Lipid Content and Composition of Wagyu and Domestic Breeds of Beef

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The influence of beef source and cooking method on neutral (NL) and polar (PL) lipid contents, fatty acid profiles, and cholesterol contents of Wagyu and domestic sources of beef was determined. Longissimus dorsi muscle from Japanese Wagyu, American Wagyu, Longhorn, Angus, and U.S. Choice was boiled or roasted. Beef from Wagyu breeds had a significantly higher ($P < 0.05$) NL content than that of domestic sources. The NL from Japanese Wagyu samples was lower in saturated fatty acid content and higher in monounsaturated fatty acid content than samples from other beef sources. The PL from the Japanese Wagyu had the lowest content of saturated fatty acids, while the PL from the American Wagyu had the highest content of monounsaturated fatty acids and the lowest content of polyunsaturated fatty acids. Cholesterol content was highest for the Wagyu breeds. The contents of total NL and individual fatty acids were significantly ($P < 0.05$) higher in the roasted beef than boiled beef. Cooking method did not have a significant effect on the PL content, PL fatty acid profiles, and cholesterol content.

Keywords: *Lipids; beef; breeds; fatty acids; beef cattle*

INTRODUCTION

Japanese Wagyu beef is noted for its extensive marbling and minimal backfat which contributes to its characteristic taste and tenderness. These desirable attributes are especially apparent when the beef is cooked in the traditional Japanese style of boiling, known as shabu-shabu (Jussaume et al., 1990). Busboom et al. (1993) showed that the Japanese Wagyu beef, prepared as shabu-shabu or steaks, was superior in palatability when compared with Angus, Longhorn, and U.S. Choice beef. In addition to the superior palatability characteristics, Wagyu beef also has significantly higher ratios of monounsaturated (MUFA) to saturated (SFA) fatty acids than does beef from domestic sources (Sturdivant et al., 1992). Consumption of higher levels of MUFA, in conjunction with reduced levels of saturated fatty acids, is believed to prevent increases in blood cholesterol levels and, in the case of oleate, to possibly lower blood cholesterol (National Research Council, 1988).

Emphasis has been placed on production of higher quality beef carcasses for the Japanese market since the liberalization of that market on April 1, 1991. To be successful in the Japanese market, the beef must meet the high quality, in terms of texture and flavor characteristics, demanded by the Japanese consumer (Jussaume et al., 1990; Nelson et al., 1990). In the Japanese market, Wagyu beef exclusively holds the top range market price (Nelson et al., 1990), while imported U.S. Choice, grain-fed beef command only a middle range market price (Lunt, 1991).

The unique characteristics of Wagyu beef have generated interest in developing beef products that fit the Japanese criteria for beef through incorporating Japanese Wagyu beef cattle genetics and Japanese feeding practices into the U.S. beef production system. Thus far, the research has focused on growth and carcass characteristics (Johnson et al., 1991; Lunt et al., 1993) and lipid composition of raw muscle and subcutaneous fat (Sturdivant et al., 1992; May et al., 1993). The objectives of this study were to determine the influence of beef source and cooking method on the lipid content and composition of beef. Meat from five sources, Japanese Wagyu, American Wagyu, Angus, Longhorn, and U.S. Choice beef, and two cooking methods, boiling and roasting, were compared in this study.

MATERIALS AND METHODS

Beef. American Wagyu (AW), Angus (A), and Longhorn (LH) cattle were raised at Washington State University, Department of Animal Sciences, as part of a feeding trial to evaluate the growth, feed efficiency, and final carcass characteristics of the three breeds. American Wagyu cattle were crossbreeds from purebred Wagyu and consisted of one 82.5% purebred Wagyu and two 75% purebred Wagyu cattle. Cattle were grouped by weight and fed a ration that consisted of ammoniated wheat straw, rolled barley, dehydrated alfalfa, and cracked corn for 524 days, typical of Japanese feeding practices (Busboom et al., 1993).

Boneless loin sections were removed from the carcasses at 3 days postmortem, vacuum packaged, and aged at 0 °C for 10 days (Busboom et al., 1993). Loin sections from Japanese Black Wagyu (JW) and U.S. Choice (CH) were obtained from commercial sources for comparison. Loin sections were stored at −35 °C until analyzed. Steaks from four animals for Angus, Longhorn, and U.S. Choice and from three animals for Japanese Wagyu and American Wagyu were analyzed for lipid content and composition.

Cooking Treatments. Two cooking treatments, roasting and boiling, were compared. Steaks (2.5 cm thick) were roasted in a 175 °C oven to an internal temperature of 70 °C. Boiled beef was sliced into 3 mm thick slices and cooked in boiling water for 60 s.

