carcasses had smaller ($P < 0.05$) ribeye area than carcasses from all treatments except 0D. Key characteristics of focus for this study including final body weight ($P = 0.76$), hot carcass weight ($P = 0.54$), skeletal maturity ($P = 0.17$), marbling score ($P = 0.06$), and backfat ($P = 0.15$) were maintained across treatments.

Table 4. Least squares means of proximate components and Warner-Bratzler shear force (WBSF) values of steaks from the *M. longissimus lumborum* of New Zealand grass-fed cattle and cattle fed high-concentrate diets for variable time periods prior to pasture-finishing

	Treatment[1]						
Item	NZ	0D	40D	80D	120D	SEM[2]	P- value[3]
n	8	8	8	8	8	–	–
Fat, %	5.19	4.83	4.97	4.97	5.28	0.197	0.50
Moisture, %	72.43	73.13	73.17	73.04	72.55	0.415	0.59
Protein, %	23.76	23.52	23.44	22.69	23.75	0.389	0.30
Ash, %	1.15[a]	1.12[ab]	1.14[a]	1.11[ab]	1.06[b]	0.021	0.03
WBSF[4], kg	2.03	2.53	2.73	2.54	2.53	0.178	0.08

[a,b]Means within a row without a common superscript differ ($P < 0.05$).

[1]NZ: process-verified grass-fed beef imported from New Zealand; 0D: cattle consuming only forage; 40D: high-concentrate diet for 40 d prior to pasture-finishing; 80D high-concentrate diet for 80 d prior to pasture-finishing; 120D: high-concentrate diet for 120 d prior to pasture-finishing.

[2]Largest standard error of the least squares means.

[3]*P*- values < 0.05 considered significant.

[4]Cook loss included as a significant covariate for WBSF ($P < 0.01$).

Composition and shear force

Proximate composition and WBSF data are presented in Table 4. No differences were detected across samples from treatments for percent fat ($P = 0.50$), moisture ($P = 0.59$), or protein ($P = 0.30$). Fat percentages in this study were slightly higher than previously published values for top loin steaks from USDA Select carcasses, although different methodologies were used between this study and previous reports of fat percentage of Select steaks (Corbin et al., 2015; Gredell et al., 2018). Additionally, lack of difference in percent fat across samples from treatments indicates that intramuscular fat was appropriately controlled through product selection. Percent ash differed across treatments ($P = 0.03$) and was greater in samples from

NZ and 40D compared with samples from 120D ($P < 0.05$), suggesting that the mineral composition of the grain-based diets and forages may have varied affecting the percent ash. Duckett et al. (1993) and Chail et al. (2016) reported similar decreases in overall ash content with increased time on feed.

Warner-Bratzler shear force values did not differ ($P = 0.08$; Table 2) across treatments and were below accepted threshold values for tenderness (WBSF < 4.4 kg; Miller et al., 2001; Shackelford et al., 2001; ASTM, 2011). Others (Bidner et al., 1986; French et al., 2001; Faucitano et al., 2008; Duckett et al., 2013) have similarly reported no difference in WBSF in beef from cattle finished on pasture compared to grain when harvested at a similar age or degree of finish. Kerth et al. (2007) found that cattle grazing ryegrass prior to finishing with ad libitum access to grain for 94 d had similar, intermediate WBSF values to both cattle finished on ryegrass and those with only ad libitum access to grain for the duration of the study when all animals were harvested at an estimated 1.0 cm of subcutaneous backfat at the 12th rib. These results indicate that exposure to grain for 94 d may increase tenderness of beef from cattle grazing grass pastures to a degree similar to that of beef from cattle with increased exposure to grain. Additionally, Schmidt et al. (2013) found that grazing high-quality, legume-based pastures decreased WBSF compared to grass-based pastures, indicating that tenderness may be more related to inherent quality and energy provided by the diet than whether that diet is primarily composed of forage or grain. When differences in tenderness values in studies regarding pasture- and grain-finishing of beef, or exposure to low- or high-energy finishing diets have been reported, they have often been confounded by animal age or overall fatness of cattle (Muir et al., 1998). While cattle from 0D, 40D, 80D, and 120D treatments were finished to a target final BW, all cattle in the study were < 30 mo of age with carcasses grading A or low B maturity, likely contributing to similarity in WBSF. Low WBSF values in this study may also be attributed to the 21 d age of the product. Vacuum aging of meat from pasture- and grain-finished beef for 14 d or more has been previously attributed with increasing product tenderness and eliminating tenderness differences across product from cattle exposed to various dietary regimes (Smith et al., 1979; Duckett et al., 2007; Stelzleni et al., 2008).

Demographic data

Demographic and meat consumption preference distributions are reported in Tables 5 and 6, re-

Table 5. Demographic profiles of consumers participating in consumer sensory panels[1]

Characteristic	Response	% of consumers
Age	Younger than 20 years	0.92
	20 – 29 years	24.77
	30 – 39 years	30.73
	40 – 49 years	19.72
	50 – 59 years	16.97
	60 years or older	6.88
Gender	Male	45.16
	Female	54.84
Occupation	Tradesperson	11.68
	Professional	30.37
	Administration	19.63
	Sales and service	17.29
	Laborer	7.94
	Homemaker	3.27
	Student	3.74
	Not currently employed/retired	6.07
Household size		
Adults	1	12.90
	2	66.82
	3	13.82
	4	5.07
	5	0.46
	6	0.92
	7	0.00
	8 or more	0.00
Children	0	47.00
	1	13.36
	2	21.66
	3	8.29
	4	6.91
	5	2.30
	6	0.00
	7	0.46
	8 or more	0.00
Annual household income, USD	Less than $20,000 per year	6.94
	$20,000 - $50,000 per year	25.93
	$50,001 - $75,000 per year	25.93
	$75,001 - $100,000 per year	15.28
	More than $100,000 per year	25.93
Level of education	Non- high school graduate	1.40
	High school graduate	20.93
	Some college/ technical school	33.95
	College graduate	29.30
	Post graduate	14.42
Cultural heritage	African- American	15.28
	Asian	1.39
	Caucasian/ white	45.37
	Hispanic	35.65
	Native American	0.93
	Other	1.39

[1]Based on demographic responses by consumers (n= 220).

