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Sire variation in fatty acid composition of crossbred Wagyu steers and heifers

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Abstract

Effects of sires on lipid composition of subcutaneous adipose tissue and *longissimus dorsi* muscle were studied using 113 F_1 heifer and steer calves sired by eight Wagyu bulls out of three different cow herds. Wagyu sires were used and grouped as Old ($n=6$) and New ($n=2$) sires, respectively, based on the chronological order in which they were imported into the US. Animals were fed a backgrounding diet for 112 days consisting of an 80:20 ratio of roughage:concentrate, then grazed on orchard grass and bluegrass for 84 days, and finished on a 10:90 ratio of roughage:concentrate diet for 231 days in a feedlot. For *longissimus dorsi* muscle, progeny from Old sires had higher ($P<0.05$) monounsaturated to saturated fatty acid ratios (MUFA:SFA) than progeny of New sires. There were also differences ($P<0.05$) among individual sires for polyunsaturated to saturated fatty acid ratio (PUFA:SFA) (0.05–0.08) and MUFA:SFA (1.03–1.21). Progeny of Angus cows at Washington State University (WSU) had lower ($P<0.05$) MUFA:SFA and lower SFA than progeny of WSU crossbred and commercial cows. Steers had lower ($P<0.05$) MUFA:SFA and higher ($P<0.05$) SFA than heifers. For subcutaneous fat, heifers had higher levels ($P<0.05$) of linoleic acid (C18:2) and PUFA:SFA than the steers. Means for ether extractable fat in *longissimus dorsi* muscle differed among sires ($P<0.05$) and ranged from 7.58 to 13.13%. Progeny from WSU Angus cows had higher ($P<0.05$) ether extractable fat than WSU crossbred and commercial cows. Cholesterol content of *longissimus dorsi* muscle was not influenced by sire, cow herd or sex ($P>0.05$).

1. Introduction

The contribution of beef to dietary intake of cholesterol, monounsaturated (MUFA) and saturated fatty acids (SFA) is an important issue to consumers and consequently the meat industry (Mills, Comerford, Hollender, Harpster, House & Henning, 1992; Morgan et al., 1991; National Research Coucil [NRC], 1988). Dietary fatty acids are important because they provide calories and essential fatty acids and play a role as carriers of fat soluble vitamins (Dryden & Marchello, 1970; Larick & Turner, 1989, 1990; Waldman, Suess & Brungardt, 1968). Dietary fatty acids have been an issue of controversy because of their possible association with coronary heart disease (Nawar, 1985). A modern genetic approach to manipulating fatty acid profiles in cattle should be to select for individuals or breed types capable of transmitting to their descendants the ability to accumulate lipid with less palmitic and (or) more oleic and stearic acids because the latter have desirable effects in humans (Bonanome & Grundy, 1988; Grundy et al., 1982). A desirable beef product must be produced economically, and be highly tender, juicy and flavorful with an adequate amount of marbling, minimal external fat, and a high ratio of monounsaturated fatty acids to saturated fatty acids (MUFA:SFA) (NRC, 1988).

The degree of intramuscular-lipid deposition in muscles is one of the main factors that influence organoleptic properties of beef (Blumer, 1963; Purchas & Davies, 1974). Therefore, it is important to understand and evaluate factors affecting the lipid quantity and composition in bovine muscle and adipose tissue (Eichhorn, Coleman, Wakayama, Blomquist, Bailey & Jenkins,

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1986). Under normal feeding conditions, the lipid deposition in muscles increases with age or animal growth (Zembayashi, Nabeta & Mototsuji, 1988) and it is difficult to modify via dietary manipulation (Reiser & Shortland, 1990; Smith, 1991). Furthermore, it is reported that lipid deposition in muscle is affected by degree of external finish and breed (Garcia, Casal & Parodi, 1986; Huerta-Leidenz et al., 1993). Thus, modification of fatty acids by selective breeding may be effective (Sturdivant, Lunt, Smith & Smith, 1992).