Reagents and Chemicals. All reagents and chemicals used were of analytical grade. Chloroform and methanol were redistilled in glass prior to use.

Extraction and Fractionation. Lipids were extracted from the cooked beef tissue and separated into neutral (NL)

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and polar (PL) lipid fractions using the dry column method of Marmer and Maxwell (1981). Lipid contents were determined by evaporating aliquots (NL, 1.0 mL; PL, 2.0 mL) of the lipid extracts to a constant weight under a stream of nitrogen. All lipid extracts were stored at −26 °C.

Fatty Acid Composition. Fatty acid methyl esters (FAME) of neutral and polar lipid extracts were prepared with boron trifluoride–methanol reagent (Supelco, Inc., Bellefonte, PA; Morrison and Smith, 1964). FAME were separated on an Omegawax 320 fused silica capillary column (30 m, 0.32 mm i.d., 0.25 μm film thickness, Supelco) installed in a gas chromatograph (Varian, Model 3400, Walnut Creek, CA) equipped with a flame ionization detector. The oven temperature program was 160 °C for 8 min, increased to 200 °C at 2 °C/min, and held for 12 min. Samples (1.0 μL) were injected into a split injection port with a 25:1 split ratio. Flow rates were as follows: He carrier, 2.5 mL/min; He makeup, 25 mL/min; compressed air, 25 mL/min; and H_2, 30 mL/min. Injector and detector temperatures were set at 200 and 250 °C, respectively.

FAME were identified on the basis of retention times, in comparison with an external standard (PUFA No. 2 Standard, Supelco). Fatty acid contents (milligrams of FA per 100 g of cooked beef) were calculated by multiplying the amount of the NL or PL fraction (grams of lipid per 100 g of cooked beef) by the percentage of the individual fatty acids present (based on peak area).

Cholesterol Content. Neutral lipids (100 mg) and stigmasterol (internal standard, 5 μg) were saponified, with aqueous KOH in ethanol, to extract cholesterol (Tercyak, 1991). Cholesterol was quantified using a polydimethylsiloxane capillary column (Econocap SE-30, 30 m, 0.32 mm i.d., 0.25 μm film thickness, Alltech Associates Inc., Deerfield, IL) installed in a gas chromatograph (Varian, Model 3400) equipped with a flame ionization detector. The oven temperature was held isothermally at 270 °C for 15 min. Samples (1.0 μL) were injected into a split injection port with a 20:1 split ratio. Flow rates of carrier and detector gases were as for the FAME analysis. Injector and detector temperatures were set at 275 and 300 °C, respectively.

Standard curves for cholesterol and stigmasterol were prepared for quantification of cholesterol in the lipid extracts. Cholesterol content of samples was determined on the basis of recovery of the internal standard, stigmasterol.

Moisture Content. Moisture content was determined by drying cooked beef samples (5.0 g) in a drying oven (TempCon, Baxter Scientific Products, McGaw Park, IL) at 100 °C for 16 h.

Statistical Analysis. The study was designed as a two-way factorial, with beef source and cooking method as the main factors. Individual animals within each beef source were treated as nested variables, with the error term, Animal-(Breed), used to test for beef source effects. Analysis of variance and least-squares means were used to determine the influence of beef source, cooking method, and the interactions between these factors on the content of the lipid constituents (SAS Institute, 1987). The experiment was replicated two times, with duplicate FAME and cholesterol analyses for each lipid extract.

RESULTS AND DISCUSSION

Interactions between breed and cooking method were not significant ($P > 0.05$); therefore, the data for these two main factors were pooled for evaluation of statistical significance. The effects of breed and cooking method on lipid content and composition will be discussed separately.

Beef Source. Neutral lipid (NL) contents of the five breeds of beef ranged from 9.5 g/100 g of tissue in U.S. Choice to 23.9 g/100 g of tissue in American Wagyu (Table 1). Wagyu breeds (AW and JW) had higher NL and, as a result, higher total lipid content than the other three beef sources. Among the experimental animals,