Table 6. Meat consumption preferences of consumers participating in consumer sensory panels[1]

Characteristic	Response	% of consumers
Frequency of beef consumption	Daily	26.27
	Weekly	62.67
	Every other week	5.53
	Monthly	2.76
	Every other month	0.46
	2 – 3 times per year	2.30
	Never eat beef	0.00
Enjoyment of beef	Enjoy beef/ important part of diet	53.77
	Like beef/ regular part of diet	37.74
	Eat some beef	8.02
	Rarely/ never eat beef	0.47
Degree of doneness preference	Blue	0.00
	Rare	0.93
	Medium/ rare	26.17
	Medium	27.57
	Medium/ well done	31.78
	Well done	13.55

[1]Based on responses by consumers (n = 220).

spectively. Nearly one third of consumers surveyed were between 30 to 39 yr old, with the majority of consumers aged between 20 and 59 yr old. Based on the 2017 American Community Survey (U.S. Census Bureau, 2017), this range is similar to that of the US population, with the majority of the population ranging from 25 to 54 yr old. Slightly more females than males participated in the study, with a greater difference than that of the current US population, which is nearly even, with 49.2% of the population male and 50.8% of the population female (U.S. Census Bureau, 2017). More than 80% of consumers surveyed in this study were of Caucasian or Hispanic heritage, however, the percentage of Caucasian representation is less than that of the general US population (72.3 to 75.1%), and the Hispanic representation was greater than the general US population (18.1%; U.S. Census Bureau, 2017). African American representation was moderate and was similar to that of the US population (12.7 to 14.1%; U.S. Census Bureau, 2017). Asian and Native American or other heritage were the least represented in this study, with Asian representation slightly less than that of the general US population (5.6 to 6.6%) and Native American representation similar to that of the US population (0.8 to 1.7%; U.S. Census Bureau, 2017). The majority of consumers surveyed reported living in a household with 2 adults and no children. Those households that reported having children most frequently reported having 1 to 2 children. Most participants stated that they were employed as professionals and had some college/technical school or were college graduates. An equal percentage of the consumers surveyed stated they had annual household incomes ranging from $20,000 to $50,000 per yr, $50,001 to $75,000 per yr, or more than $100,000 per yr.

Most consumers surveyed in this study were regular consumers of red meat, reporting consuming red meat at least weekly. More than 90% of consumers surveyed indicated that they like or enjoy eating beef. The majority of consumers surveyed in this study prefer beef cooked between medium rare and medium well done (85.52%), with a slight majority preferring beef cooked to medium well done.

Table 7. Least squares means of consumer sensory scores (n = 220) for palatability traits of steaks from the *M. longissimus lumborum* of New Zealand grass-fed cattle and cattle fed high-concentrate diets for variable time periods prior to pasture-finishing[1]

	Treatment[2]						p-
Variable	NZ	0D	40D	80D	120D	SEM[3]	value[4]
Tenderness	71.24^{a}	57.66^{c}	57.70^{c}	58.23^{c}	63.61^{b}	1.688	<0.01
Juiciness	67.15^{a}	59.92^{b}	63.97^{ab}	63.06^{b}	67.13^{a}	1.677	<0.01
Flavor liking	61.58^{a}	57.04^{bc}	52.80^{d}	55.75^{cd}	59.63^{ab}	1.670	<0.01
Overall liking	64.20^{a}	56.24^{b}	54.95^{b}	56.46^{b}	61.47^{a}	1.670	<0.01

$^{a–d}$Least squares means within a column without a common superscript differ (P < 0.05).

[1]Scores based on 100-mm line scale: 0 = not tender/juicy, dislike flavor/ overall extremely; 100 = very tender/juicy, like flavor/overall extremely.

[2]NZ: grass-fed beef imported from New Zealand; 0D: cattle consuming only forage; 40D: high-concentrate diet for 40 d prior to pasture-finishing; 80D: high-concentrate diet for 80 d prior to pasture-finishing; 120D: high-concentrate diet for 120 d prior to pasture-finishing.

[3]Largest standard error of the least squares means.

[4]P- values < 0.05 considered significant.

Consumer palatability

Despite similarity in WBSF across treatments, consumers surveyed in this study observed tenderness differences (P < 0.01; Table 7) across samples from the treatments and differences in acceptability of tenderness (P < 0.01; Table 8). Samples from NZ received the greatest scores for tenderness (P < 0.05) and were most often (P < 0.05) rated as acceptable for tenderness compared to samples from all other treatments. Steaks from 120D received lesser (P < 0.05) mean scores for tenderness than steaks from NZ, but greater scores than those from all other treatments. Similarly, Dolezal et al. (1982) reported that tenderness scores significantly increased after at least 90 d on concentrate. Steaks from

120D were less often rated as acceptable ($P < 0.05$) than steaks from NZ but were of similar ($P > 0.05$) acceptability to those from 80D, which did not differ ($P > 0.05$) from samples from 0D or 40D. Miller et al. (1995) reported that the average consumer can detect a difference of 0.5 kg in WBSF when consuming a steak at home. In the present study, the average WBSF of NZ was at least 0.5 kg less than all other treatments, indicating that consumers were likely detecting this 0.5 kg difference. Differences in perceived tenderness may also be related to carcass treatment at slaughter. Carcasses from New Zealand were exposed to low voltage electrical stimulation at slaughter while cattle from United States-based treatments (0D, 40D, 80D, 120D) did not receive any electrical stimulation. Low voltage electrical stimulation increases tenderness of tough carcasses by promoting a more rapid onset of rigor mortis and increasing proteolysis and protein denaturation (Savell et al., 1978). Decreased time to rigor helps prevent cold shortening, and increased proteolysis causes breakdown of muscle proteins; therefore, differences associated with low voltage electrical stimulation may be responsible, at least in part, for increased tenderness scores of NZ samples in this study. Despite differences in tenderness scores between some treatments, most samples were frequently classified as acceptable for tenderness, with more than 76% of each treatment designated as acceptable by consumers.

Consumers also noted differences ($P < 0.01$) in juiciness, flavor liking, and overall liking across treatments. Steaks from NZ and 120D were juicier ($P < 0.05$) than those from 0D and 80D; steaks from 40D were intermediate and did not differ ($P > 0.05$) from steaks from other treatments. Consumers classified 120D steaks as acceptable for juiciness more often ($P < 0.05$) than those from all other treatments except NZ ($P > 0.05$). The proportion of samples considered acceptable for juiciness from 0D and 80D were intermediate ($P > 0.05$) between those from NZ and 40D. Greater than 82% of samples from each treatment were classified as acceptable for juiciness by consumers. Juiciness increases with exposure to a corn diet (Sitz et al., 2005; Duckett et al., 2007); however, in some cases, these differences have been attributed to increased intramuscular fat related to grain exposure (Corbin et al., 2015). It is well-established that increased intramuscular fat content is related to perception of juiciness (Smith and Carpenter, 1974; Miller et al., 1997; Killinger et al., 2004; O'Quinn et al., 2012; Emerson et al., 2013; Lucherk et al., 2016, Nyquist et al., 2018). Intramuscular fat between treatments was controlled in this study for this reason. Muir et al. (1998) concluded from a review of the prior studies that effects of diet on perceived juiciness were inconsistent, and more recent work has reported there were not differences in perceived juiciness due to diet, especially when results were not confounded by varying degrees of intramuscular fat (French et al., 2001; Duckett et al., 2013). Roberts et al. (2009) reported that when steers were finished on winter annual ryegrass with various levels of corn supplementation, steers receiving the greatest and least amounts of grain produced beef that received the highest juiciness scores. While perceived juiciness is correlated to the amount of intramuscular fat, it is not solely dependent on this relationship. Juiciness can be influenced by other factors affecting water remaining in the cooked product including ultimate pH, rate of denaturation of proteins during cooking, differences in water holding capacity, degree of doneness, and even variation in physiological factors of the panelists (Winger and Hagyard, 1994; Honikel, 1998; Lorenzen et al., 1999; Aberle et al., 2001; Lucherk et al., 2016). Additionally, Miller et al. (2001) proposed that when one of the palatability traits is perceived favorably, consumers are likely to assign greater scores to other palatability traits as well. It has also been reported that consumers have difficulty separating perception of traits (the halo effect; Roeber et al., 2000). Accordingly, it is possible that increased juiciness scores for NZ and 120D samples may be related to increased tenderness and flavor scores for these samples.