Table 1. Neutral, Polar, and Total Lipid Contents[a] of Cooked Beef

cooking method	beef source	neutral mean	neutral SE	polar mean	polar SE	total mean	total SE
boiled	Angus	13.4	1.4	1.04	0.08	14.4	1.4
	A. Wagyu	21.5	1.6	1.02	0.09	22.6	1.6
	Longhorn	12.8	1.4	1.12	0.08	13.9	1.4
	J. Wagyu	22.3	1.6	1.06	0.09	23.4	1.6
	U.S. Choice	8.0	1.4	1.24	0.08	9.2	1.4
	mean[b]	15.6[d]	0.7	1.10[c]	0.04	16.7[d]	0.7
roasted	Angus	17.4	1.4	1.14	0.08	18.6	1.4
	A. Wagyu	26.3	1.6	0.99	0.09	27.3	1.6
	Longhorn	14.5	1.4	1.09	0.08	15.6	1.4
	J. Wagyu	24.7	1.6	1.01	0.09	25.8	1.6
	U.S. Choice	11.0	1.4	1.31	0.08	12.3	1.4
	mean[b]	18.8[c]	0.7	1.11[c]	0.04	19.9[c]	0.7
mean[b]	Angus	15.4[f]	1.0	1.09[f]	0.04	16.5[f]	1.0
	A. Wagyu	23.9[e]	1.2	1.01[f]	0.05	24.9[e]	1.2
	Longhorn	13.6[f]	1.0	1.10[f]	0.04	14.8[f]	1.0
	J. Wagyu	23.5[e]	1.2	1.03[f]	0.05	24.6[e]	1.2
	U.S. Choice	9.5[g]	1.0	1.27[e]	0.04	10.8[g]	1.0

[a] g/100 g of cooked weight. [b] Interactions between beef source and cooking method were not significant ($P > 0.05$). Data were pooled to determine the effects of beef source and cooking method on lipid content. [c,d] Means for cooking method treatments with the same superscript are not significantly different ($P > 0.05$). [e–g] Means for beef source treatments with the same superscript are not significantly different ($P > 0.05$).

the NL content of American Wagyu was significantly higher ($P < 0.05$) than that of Angus and Longhorn. Lunt et al. (1993) also observed that strip steaks from American Wagyu beef had significantly higher fat (ether extractable) content than Angus. The influence of beef source on the NL content of group-fed animals has been demonstrated not only in the comparison of Wagyu and domestic sources of beef (Lunt et al., 1993) but also in the comparison of muscle from Bison, Hereford, and Brahman steers (Larick et al., 1989). Higher neutral and total lipid contents of the Wagyu breeds have been attributed to the greater propensity of this breed to lay down intramuscular fat (Nelson et al., 1990; Lunt et al., 1993).

Polar lipids (PL) account for a minor fraction of lipid in beef, with contents ranging from 1.0 g/100 g of tissue in the Wagyu cattle to 1.3 g/100 g of tissue in U.S. Choice (Table 1). PL values of approximately 1% (w/w) are similar to those measured in cooked beef by Igene et al. (1979). Polar lipid content was not significantly different ($P > 0.05$) among beef sources with the exception of U.S. Choice. The difference in PL content could be due to differences in feeding regimens. The Angus, American Wagyu, and Longhorn steers were fed following a regimen typical of Japanese cattle feeders, which is almost twice as long as U.S. cattle feeding (Johnson et al., 1991; Cameron et al., 1993). Differences in time on feed and finishing weights of the Japanese Wagyu and experimental steers in comparison to the U.S. Choice steers could contribute to the observed differences in the polar lipid content of the beef sources.

Beef source had a significant influence on the fatty acid content of the NL fraction (Table 2). Japanese Wagyu had a consistently higher content of unsaturated fatty acids when compared to the other breeds, with the exception of American Wagyu. In comparing the fatty acid content of Angus and American Wagyu beef, May et al. (1993) observed the Wagyu breeds to have a significantly higher ($P < 0.05$) content of unsaturated