Forage-finished beef has often received lower scores from consumers in the United States for flavor

Table 8. Least squares means of percentage of steaks from the *M. longissimus lumborum* of New Zealand grass-fed cattle and cattle fed high-concentrate diets for variable time periods prior to pasture-finishing rated as acceptable by consumer panelists (n = 220) for palatability traits

	Treatment[1]						*P*-
Acceptability, %	NZ	0D	40D	80D	120D	SEM[2]	value[3]
Tenderness	94.86[a]	81.45[c]	78.45[c]	83.31[bc]	88.30[b]	2.937	<0.01
Juiciness	89.26[ab]	83.84[bc]	82.44[c]	84.59[bc]	91.01[a]	2.693	0.03
Flavor liking	84.25	77.70	77.76	80.80	83.38	3.147	0.27
Overall liking	88.31[a]	81.37[bc]	76.71[c]	80.90[bc]	84.75[ab]	3.215	0.02

[a–c]Least squares means within a column without a common superscript differ ($P < 0.05$).

[1]NZ: grass-fed beef imported from New Zealand; 0D: cattle consuming only forage; 40D: high-concentrate diet for 40 d prior to pasture-finishing; 80D: high-concentrate diet for 80 d prior to pasture-finishing; 120D: high-concentrate diet for 120 d prior to pasture-finishing.

[2]Largest standard error of the least squares means.

[3]*P*- values < 0.05 considered significant.

Table 9. Pearson correlation coefficients of relationships between consumer palatability scores, proximate composition, and Warner-Bratzler Shear Force (WBSF) of beef strip loin steaks from New Zealand grass-fed cattle and cattle fed high-concentrate diets for variable time periods prior to pasture-finishing

	Consumer panel ratings				Proximate composition			
Measurement	Tenderness	Juiciness	Flavor liking	Overall liking	%Fat	%Moisture	%Protein	%Collagen
Consumer panel ratings								
Juiciness	0.65**							
Flavor liking	0.55**	0.48**						
Overall liking	0.62**	0.56**	0.88**					
Proximate composition								
%Fat	-0.01	-0.01	0.02	0.01				
%Moisture	0.009	0.04	-0.02	-0.009	-0.87**			
%Protein	-0.02	-0.03	-0.008	-0.03	0.14**	-0.40**		
%Collagen	0.03	0.02	0.04	0.05	0.11**	0.01	-0.31**	
WBSF, kg	-0.24**	-0.09**	-0.15**	-0.18**	-0.06*	0.13**	0.05	-0.19**

*Correlation coefficient differs from 0 ($P < 0.05$).

**Correlation coefficient differs from 0 ($P < 0.01$).

liking and/or intensity of beef flavor compared to grain-fed beef and is often recorded as having increased off-flavors (including "grassy," "gamey," and "barny") and decreased favorable beef flavors (Muir et al., 1998; Priolo et al., 2001; Maughan et al., 2012; van Elswyk and McNeill, 2014). However, samples from NZ received greater ($P < 0.05$) scores for flavor liking than those from all other treatments except 120D, which in turn, did not differ ($P > 0.05$) from 0D samples. Flavor liking scores were less ($P < 0.05$) for 40D samples than those from all treatments except 80D, which also did not differ ($P > 0.05$) from samples from 0D. It has been cited that increased exposure to grain-based diets prior to slaughter decreases off-flavors in pasture-fed beef (Melton et al., 1982a; Larick et al., 1987). However, Chail et al. (2016) found that when grass-fed cattle are finished on high-quality legume-based pastures, consumer liking of flavor was like that of meat from cattle exposed to grain prior to slaughter. Additionally, Muir et al. (1998) proposed that differences in palatability of pasture- and grain-fed beef are more influenced by growth rate provided by the diet than the diet itself. Beef cattle in New Zealand are rarely finished on grain and are most often finished on carefully-managed, nutrient-dense grass and legume mixed pastures (typically ryegrass and white clover) ideal for providing a high plane of nutrition (Boom, 2014a; Boom, 2014b; Beef and Lamb New Zealand, 2017). Therefore, greater flavor liking scores for NZ similar to those of 120D may indicate that New Zealand pastures provided a similarly high plane of nutrition during finishing as the combined grain exposure and pasture-finishing of the 120D treatment. It should be noted that scores ranged from 52.80 (40D) to 61.58 (NZ), which may indicate that consumers were able to detect the pasture-attributed off-flavors in all samples. However, the classification of flavor liking acceptability did not differ between treatments ($P > 0.27$).

Consumers scored samples from NZ and 120D greater ($P < 0.05$) for overall liking than those from all other treatments, but samples from the remaining treatments did not differ ($P > 0.05$). Likewise, overall acceptability differed ($P = 0.02$) among treatments. Steaks from NZ were more often ($P < 0.05$) considered acceptable by consumers than steaks from all other treatments except 120D ($P > 0.05$). Steaks from 0D and 80D were classified as acceptable less often than those from NZ ($P < 0.05$), but intermediate ($P > 0.05$) between those from 120D and 40D. Despite differences, steaks from all treatments were considered acceptable overall nearly 77% of the time, suggesting that, when perceived together, the three palatability traits (tenderness, juiciness, and flavor) all contribute to the overall palatability of samples, and greater perceived scores for one trait may increase the perceived palatability of a sample as a whole. The overall preference for NZ samples may indicate that the nutrition provided by New Zealand pastures resultant of more intensive pasture management was greater than that provided during the grazing period of cattle from experimental treatments. Samples from 120D did generally perform better than other experimental treatments in terms of palatability, indicating that increased exposure to high concentrate diets of at least 120 d increases overall palatability of beef finished on high-quality pastures in the southeastern United States. Dolezal et al. (1982) similarly reported that palatability traits including tenderness, juiciness, and overall palatability were increased

when cattle were fed a high-concentrate diet for at least 90 to 100 d prior to slaughter compared to shorter fed periods. Increased overall palatability of 120D samples compared to those from other experimental treatments is also supported by prior work focused both on time of exposure to high-concentrate diets and on energy of backgrounding diets (Smith et al., 1977; Aberle et al., 1981; Miller et al., 1987; Schaake et al., 1993; Owens and Gardner, 1999; Scheffler et al., 2014).

These differences in overall liking and acceptability are reflective of a culmination of the individual palatability traits. Overall liking scores were most highly correlated to flavor liking ($P < 0.01$; Table 9), similar to the previous reports of relationships of overall liking with flavor in grass-fed beef (Crownover et al., 2017; Hardcastle et al., 2018). Overall liking was also positively correlated to tenderness ($P < 0.01$) and juiciness ($P < 0.01$), though to a lesser degree. All other correlation coefficients are reported in Table 9. Corbin et al. (2015) reported that when tenderness is acceptable, flavor becomes the most important contributor to overall liking in cooked beef, which supports our findings given the low WBSF values in the current study coupled with the high proportion of samples considered acceptable for tenderness (> 78%).

When assigned by consumers into perceived quality categories, NZ samples were classified as unsatisfactory less often ($P < 0.05$) than all other treatments except 120D samples ($P > 0.05$), which did not differ ($P > 0.05$) from any other treatment (Table 10). Treatment differences were only noted for unsatisfactory quality ($P = 0.05$). Nearly half of all samples were placed in the "Good every day quality" category, indicating that consumers would be willing to consume product from any of the treatments as part of their regular beef consumption. This is in agreement with the conclusion of French et al. (2001) that cattle could be finished on grass without an overall negative effect on meat quality.

Table 10. Least squares means of percentage of steaks from the *M. longissimus lumborum* of New Zealand grass-fed cattle and cattle fed high-concentrate diets for variable time periods prior to pasture-finishing rated at different perceived quality levels by consumer panelists ($n = 220$)

	Treatment[1]						
Quality level, %	NZ	0D	40D	80D	120D	SEM[2]	P-value[3]
Unsatisfactory	10.63[b]	18.09[a]	20.14[a]	17.79[a]	13.69[ab]	3.030	0.04
Good everyday	48.62	50.19	47.24	52.77	45.86	3.503	0.64
Better than everyday	27.68	25.52	23.59	20.41	28.60	3.081	0.28
Premium	10.47	3.87	6.48	6.48	9.13	2.110	0.07

[a,b]Least squares means within a column without a common superscript differ ($P < 0.05$).

[1]NZ: grass-fed beef imported from New Zealand; 0D: cattle consuming only forage; 40D: high-concentrate diet for 40 d prior to pasture-finishing; 80D: high-concentrate diet for 80 d prior to pasture-finishing; 120D: high-concentrate diet for 120 d prior to pasture-finishing.

[2]Largest standard error of the least squares means.

[3]*P*- values < 0.05 considered significant.

Fatty acid composition

Diet influences the intramuscular fat content and fatty acid composition of meat. Fatty acid profiles of ruminants are resultant of diet combined with ruminal biohydrogenation. Grain-based diets typically provide increased energy density and increased intramuscular adiposity (Daley et al., 2010; Smith et al., 2012; Scollan et al., 2014). However, with quality grade controlled, total fatty acids (g/100g wet sample) were greatest in NZ samples ($P < 0.05$) and least in 0D samples ($P < 0.05$); samples from all treatments that included grain exposure were intermediate in total fatty acids (Table 11).

Reports of total saturated fatty acids among pasture- and grain-fed beef have been inconsistent (Daley et al., 2010). Beef from NZ contained a lesser proportion of saturated fatty acids than that from all other treatments ($P < 0.05$) which did not differ from each other ($P > 0.05$). The difference is likely attributed to the decrease ($P < 0.05$) in stearic (C18:0) acid in NZ samples compared to samples from all other treatments except 120D ($P > 0.05$). This decrease in stearic acid in NZ samples is contrary to more typical reports of elevated stearic acid in pasture-fed cattle; however, values for all treatments were greater than those generally reported for grain-fed cattle (Daley et al., 2010; Duckett et al., 2013). Myristic (C14:0) and palmitic (C16:0) acid have generally been reported as being elevated in grain-fed cattle as a result of increased energy density and effect on lipogenic gene expression (Leheska et al., 2008; Alfaia et al., 2009; Duckett et al., 2009; Daley et al., 2010), but did not differ ($P > 0.05$) among samples from treatments in the present study, likely as a result of pasture-finishing of all treatments.

Total odd-chain fatty acids differed ($P < 0.01$) among treatments. Beef from NZ contained the least concentration of both pentadecyclic (C15:0) and margaric (C17:0) acids, and beef from all grain-fed treatments possessed generally greater ($P < 0.05$) concentrations. Odd-chain fatty acids are produced when propionate is used preferentially over acetate in *de novo* FA synthesis (Duckett et al., 1993). Duckett et al. (2009) also reported increased concentration of odd-chain fatty acids in grain-fed or supplemented

Table 11. Least squares means of the fatty acid composition of the *M. longissimus lumborum* of New Zealand grass-fed cattle and cattle fed high-concentrate diets for variable time periods prior to pasture-finishing