Table 2. Fatty Acid Content[a] of Neutral Lipid Fraction of Cooked Meat

cooking method	beef source	C14:0		C14:1		C16:0		C16:1		C18:0		C18:1ω9		C18:1ω7		C18:2		C18:3	
		mean	SE	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE
boiled	Angus	322.0	35.8	76.3	18.2	4115.5	391.5	580.1	81.0	1206.0	132.6	6710.6	726.2	211.8	93.7	129.7	18.5	18.2	3.4
	A. Wagyu	519.1	41.3	240.1	21.0	6453.4	452.1	1213.3	93.6	1311.5	153.1	11320.9	838.5	396.8	108.2	155.7	21.4	8.1	3.9
	Longhorn	321.7	35.8	164.7	18.2	3624.0	391.5	904.0	81.0	817.5	132.6	6514.5	726.2	363.7	93.7	98.5	18.5	10.8	3.4
	J. Wagyu	359.5	41.3	169.2	21.0	5231.2	452.1	1223.3	93.6	1524.6	153.1	12925.2	838.5	635.5	108.2	323.1	21.4	9.3	3.9
	U.S. Choice	203.7	35.8	56.2	18.2	2240.8	391.5	377.2	81.0	726.8	132.6	3892.3	726.2	386.3	93.7	93.7	18.5	14.0	3.4
	mean	345.2[d]	17.1	141.3[d]	8.7	4333.0[d]	186.4	859.6[d]	38.6	1117.3[d]	63.1	8272.7[d]	345.7	398.8[e]	44.6	160.1[d]	8.8	12.1[d]	1.6
roasted	Angus	459.6	35.8	131.8	18.2	5467.2	391.5	807.8	81.0	1577.8	132.6	8532.9	726.2	284.1	93.7	161.5	18.5	23.0	3.4
	A. Wagyu	703.2	41.3	320.8	21.0	7933.8	452.1	1500.6	93.6	1737.3	153.1	13278.2	838.5	656.0	108.2	201.0	21.4	26.1	3.9
	Longhorn	369.5	35.8	199.1	18.2	4042.0	391.5	1079.7	81.0	873.9	132.6	7299.9	726.2	493.4	93.7	111.1	18.5	9.6	3.4
	J. Wagyu	409.6	41.3	179.5	21.0	5674.1	452.1	1237.6	93.6	1755.3	153.1	14581.7	838.5	540.5	108.2	356.1	21.4	12.7	3.9
	U.S. Choice	290.4	35.8	56.2	18.2	3118.5	391.5	482.0	81.0	1066.5	132.6	5256.8	726.2	555.5	93.7	131.4	18.5	19.0	3.4
	mean[b]	446.5[c]	17.1	181.5[c]	8.7	5247.1[c]	186.4	1021.6[c]	38.6	1402.2[c]	63.1	9788.7[c]	345.7	505.9[c]	44.6	192.2[c]	8.8	18.1[c]	1.6
mean[b]	Angus	390.8[f]	55.0	104.0[f,g]	28.3	4791.4[f]	282.4	693.9[g]	72.4	1391.9[g]	98.0	7621.8[f]	642.2	248.0[g]	105.3	145.6[f,g]	17.9	20.6[g]	4.0
	A. Wagyu	611.1[e]	63.5	280.4[e]	32.7	7193.6[e]	326.1	1356.9[e]	83.6	1524.4[e]	113.1	12299.6[e]	741.6	526.4[e]	121.6	178.4[f]	20.6	17.1[e]	4.6
	Longhorn	345.6[f]	55.0	181.9[f]	28.3	3833.0[g]	282.4	991.9[f]	72.4	845.7[f]	98.0	6907.2[f]	642.2	428.5[e]	105.3	104.8[g]	17.9	10.2[g]	4.0
	J. Wagyu	384.6[f]	63.5	174.3[f]	32.7	5452.6[f]	326.1	1230.5[e,f]	83.6	1639.9[e]	113.1	13753.4[e]	741.6	588.0[e]	121.6	339.6[e]	20.6	11.0[g]	4.6
	U.S. Choice	247.1[f]	55.0	66.3[g]	28.3	2679.6[h]	282.4	429.6[h]	72.4	896.7[f]	98.0	4571.6[g]	642.2	470.9[e]	105.3	112.5[f]	17.9	16.5[e]	4.0

[a] mg/100 g of cooked weight. [b] Interactions between beef source and cooking method were not significant ($P > 0.05$). Data were pooled to determine the effects of beef source and cooking method on fatty acid content. [c,d] Means for cooking method treatments with the same superscript are not significantly different ($P > 0.05$). [e–h] Means for beef source treatments with the same superscript are not significantly different ($P > 0.05$).

fatty acids and a significantly lower ($P < 0.05$) content of saturated fatty acids in subcutaneous and intramuscular adipose tissue. These researchers did not detect significant differences in the content of the major fatty acids of the M. longissimus dorsi muscle. Among the experimental animals, NL unsaturated fatty acid contents (myristoleic, 14:1; palmitoleic, 16:1; and oleic, 18:1ω9) were significantly higher ($P < 0.05$) in American Wagyu than in Angus or Longhorn. Palmitic acid (16:0) content was significantly higher ($P < 0.05$) in American Wagyu than in either Longhorn or Angus. The content of palmitic acid was highest in American Wagyu and lower in Longhorn and U.S. Choice, with the palmitic acid content of Angus and Japanese Wagyu beef not significantly different ($P > 0.05$). Japanese Wagyu, American Wagyu, and Angus had significantly higher contents of stearic acid than either Longhorn or U.S. Choice.