	Treatment[1]						*P*-
Variable	NZ	0D	40D	80D	120D	SEM[2]	values[3]
n	8	8	8	8	8		
Total fatty acids, g/100g	3.22^{a}	1.53^{c}	2.20^{b}	2.23^{b}	2.52^{b}	0.212	<0.01
Fatty acids[4,5], %							
C14:0	2.43	2.29	2.60	2.28	2.73	0.137	0.10
C16:0	25.96	26.26	27.17	26.69	27.84	0.529	0.11
C18:0	14.40^{c}	16.89^{a}	16.92^{a}	16.30^{ab}	15.55^{bc}	0.443	<0.01
C20:0	0.05	nd	nd	nd	nd	0.007	-
C15:0	0.36^{c}	0.44^{b}	0.52^{a}	0.46^{ab}	0.51^{a}	0.022	<0.01
C17:0	0.59^{c}	1.08^{b}	1.20^{a}	1.17^{a}	1.21^{a}	0.024	<0.01
C14:1	0.68^{a}	0.36^{c}	0.48^{bc}	0.44^{bc}	0.59^{ab}	0.063	<0.01
C16:1 cis-9	3.91^{a}	3.16^{b}	3.04^{b}	3.18^{b}	3.39^{ab}	0.198	0.02
C18:1 cis-9	40.20^{a}	36.57^{b}	36.20^{b}	36.25^{b}	35.69^{b}	0.649	<0.01
C18:1 trans-9	0.09	nd	nd	0.11	0.11	0.063	0.47
C18:1 trans-10	<0.01^{b}	<0.01^{b}	<0.01^{b}	<0.01^{b}	0.37^{a}	0.078	<0.01
C18:1 trans-11	1.46^{b}	1.86^{ab}	2.05^{a}	2.14^{a}	2.18^{a}	0.162	0.02
C18:1 cis-11	1.42	1.28	1.24	1.35	1.39	0.063	0.26
C20:1	0.13	nd	nd	nd	nd	0.006	-
C18:2 cis-9 trans-11	0.17^{b}	0.36^{a}	0.40^{a}	0.41^{a}	0.44^{a}	0.043	<0.01
C18:2 n-6	2.10^{b}	2.34^{b}	2.34^{b}	3.24^{a}	3.23^{a}	0.195	<0.01
C20:2 n-6	<0.01	nd	nd	nd	nd	<0.001	-
C20:3 n-6	0.21	nd	nd	nd	nd	0.005	-
C20:4 n-6	0.73^{b}	0.94^{b}	0.99^{ab}	1.28^{a}	1.04^{ab}	0.107	0.01
C18:3 n-3	0.84	1.14	0.70	0.66	0.64	0.140	0.09
C20:5 n-3	0.33^{b}	0.46^{a}	0.30^{bc}	0.22^{cd}	0.16^{d}	0.034	<0.01
C22:5 n-3	0.50^{bc}	0.72^{a}	0.52^{b}	0.49^{bc}	0.37^{c}	0.048	<0.01
C22:6 n-3	0.05^{b}	0.10^{a}	0.08^{ab}	0.06^{b}	0.07^{b}	0.010	0.01
SFA	42.86^{b}	45.45^{a}	46.70^{a}	45.28^{a}	46.12^{a}	0.632	<0.01
OCFA	0.96^{c}	1.52^{b}	1.72^{a}	1.63^{a}	1.73^{a}	0.037	<0.01
MUFA	44.94^{a}	40.11^{b}	39.73^{b}	39.88^{b}	39.67^{b}	0.679	<0.01
n-6 PUFA	3.05^{b}	3.29^{b}	3.34^{b}	4.53^{a}	4.27^{a}	0.283	<0.01
n-3 PUFA	1.74^{b}	2.44^{a}	1.60^{b}	1.45^{b}	1.26^{b}	0.193	<0.01
n-6:n-3	2.10^{b}	1.39^{b}	2.10^{b}	3.16^{a}	3.60^{a}	0.258	<0.01

$^{a–d}$Means within a row without a common superscript differ ($P < 0.05$).

[1]NZ: grass-fed beef imported from New Zealand; 0D: cattle consuming only forage; 40D: high-concentrate diet for 40 d prior to pasture-finishing; 80D: high-concentrate diet for 80 d prior to pasture-finishing; 120D: high-concentrate diet for 120 d prior to pasture-finishing.

[2]Largest standard error of the least squares means.

[3]*P*- values < 0.05 considered significant.

[4]SFA: saturated fatty acids; OCFA: odd chain fatty acids; MUFA: monounsaturated fatty acids; PUFA: polyunsaturated fatty acids.

[5]nd: not detected.

cattle, indicating a greater availability of propionate with grain-feeding. Our results, therefore, indicate that there is a residual effect of grain-feeding on fatty acid profile even after pasture-finishing for 188 d to 314 d.

Total monounsaturated fatty acid concentration was increased ($P < 0.05$) in NZ samples compared to those from all other treatments and can be attributed to greater ($P < 0.05$) concentrations of myristoleic (C14:1), palmitoleic (C16:1), and oleic (C18:1) acids in these samples. Concentration of monounsaturated fatty acids is typically increased in grain-fed cattle as a result of upregulation of stearoyl coenzyme A desaturase which desaturates stearic acid to synthesize oleic acid (Wood et al., 2008; Duckett et al., 2009; Daley et al., 2010; Smith et al., 2012; Wright et al., 2015). Increased oleic acid concentration in NZ despite decreased stearic acid may indicate progression of stearic acid through the Δ-9 desaturase pathway. However, values for all treatments were less than those generally reported for grain-finished beef and similar to those from pasture-finished beef (Daley et al., 2010). Elevated concentrations of palmitoleic and oleic acid in NZ samples may help explain increased consumer flavor scores as both have previously been associated with increases in desirable beef flavor (Melton et al., 1982b; O'Quinn et al., 2016). Myristoleic acid concentration was similar ($P > 0.05$) among NZ and 120D samples, though previous reports indicate greater myristoleic acid concentration in grain-finished cattle (Duckett et al., 2009; Duckett et al., 2013). Wright et al. (2015) reported that grazing legume pastures increased myristoleic acid concentration. These results taken together with the results of the present study may indicate a response of myristoleic acid to diet energy.

Concentrations of polyunsaturated fatty acids are largely affected by diet. Linoleic (C18:2 n-6) and α-linolenic (C18:3 n-3) acids are essential fatty acids and cannot be synthesized by mammals. Therefore, these fatty acids must be provided in the diet. Grain-based diets are largely composed of linoleic acid, while forages largely contribute α-linolenic acid (Wood et al., 2008; Schmidt et al., 2013). In the ruminant, 70 to 95% of dietary polyunsaturated fatty acid undergoes microbial biohydrogenation to form monounsaturated or saturated fatty acids and several intermediates (Wood et al., 2008). Trans-vaccenic acid (C18:1 trans-11) and conjugated linoleic acid (C18:2 cis-9 trans-11) are nutritionally important fatty acids for the human diet that are available in ruminant muscle tissue. Their concentration in muscle tissue is dependent on polyunsaturated fatty acid intake by the ruminant animal. Contrary to reports by Leheska et al. (2008) and Duckett et al. (2009), trans-vaccenic acid concentration was greater ($P < 0.05$) in meat from cattle exposed to grain, while beef from 0D was intermediate and did not differ from ($P > 0.05$) beef from NZ or other treatments. Trans-vaccenic acid is synthesized through biohydrogenation of linoleic acid and is a precursor for conjugated lin-

oleic acid. Consequently, concentrations of conjugated linoleic acid were greater ($P < 0.05$) in the present study for beef from 0D, 40D, 80D, and 120D than that from NZ. Daley et al. (2010) discussed the relationship of ruminal pH with bacterial synthesis of trans-vaccenic acid and conjugated linoleic acid from linoleic acid. Increased grain in diets typically decreases ruminal pH to a point less favorable for activity of *Butryvibrio fibrisolvens*, the bacterium responsible for synthesis of trans-vaccenic acid and conjugated linoleic acid from linoleic acid. Increased trans-vaccenic acid concentration in grain-exposed cattle in the present study may be resultant of increased intake of linoleic acid from grain-exposure prior to a return to favorable rumen pH for biosynthesis of trans-vaccenic acid and conjugated linoleic acid. It is also worth noting that treatments which had increased concentrations of trans-vaccenic acid and conjugated linoleic acid also had decreased concentrations of oleic acid and total monounsaturated fatty acid. Smith et al. (2009) reported that isomers of conjugated linoleic acid can cause decreased expression of stearoyl coenzyme A desaturase and therefore lead to decreased monounsaturated fatty acid concentration, and particularly oleic acid.

The concentration of n-6 and n-3 polyunsaturated fatty acids were different ($P < 0.01$) among treatments, with increased concentrations of linoleic and arachidonic (C20:4) acid in 80D and 120D samples, contributing to an overall difference in n-6 polyunsaturated fatty acids. Concentrations of n-3 polyunsaturated fatty acids were increased in 0D samples ($P < 0.05$) but did not differ ($P > 0.05$) among samples from other treatments, including NZ. Beef from 0D contained greatest ($P < 0.05$) concentrations of all long chain n-3 polyunsaturated fatty acids, including eicosapentaenoic (C20:5), docosapentaenoic (C22:5), and docosahexaenoic acid (C22:6). Concentrations of α-linolenic acid did not differ ($P = 0.10$) among treatments but are in a range similar to those previously reported for pasture-fed cattle (Wood et al., 2008; Daley et al., 2010). Long-chain polyunsaturated fatty acids like eicosapentaenoic, docosapentaenoic, and docosahexaenoic acid are synthesized through elongation of α-linolenic acid by desaturase enzymes during metabolism (Simopoulos, 1991); therefore, it would be reasonable to infer that lack of difference in concentration of α-linolenic acid may be due to increased concentrations of long-chain polyunsaturated fatty acids resultant of α-linolenic acid metabolism. Differences ($P < 0.01$) of the n-6:n-3 ratio reflect the overall differences in polyunsaturated fatty acid concentration among treatments with increased ratio of n-6:n-3 in meat from 80D and 120D. This indicates that early grain feeding may have residual effects on polyunsaturated fatty acid composition of the LM.

Volatile compounds

Fatty acids are one of two main groups of precursor compounds contributing to meat flavor (Mottram, 1998). The specific fatty acids composing beef fat are most related to the lipid-derived volatile compounds which are produced through oxidation during storage and accelerated by heat during cooking (Calkins and Hodgen, 2007). This class of volatile compounds has been implicated as a vital contributor to beef flavor (Mottram, 1998; Brewer and Novakofski, 2008). Polyunsaturated fatty acids are less stable and more prone to degradation. Several long chain polyunsaturated fatty acids have been positively correlated with off-flavors including "cowy," "cardboard," "painty," and "livery" (Camfield et al., 1997). However, several saturated and monounsaturated fatty acids, as well as linoleic and α-linolenic acid have been positively correlated with desirable beef flavor (Melton et al., 1982a, 1982b). Differences in lipid-derived volatile compounds among treatments are reported in Table 12.

Most differences in lipid-derived compounds among treatment groups were of compounds classified as alcohols and *n*-aldehydes. Aldehydes have previously been cited as contributing positively to beef flavor attributes and consumer sensory scores (Gredell et al., 2018). Overall, NZ beef contained greater ($P < 0.05$) concentrations of compounds from these classes compared to beef from most other treatments. In particular, 1-penten-3-ol was greater ($P < 0.05$) in NZ samples than those from all other treatments, and 1-octanol was greater ($P < 0.05$) in NZ samples than those from all treatments except 40D ($P > 0.05$) and lesser in 120D samples than NZ and 40D samples ($P < 0.05$). Hexanal was greater in meat from NZ than meat from all other treatments ($P < 0.05$) except 80D ($P > 0.05$), and octanal was greater in NZ beef than 80D and 120D beef ($P < 0.05$). Additionally, beef from 120D produced the least amount of hexanal. Calkins and Hodgen (2007) reported that hexanal and octanal are generally increased when cattle are exposed to grain rather than grass-fed. Elmore et al. (2004) also reported that cattle finished on grain produced increased amounts of linoleic acid-derived volatile compounds (like pentanal and hexanal) and cattle finished on grass-silage produced greater amounts of α-linolenic acid-derived compounds (1-penten-3-ol and cis-2-penten-1-ol). Similarities among our treatment groups may be ex-

Table 12. Least squares means of thermal degradation-derived volatile compounds of steaks from the *M. longissimus lumborum* of New Zealand grass-fed cattle and cattle fed high-concentrate diets for variable time periods prior to pasture-finishing

	Treatment[1]						
Volatile compound, nmol·mL^{-1}	NZ	0D	40D	80D	120D	SEM[2]	P- values[3]
Alcohols							
1-Hexanol	2.44^{a}	1.48^{b}	1.73^{ab}	1.82^{ab}	1.26^{b}	0.288	0.04
1-Octen-3-ol	4.42^{a}	1.67^{c}	2.44^{bc}	3.13^{ab}	2.10^{bc}	0.518	<0.01
1-Penten-3-ol	0.33^{a}	0.14^{b}	0.17^{b}	0.14^{b}	0.10^{b}	0.028	<0.01
1-Octanol	5.17^{a}	3.97^{bc}	4.41^{ab}	3.86^{bc}	3.06^{c}	0.404	<0.01
2,3-Butanediol	8.89	3.71	6.74	4.80	5.83	1.571	0.15
Pentanol	9.28	6.96	8.26	10.41	7.06	1.407	0.32
Ethanol	1.48	13.26	13.44	6.24	17.14	7.788	0.58
n-Aldehydes							
Pentanal	1.43^{a}	0.78^{b}	1.01^{ab}	1.00^{ab}	0.71^{b}	0.172	0.02
Hexanal	134.90^{a}	46.56^{c}	68.49^{bc}	94.02^{ab}	52.27^{bc}	16.597	<0.01
Heptanal	19.38^{a}	13.48^{bc}	15.07^{ab}	14.10^{abc}	9.73^{c}	1.957	0.01
Octanal	34.00^{a}	27.19^{ab}	30.54^{ab}	23.75^{bc}	18.00^{c}	2.756	<0.01
Nonanal	7.30^{a}	6.15^{ab}	6.98^{ab}	5.35^{bc}	4.37^{c}	0.642	<0.01
Decanal	1.42	1.56	1.57	1.31	1.46	0.144	0.69
Dodecanal	3.64	3.59	4.74	3.26	4.70	0.976	0.76
Ketones							
2-Propanone	67.94	59.35	79.77	57.52	61.26	8.136	0.33
2-Butanone	27.07	20.62	26.21	21.31	21.50	2.873	0.31
2-Heptanone	1.09^{a}	0.68^{b}	0.76^{b}	0.83^{b}	0.71^{b}	0.061	<0.01
2-Pentanone	0.14	0.13	0.16	0.14	0.15	0.014	0.65
Lactones							
Butyrolactone	0.49^{a}	0.24^{b}	0.29^{b}	0.27^{b}	0.29^{b}	0.048	<0.01
Furans							
2-Pentylfuran	1.32^{a}	0.42^{b}	0.57^{b}	0.77^{b}	0.48^{b}	0.135	<0.01
Alkanes							
Octane	4.40	3.22	3.38	2.48	2.06	0.600	0.05
Decane	2.07	1.98	2.10	2.00	1.92	0.112	0.72
Tetradecane	1.19	0.95	1.69	1.04	1.00	0.196	0.07
Methyl heptane	4.75	3.69	4.17	4.89	3.74	0.652	0.53
Carboxylic acids							
Acetic acid	5.92^{a}	3.68^{b}	4.00^{b}	3.57^{b}	3.50^{b}	0.603	0.02
Butanoic acid	177.40	214.77	144.83	112.89	135.74	36.444	0.25
Hexanoic acid	32.24	16.47	25.52	27.00	18.41	4.324	0.05
Octanoic acid	0.29	0.13	0.44	0.40	0.20	0.097	0.11
Nonanoic acid	117.21	69.54	209.87	208.10	105.61	52.400	0.16
Esters							
Hexanoic acid methyl ester	1.07	0.94	0.77	0.94	0.47	0.161	0.08
Butanoic acid methyl ester	0.14	0.18	0.14	0.13	0.14	0.022	0.49
Alkenes							
Toluene	10.17	7.08	11.12	8.44	8.43	1.412	0.27
2-Methyl-1-pentene	0.36	0.36	0.36	0.36	0.36	<0.001	0.60
p- xylene	242.50	202.53	232.11	223.78	162.13	35.620	0.45