The distribution of the NL fatty acids, as expressed as a percentage of lipid, shows the Japanese Wagyu beef to have significantly lower percentages of palmitic acid than the other beef sources (Table 3). In addition, the percentage of oleic acid was significantly higher in the Japanese Wagyu than in the other four sources. The American Wagyu steers had a greater propensity to lay down fat than the Longhorn and Angus steers: however, the percentages of palmitic and oleic acids were not different for these three breeds. Similar results have been observed by Smith et al. (1990) in the comparison of Japanese Wagyu and domestic U.S. sources. Larick et al. (1989) have also demonstrated the influence of genetics on the neutral lipid fatty acid composition of Bison, Hereford, and Brahman steers. Increased absorption of dietary fatty acids and elevated activity of stearoyl-CoA desaturase within adipose tissue have been proposed as factors contributing to the higher content of monounsaturated fatty acids in the adipose of Wagyu breeds (Sturdivant et al., 1992). Although the increased ratio of monounsaturated fatty acids to saturated fatty acids in the Japanese Wagyu beef is desirable from a nutritional viewpoint, it is also important to recognize that the contents of palmitic and oleic acids are higher than for the Angus, Longhorn, and U.S. Choice beef steaks because of the significantly higher lipid content of the Wagyu breeds.

The fatty acid content of the PL fraction of the five sources was not as variable as was the NL fraction (Table 4). Contents of palmitic, stearic, and linoleic acids were higher in the U.S. Choice samples than in the other beef sources. These differences are attributed, in part, to the higher PL content of U.S. Choice beef. For the other major fatty acids, American Wagyu had the highest content of oleic acid, Japanese Wagyu and U.S. Choice had the highest content of linoleic acid, and Angus and Japanese Wagyu had the highest content of arachidonic acid (20:4). Among the experimental animals, oleic acid content (milligrams per 100 g of tissue) in American Wagyu was significantly higher ($P < 0.05$) than that of Longhorn. Larick et al. (1989) attributed the observed genetic differences in fatty acid profiles of the major phospholipid components of Bison, Hereford, and Brahman steers fed the same diets to the incorporation of different amounts of endogenously produced fatty acids.

During the preparation of fatty acid methyl esters of the polar lipid fraction, dimethylacetal (DMA) derivatives are also formed from plasmalogens, which are naturally occurring constituents of animal lipids (Crack-

Table 3. Fatty Acid Distribution[a] of Neutral Lipid Fraction of Cooked Beef

cooking method	beef source	C14:0		C14:1		C16:0		C16:1		C18:0		C18:1ω9		C18:1ω7		C18:2		C18:3	
		mean	SE	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE
boiled	Angus	2.45	0.09	0.56	0.06	30.83	0.39	4.41	0.17	8.76	0.32	50.25	0.76	1.60	0.41	1.00	0.06	0.14	0.02
	A. Wagyu	2.41	0.11	1.13	0.06	29.89	0.45	5.66	0.20	5.93	0.37	52.78	0.87	1.84	0.47	0.72	0.07	0.03	0.02
	Longhorn	2.46	0.09	1.24	0.06	28.03	0.39	7.09	0.17	6.37	0.32	51.12	0.76	2.84	0.41	0.76	0.06	0.09	0.02
	J. Wagyu	1.61	0.11	0.76	0.06	23.49	0.45	5.48	0.20	6.88	0.37	57.78	0.87	2.82	0.47	1.43	0.07	0.04	0.02
	U.S. Choice	2.49	0.09	0.66	0.06	28.18	0.39	4.69	0.17	9.46	0.32	49.08	0.76	4.19	0.41	1.08	0.06	0.16	0.02
	mean[b]	2.28[d]	0.04	0.87[c]	0.03	28.09[c]	0.19	5.47[c]	0.08	7.48[c]	0.15	52.20[d]	0.36	2.66[c]	0.19	1.00[c]	0.03	0.09[c]	0.01
roasted	Angus	2.62	0.09	0.75	0.06	31.37	0.39	4.62	0.17	9.05	0.32	48.92	0.76	1.62	0.41	0.93	0.06	0.13	0.02
	A. Wagyu	2.69	0.11	1.20	0.06	30.34	0.45	5.68	0.20	6.72	0.37	50.26	0.87	2.50	0.47	0.76	0.07	0.10	0.02
	Longhorn	2.50	0.09	1.32	0.06	27.65	0.39	7.39	0.17	6.09	0.32	50.94	0.76	3.29	0.41	0.76	0.06	0.06	0.02
	J. Wagyu	1.68	0.11	0.74	0.06	23.06	0.45	5.08	0.20	7.02	0.37	58.71	0.87	2.22	0.47	1.44	0.07	0.05	0.02
	U.S. Choice	2.79	0.09	0.67	0.06	29.11	0.39	4.55	0.17	10.14	0.32	46.70	0.76	4.66	0.41	1.20	0.06	0.19	0.02
	mean[b]	2.45[c]	0.04	0.94[c]	0.03	28.30[c]	0.19	5.46[c]	0.08	7.80[c]	0.15	51.10[c]	0.36	2.83[c]	0.19	1.02[c]	0.03	0.11[c]	0.01
mean[b]	Angus	2.53[e]	0.30	0.65[f]	0.16	31.10[e]	0.84	4.52[f]	0.41	8.91[e]	0.55	49.58[f]	1.47	1.61[f]	0.65	0.97[f,g]	0.12	0.13[e,f]	0.03
	A. Wagyu	2.55[e]	0.35	1.17[e,f]	0.18	30.11[e,f]	0.96	5.67[f]	0.47	6.32[f]	0.64	51.52[f]	1.70	2.08[f]	0.75	0.74[g]	0.14	0.07[f]	0.03
	Longhorn	2.48[e]	0.30	1.28[e]	0.16	27.84[f]	0.84	7.24[e]	0.41	6.23[f]	0.55	51.03[f]	1.47	3.07[e,f]	0.65	0.76[g]	0.12	0.07[f]	0.03
	J. Wagyu	1.65[e]	0.35	0.75[f]	0.18	23.28[g]	0.96	5.28[f]	0.47	6.95[f]	0.64	58.24[e]	1.70	2.52[e,f]	0.75	1.43[e]	0.14	0.05[f]	0.03
	U.S. Choice	2.64[e]	0.30	0.67[f]	0.16	28.65[e,f]	0.84	4.62[f]	0.41	9.80[e]	0.55	47.89[f]	1.47	4.43[e]	0.65	1.14[e,f]	0.12	0.18[e]	0.03