[a–d]Means within a row without a common superscript differ ($P < 0.05$).

[1]NZ: grass-fed beef imported from New Zealand; 0D: cattle consuming only forage; 40D: high-concentrate diet for 40 d prior to pasture-finishing; 80D: high-concentrate diet for 80 d prior to pasture-finishing; 120D: high-concentrate diet for 120 d prior to pasture-finishing.

[2]Largest standard error of the least squares means.

[3]*P*- values < 0.05 considered significant.

plained by the pasture-finishing of all treatments on similar quality pastures, which was previously discussed as a source of similarities in fatty acid concentrations. However, a numerical trend for hexanal to increase in 0D beef to 40D beef to 80D beef does suggest that increased grain exposure does lead to increases in these compounds. Additionally, hexanal in cooked beef is related to linoleic acid (Calkins and Hodgen, 2007). While exposure to grain increased concentration of linoleic acid, hexanal concentration did not consistently increase in a similar fashion ($P < 0.05$). The elevated quantity of hexanal in NZ beef may be related to the increased total fatty acids in NZ samples compared to those from all other treatments.

When present in high concentrations, hexanal can contribute flavors including "fatty-green," "grassy," and "tallow," which are also terms often used to describe off-flavors associated with grass-fed beef, and it is also an indicator of lipid oxidation (Calkins and Hodgen, 2007; Kerth and Miller, 2015). However, in low concentrations, hexanal is also cited as being a key contributor to characteristic beef flavor, and Gredell et al. (2018) reported a positive correlation between hexanal concentration and consumer overall liking, albeit weak, as well as positive correlations to beef flavors including "beefy/brothy," "browned/grilled," "bloody/metallic," "earthy/mushroom," and "livery." Elevated concentrations of hexanal, particularly in NZ samples, may therefore have contributed to consumer perceptions of beef flavor and overall liking in the present study. Elmore et al. (1999) suggested that oxidation products of polyunsaturated fatty acids could increase oxidation of linoleic and oleic acids, and therefore may explain the increase in short-chain *n*-aldehydes found in NZ beef compared to that from other treatments in our study. Conjugated linoleic acid and trans-vaccenic acid have also been previously implicated as precursors to volatile compounds increasing off-flavors (Calkins and Hodgen, 2007). Melton et al. (1982a) reported that myristoleic, palmitoleic, stearic, oleic, linoleic, and α-linolenic acids were positively correlated with beef flavor. As previously mentioned, beef from NZ was greater in concentration for 3 of these compounds and their resulting volatile compounds, likely contributing to greater consumer flavor liking for NZ samples.

Other aldehydes worth noting are heptanal and decanal. Heptanal has previously been reported to be increased in forage-finished beef and also to be positively correlated to grassy flavors (Larick et al., 1987). Similarly, cooked NZ samples produced the greatest concentration of heptanal and 120D samples the least, with samples from remaining treatments producing intermediate concentrations of heptanal. Decanal did not differ ($P = 0.69$) among treatment groups in this study. Gredell et al. (2018) reported that decanal decreased as marbling increased. Therefore, lack of difference in heptanal concentration produced by samples in this study may be related to similar fat levels of samples from all treatments.

Lipid-derived ketones including 2-propanone, 2-butanone, 2-heptanone, and 2-pentanone, as well as their Maillard-derived counterparts (2,3-butanedione and 3-hydroxy-2-butanone) have previously been associated with flavors and aromas including "buttery," "creamy," "pungent," "chemical-like," "fruity-green," and "cheesy" (Kerth and Miller, 2015). Differences between lipid-derived ketones in the present study were minimal, with only 2-heptanone differing among treatments ($P < 0.01$). Concentrations of 2-heptanone were greater ($P < 0.05$) in NZ samples than samples from all other treatments, though overall concentrations were low compared to other ketones like 2-propanone and 2-butanone.

No differences ($P > 0.05$) were detected between treatments for alkane compounds, which are typically products of thermal degradation of saturated fatty acids. However, there was a numerical trend for concentration of octane to decrease with increased exposure to pasture. This is similar to reports both by Larick et al. (1987) and Gredell et al. (2018), who also reported numerical difference in octane concentration with increased days on feed and exposure to concentrate, respectively, indicating that there is likely a relationship between octane and pasture-finishing. Additionally, NZ samples had greater ($P < 0.05$) concentrations of butyrolactone, 2-pentylfuran, and acetic acid than samples from all other treatments. In a review by Resconi et al. (2013), it was stated that lactones in general are a product of oxidation of fatty acids in the rumen and may be increased in grain-fed animals but that butyrolactone predominates in forage-fed cattle. Increased 2-pentylfuran in NZ samples disagrees with the findings of Elmore et al. (2004), though others have cited 2-pentylfuran as contributing to green flavors often associated with pasture-fed beef (Calkins and Hodgen, 2007). Carboxylic acids are commonly increased with increased concentration of polyunsaturated fatty acids and may also be related to chemical breakdown associated with aging (Mottram, 1998). While present, differences in acetic acid may be minimized by the much greater concentration of other carboxylic acids, including butanoic and nonanoic acids, produced by all treatments, as butanoic acid has been shown to influence beef flavor with a weak correlation to overall liking when present in small concentrations, but the production of a strong, unpleasant odor when concentrations

Table 13. Least squares means of Maillard-derived volatile compounds of steaks from the *M. longissimus lumborum* of New Zealand grass-fed cattle and cattle fed high-concentrate diets for variable time periods prior to forage-finishing