[a] Percent of total fatty acids. [b] Interactions between beef source and cooking method were not significant ($P > 0.05$). Data were pooled to determine the effects of beef source and cooking method on fatty acid content. [c,d] Means for cooking method treatments with the same superscript are not significantly different ($P > 0.05$). [e–g] Means for beef source treatments with the same superscript are not significantly different ($P > 0.05$).

Table 4. Fatty Acid Content[a] of Polar Lipid Fraction of Cooked Meat

cooking method	beef source	C14:0		C16:0		C16:1		C18:0		C18:1ω9		C18:1ω7		C18:2		C18:3		C20:4		C16:0 DMA[b]		C18:0 DMA[b]	
		mean	SE	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE	mean	SE
boiled	Angus	0.7	0.6	189.1	14.0	22.3	2.2	75.8	8.5	187.9	25.6	9.9	3.1	90.5	14.6	1.0	0.6	42.6	5.3	141.6	11.3	76.0	5.8
	A. Wagyu	0.6	0.7	184.4	16.1	27.8	2.5	79.6	9.8	211.0	29.6	13.9	3.6	78.3	16.9	0.0	0.7	34.0	6.1	141.8	13.0	64.2	6.7
	Longhorn	1.2	0.6	210.4	14.0	32.6	2.2	72.6	8.5	193.3	25.6	16.2	3.1	91.4	14.6	1.0	0.6	32.3	5.3	153.8	11.3	75.2	5.8
	J. Wagyu	0.0	0.7	168.1	16.1	20.6	2.5	77.8	9.8	204.0	29.6	24.1	3.6	153.4	16.9	0.0	0.7	47.6	6.1	147.5	13.0	68.3	6.7
	U.S. Choice	1.0	0.6	221.9	14.0	25.8	2.2	91.1	8.5	168.2	25.6	25.7	3.1	144.7	14.6	4.7	0.6	43.0	5.3	163.8	11.3	72.9	5.8
	mean[c]	0.7[d]	0.3	194.8[d]	6.7	25.8[d]	1.0	79.4[d]	4.1	192.9[e]	12.2	18.0[e]	1.5	111.7[e]	7.0	1.4[d]	0.3	39.9[e]	2.5	149.7[d]	5.4	71.3[d]	2.8
roasted	Angus	0.3	0.6	203.5	14.0	23.7	2.2	93.4	8.5	479.7	25.6	27.1	3.1	222.1	14.6	1.3	0.6	106.0	5.3	151.9	11.3	84.5	5.8
	A. Wagyu	0.7	0.7	191.3	16.1	27.8	2.5	81.6	9.8	572.8	29.6	33.8	3.6	182.4	16.9	0.0	0.7	87.8	6.1	131.8	13.0	57.5	6.7
	Longhorn	1.9	0.6	193.3	14.0	29.7	2.2	78.1	8.5	442.6	25.6	37.6	3.1	213.3	14.6	3.9	0.6	75.1	5.3	135.1	11.3	68.1	5.8
	J. Wagyu	0.0	0.7	165.6	16.1	19.9	2.5	83.9	9.8	426.7	29.6	50.3	3.6	304.7	16.9	0.0	0.7	98.5	6.1	135.7	13.0	62.5	6.7
	U.S. Choice	0.3	0.6	241.2	14.0	28.0	2.2	111.4	8.5	328.5	25.6	56.9	3.1	298.2	14.6	4.5	0.6	87.8	5.3	185.6	11.3	77.7	5.8