	Treatment[1]						
Volatile compound	NZ	0D	40D	80D	120D	SEM[2]	P- values[3]
Strecker aldehydes							
Acetaldehyde	11.03	9.53	11.18	9.76	9.90	1.021	0.66
2-Methyl butanal	1.80	1.10	3.24	1.12	1.33	0.589	0.08
3-Methyl butanal	1.90	1.51	3.03	1.46	1.87	0.445	0.13
Methional	1.56	0.95	1.75	0.92	1.29	0.263	0.13
Benzaldehyde	31.06^{a}	21.99^{b}	26.32^{ab}	22.93^{b}	21.06^{b}	2.552	0.03
Phenylacetaldehyde	2.69	1.89	3.41	1.84	2.54	0.467	0.15
Isobutyraldehyde	24.92	18.77	33.68	18.85	19.10	4.477	0.10
Ketones							
2,3-Butanedione	136.66^{a}	31.36^{b}	8.81^{b}	29.47^{b}	25.40^{b}	10.111	<0.01
3-Hydroxy-2-butanone	151.63^{a}	30.96^{b}	3.32^{b}	28.12^{b}	24.71^{b}	12.449	<0.01
Sulfur-containing							
Carbon disulfide	5.61	5.31	6.90	5.36	5.54	0.972	0.78
Dimethyl sulfide	1.41	1.28	1.39	1.26	0.85	0.211	0.27
Dimethyl disulfide	0.11	0.09	0.18	0.12	0.10	0.048	0.68
Dimethyl sulfone	1.49^{b}	8.52^{a}	13.61^{a}	8.57^{a}	9.14^{a}	2.218	<0.01
Thiols							
Methanethiol	7.52	4.95	7.89	5.76	5.56	1.018	0.16
Pyrazines							
Methyl-pyrazine	0.39	0.09	0.54	0.17	0.15	0.174	0.32
2,5-Dimethyl pyrazine	0.88	0.23	1.14	0.37	0.35	0.350	0.28
Trimethylpyrazine	0.35	0.06	0.32	0.11	0.09	0.132	0.32
3-Ethyl-2,5-dimethylpyrazine	0.50	0.20	0.69	0.25	0.27	0.181	0.29

$^{a–d}$Means within a row without a common superscript differ ($P < 0.05$).

[1]NZ: grass-fed beef imported from New Zealand; 0D: cattle consuming only forage; 40D: high-concentrate diet for 40 d prior to pasture-finishing; 80D: high-concentrate diet for 80 d prior to pasture-finishing; 120D: high-concentrate diet for 120 d prior to pasture-finishing.

[2]Largest standard error of the least squares means.

[3]*P*- values < 0.05 considered significant.

are high (Gredell et al., 2018). Increased acetic acid and butyrolactone in beef from NZ may be resultant of differences in forage types. It has been discussed that increased antioxidants in forages may prevent pasture-fed beef from being more prone to lipid oxidation than grain-fed beef despite increased concentrations of polyunsaturated fatty acids (Wood and Enser, 1997). However, our results indicate that oxidative products varied similarly to changes in fatty acid concentration with changes in diet. Many aldehydes, lactones, hydrocarbons, furans, and ketones are generally associated with undesirable and rancid off-flavors, though they typically require higher concentrations to be detected due to higher odor thresholds (Mottram, 1998).

Fewer differences were present for Maillard-derived volatile compounds, which are reported in Table 13. Differences in Maillard-derived products were more consistent among treatments than lipid-derived products, indicating that specific differences in type or availability of amino acids and/or reducing sugars were present in the food system among treatments. Beef from NZ produced the greatest ($P < 0.05$) amount of benzaldehyde and both Maillard-ketones evaluated (2,3-butanedione, 3-hydroxy-2-butanone) and the least ($P < 0.05$) amount of dimethyl sulfone compared to beef from all other treatments. Lack of difference among treatments from experimental treatment groups finished on United States southeastern pastures indicates that differences are likely the result of regional forage differences rather than differences in exposure to grain-based diets. Non-enzymatic browning-derived ketones are associated with positive flavor descriptors (Calkins and Hodgen, 2007; Kerth and Miller, 2015) and overall flavor desirability (O'Quinn et al., 2016) and may be responsible for the increased flavor liking scores in NZ beef compared to beef from other treatments despite increases in oxidative compounds such as hexanal. Melton (1990) reported that 3-hydroxy-

2-butanone (acetoin) was decreased with increased days on feed; conversely, O'Quinn et al. (2016) reported greater concentrations of acetoin with beef from cattle finished on grain. Samples from NZ had greater ($P < 0.05$) concentrations of 3-hydroxy-2-butanone than samples from other treatments. However, samples from 0D were similar ($P > 0.05$) to those from other treatments, indicating that there is some role of forage type and regional differences in production of this compound. As days on feed are increased, glucose and glucose-6-phosphate are typically increased in muscle tissue, contributing to production of volatile compounds which depend on these reducing sugars as precursors (Koutsidis et al., 2008). Pyrazines, heterocyclic compounds produced through the interaction of free amino acids and Maillard reaction products and typically associated with roasted flavors, beef flavor, and beef flavor intensity, as well as overall liking and flavor liking (Mottram, 1998; Gredell et al., 2018), did not differ ($P > 0.28$) in the present study. Gredell et al. (2018) reported that pyrazine concentrations were positively correlated to percent fat, and therefore, lack of differences in the present study may be consequential of the level of fat being controlled across treatments. Additionally, overall pyrazine concentration may have been decreased in all treatments by a greater overall concentration of lipid oxidation products, as previously reported by Mottram and Edwards (1983). Overall, lipid-derived volatile compounds varied similarly to the corresponding changes in fatty acids among treatments, indicating that diet and early exposure to grain-based diets is responsible for some variation in consumer perception of pasture-finished beef.

Conclusion

A system involving early exposure to grain for 120 d prior to pasture-finishing could be used to produce beef of similar palatability to New Zealand pasture-finished beef in the United States. However, while palatability was similar, differences in chemical properties were still evident. Maintaining a high plane of nutrition is the key contributor to palatability when cattle are finished to an equal final body weight. However, by finishing cattle to an equal endpoint body weight and controlling for intramuscular fat, large and broad conclusions about the system may be limited. Based on palatability and chemical characteristics, a system of early exposure to a high-concentrate diet post-weaning may be plausible for producers to maximize use of available resources to produce high-quality pasture-finished beef by supplementing cattle with grain during seasonal periods of low pasture quality prior to finishing cattle on pastures during seasonal periods of high quality. On a more global scale, however, pasture-finished beef from countries which specialize in that production system out-perform domestic pasture-finished beef even with early grain feeding. Therefore, a trade situation focused on specialization is most beneficial to producers in both markets.

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