	mean[c]	0.6[d]	0.3	199.0[d]	6.7	25.8[d]	1.0	89.7[d]	4.1	450.1[d]	12.2	41.1[d]	1.5	244.1[d]	7.0	1.9[d]	0.3	91.0[d]	2.5	148.0[d]	5.4	70.1[d]	2.8
mean[c]	Angus	0.5[f,g]	0.4	196.3[g]	9.9	23.0[f,g]	1.5	84.6[f,g]	6.0	333.8[f,g]	18.1	18.5[h]	2.2	156.3[g]	10.4	1.2[g]	0.4	74.3[f]	3.7	146.8[g]	8.0	80.2[f]	4.1
	A. Wagyu	0.6[f,g]	0.5	187.9[g]	11.4	27.8[f,g]	1.8	80.6[g]	6.9	391.9[f]	20.9	23.9[g,h]	2.6	130.4[g]	12.0	0.2[g]	0.5	60.9[g,h]	4.3	136.8[g]	9.2	60.8[h]	4.8
	Longhorn	1.5[f]	0.4	201.9[f,g]	9.9	31.2[f]	1.5	75.4[g]	6.0	318.0[g]	18.1	26.9[f,g]	2.2	152.3[g]	10.4	2.5[f,g]	0.4	53.7[h]	3.7	144.5[g]	8.0	71.6[f,g]	4.1
	J. Wagyu	0.0[g]	0.5	166.8[g]	11.4	20.2[g]	1.8	80.9[g]	6.9	315.4[g,h]	20.9	37.2[f,g]	2.6	229.1[f]	12.0	0.0[g]	0.5	73.0[f]	4.3	141.6[g]	9.2	65.4[g,h]	4.8
	U.S. Choice	0.6[f,g]	0.4	231.6[f]	9.9	26.9[f,g]	1.5	101.2[f]	6.0	248.3[h]	18.1	41.3[f]	2.2	221.4[f]	10.4	4.6[f]	0.4	65.4[f,g]	3.7	174.7[f]	8.0	75.3[f]	4.1

[a] mg/100 g of cooked weight. [b] DMA, dimethyl acetal derivative of fatty acid. [c] Interactions between beef source and cooking method were not significant ($P > 0.05$). Data were pooled to determine the effects of beef source and cooking method on fatty acid content. [d,e] Means for cooking method treatments with the same superscript are not significantly different ($P > 0.05$). [f–h] Means for beef source treatments with the same superscript are not significantly different ($P > 0.05$).

Table 5. Cholesterol Content of Cooked Beef

cooking method	beef source	sample basis[a] mean	sample basis[a] SE	lipid basis[b] mean	lipid basis[b] SE
boiled	Angus	49.7	4.2	364.5	57.8
	A. Wagyu	65.6	4.9	309.2	66.8
	Longhorn	55.4	4.2	446.8	57.8
	J. Wagyu	70.6	4.9	316.8	66.8
	U.S. Choice	57.4	4.2	814.9	57.8
	mean[c]	59.8[d]	2.1	450.4[d]	27.7
roasted	Angus	58.6	4.2	338.5	57.8
	A. Wagyu	67.5	4.9	258.6	66.8
	Longhorn	56.4	4.2	396.4	57.8
	J. Wagyu	65.7	4.9	272.9	66.8
	U.S. Choice	56.8	4.2	653.4	57.8
	mean[c]	61.0[d]	2.1	383.9[d]	27.7
mean[c]	Angus	54.2[g]	3.4	351.5[f,g]	41.5
	A. Wagyu	66.6[e,f]	3.9	283.9[g]	47.9
	Longhorn	55.9[f,g]	3.4	421.6[f]	41.5
	J. Wagyu	68.2[e]	3.9	294.8[f,g]	47.9
	U.S. Choice	57.1[e,f,g]	3.4	734.2[e]	41.5

[a] mg/100 g of cooked weight. [b] mg/100 g of lipid. [c] Interactions between beef source and cooking method were not significant ($P > 0.05$). Data were pooled to determine the effects of beef source and cooking method on cholesterol content. [d] Differences between cooking methods for cholesterol content were not significant ($P > 0.05$). [e–g] Means with the same superscript for beef source were not significantly different ($P > 0.05$).

el et al., 1988). The plasmalogens act in ion transport systems within animal tissues (Fogerty et al., 1991). In this research, dimethylacetal derivatives of 16- and 18-carbon chain lengths accounted for more than 1% of the components of the PL fraction (Table 4). Beef source did not significantly ($P > 0.05$) affect the C_{16} or C_{18} DMA contents, except in the case of U.S. Choice, which was significantly higher in C_{16} DMA than the other sources.

The cholesterol content of the beef tissue ranged from 54.2 mg/100 g of tissue in the Angus samples to 67.2 mg/100 g of tissue in the Japanese Wagyu samples (Table 5). Among the experimental animals, American Wagyu had a significantly higher cholesterol content than Angus. The cholesterol content follows the same trend as the neutral lipid content, with the Wagyu breeds having slightly higher amounts of cholesterol than the U.S. domestic sources, even among the experimental animals. Cholesterol content, when expressed as a function of lipid content, results in significantly different ($P < 0.05$) results for the different beef sources. The Wagyu breeds had a lower cholesterol content than the U.S. domestic sources. Among the experimental steers, the cholesterol content of American Wagyu beef was significantly lower ($P < 0.05$) than that of Longhorn, but not significantly different ($P > 0.05$) from the cholesterol content of the Angus beef. Kregel et al. (1986) also noted an inverse relationship between lipid content and cholesterol content, expressed on the basis of lipid content, of ground beef patties. The lower cholesterol content of the Wagyu breeds, as expressed on the basis of lipid content, may be attributed to greater losses of cholesterol in the drip of beef with high lipid contents (Kregel et al., 1986) and the higher cholesterol content of muscle, in comparison to intermuscular and subcutaneous fat, when compared on a lipid content basis (Rhee et al., 1982).

Cooking Methods. Cooking method significantly affected ($P < 0.05$) neutral lipid content but not polar lipid content of the samples (Table 1). Roasted samples had a significantly higher ($P < 0.05$) neutral lipid content than that of the boiled samples. The lower neutral lipid content in the boiled beef samples cannot be explained completely by the differences in moisture content of the boiled and roasted samples. The mean neutral lipid contents for the boiled and roasted beef samples, on a dry weight basis, were 27.5 and 30.9 g of lipid/100 g, respectively. The greater surface area of the boiled beef slices also contributes to greater loss of neutral lipid during cooking in comparison to the roasted beef.

The effect of cooking method on the fatty acid content of the NL and PL fractions is shown in Tables 2–4. The contents of the shorter chain fatty acids of the NL were significantly different ($P < 0.05$) depending on the cooking method. All NL fatty acid contents of boiled beef were significantly lower ($P < 0.05$) than those of roasted beef. This difference in fatty acid content was expected as a result of the lower total lipid content of boiled beef, as compared to roasted beef, as shown in Table 1. For the PL fraction, significant differences in fatty acid content were observed for the longer chain saturated fatty acids (Table 4). The contents of oleic, linoleic, and arachidonic acids of the boiled beef were all significantly lower ($P < 0.05$) than those of the roasted samples. This finding was attributed to the increased surface area of the boiled beef and, thus, a greater loss of unsaturated fatty acids from the tissue during cooking.

Cholesterol content was not significantly different ($P > 0.05$) between cooking methods, as expressed on a wet weight basis or lipid content basis (Table 5). The trend showing a higher cholesterol content, as expressed on a lipid content basis, for the boiled beef as compared to the roasted beef reflects the higher neutral and total lipid content of the roasted beef. Comparison of broiling, roasting, grilling, and microwave cooking of ground beef patties has shown no significant differences in cholesterol content as attributed to cooking method (Janicki and Appledorf, 1974; Ono et al., 1985)

Significant variability in the lipid content, fatty acid profiles, and cholesterol content of the Wagyu and domestic sources of beef was noted in this study. These differences in the lipid content and composition affect the flavor, texture, and nutritional quality of the beef. This research indicates that the genetic potential is available to the U.S. beef producer to provide beef of similar lipid content to the Japanese Wagyu. More research is needed to determine the possible advantages of using Wagyu genetics to produce changes in the fatty acid profiles of beef to improve nutritional value and consumer acceptability of beef.

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