Japanese Wagyu cattle are characterized by their ability to produce highly palatable beef containing high amounts of intramuscular fat or marbling (Yamazaki, 1981). Marbling is a very important economic trait in determining the value of carcasses in the production of beef in the US. May, Sturdivant, Lunt, Miller and Smith (1993) reported that intramuscular and subcutaneous adipose tissue from crossbred Wagyu steers contained higher percentages ($P < 0.05$) of C16:1 and C18:1 and lower percentages of C16:0 and C18:0 than those from purebred Angus steers. In addition, Wagyu cattle have also been reported to have a higher MUFA:SFA than traditional North American breeds (Sturdivant et al., 1992). Xie et al. (1996) reported similar results, indicating that muscle from American Wagyu cattle had a higher MUFA:SFA than muscle from domestic breeds. Xie et al. also showed that there were differences between sires for this trait. The variability in MUFA:SFA within Wagyu animals may suggest that genetic differences exist among North American Wagyu sires. Therefore, the objective of this study was to evaluate differences in fatty acid composition and cholesterol in *longissimus dorsi* muscle and subcutaneous adipose tissue from progeny of various Wagyu sires and to determine the effect of sires on those lipid profiles.

2. Materials and methods

2.1. Animals

Based on the chronological order in which the Wagyu sires have been imported into the United States, they can be described as Old and New Wagyu sires. Old sires used in this experiment include three of the original four full blood bulls imported into the US. in 1976, Judo, Mazda and Rueshaw. Additionally, Alvin, Konishiki and Fame, are classified as Old sires. Alvin and Konishiki, sired by Mt. Fuji another bull imported into the US in 1976, are considered purebred (containing 15/16 or greater Wagyu influence) according to the American Wagyu Association. Fame, containing 63/64 Wagyu influence was a son of Itotani 7th, whose semen was imported into Canada in 1974, is considered a purebred by the Canadian Wagyu Association. New sires used in this study were Haruki II and Michifuku, both sired by Monjiro. These sires were imported in 1993. Sixty-two steers and 51 heifers were sired by artificial insemination using semen from the eight Wagyu sires that were randomly mated to cows in three different herds of WSU Angus, WSU Angus×Hereford×Simmental and commercial (private cooperator) Angus×Hereford×Simmental. Calves were born in the spring (February–April) of 1995, weaned and transported to the WSU Cattle Feeding Laboratory in Pullman in December 1995.

2.2. Feeding phases

Upon arrival at the cattle feeding facility, steers and heifers were limit fed on a 80:20 ratio of roughage:concentrate diet for 112 days to achieve an ADG of 0.7–0.9 kg and then grazed on a mixture of orchard grass and bluegrass for 84 days from 16 April to 8 July, 1996. At the end of the grazing period, calves were weighed and allotted to pens by sex. Animals were allocated (6–7 head/pen) based on full weight and sire distribution, so every sire had progeny in the different pens. Cattle were fed for 231 days (finishing phase) on a 10:90 ratio of roughage:concentrate diet prior to slaughter. In the finishing phase, cattle were initially fed 75% roughage and 25% concentrate (Table 1). The roughage portion of the diet was decreased in five increments, while the concentrate portion was increased in the same manner over a 35-day period until the 10:90 ratio was reached. During the finishing phase, melengesterol acetate (MGA) was administrated to the heifers as a feed additive to suppress estrus and all animals had ad libitum access to the diets.

Table 1
Backgrounding and finishing diet composition

Item	Feeding period	
	Backgrounding	Finishing
	% of DM	
Alfalfa hay cubes	54.5	–
Oatlage	20.0	9.5
Steam rolled barley	25.0	90
TM salt with selenium	Ad libitum	Ad libitum
Melengesterol acetate (MGA)[a]	0.5	0.5
Chemical composition	*%, as Fed*	
Dry matter, %	69.4	84.5
Crude protein, %	14.3	11.6
Neutral detergent fiber, %	45.1	25.0
Acid detergent fiber	31.3	13.2
Estimated Nem, Mcal/kg	1.30	1.87
Estimated Neg, Mcal/kg	0.95	1.40

[a] MGA was fed only to the heifers.

2.3. Sample collection and preparation

Upon the termination of the feeding period, the steers and heifers were humanely slaughtered at a commercial packing plant in Boise, ID. Carcasses were chilled at 2 ± 1°C. Approximately 48 h post mortem, 10 g samples of *longissimus dorsi* muscle and the outer layer of subcutaneous fat at the 12th rib were obtained from the right side of each animal for analyses of cholesterol and fatty acids. Muscle and fat samples were lyophilized and then ground with dry ice in a household coffee grinder until a homogeneous composition was obtained. After grinding, samples were stored for up to 60 days at −20°C for subsequent lipid extraction.

2.4. Lipid extraction

Total lipids were extracted (in duplicate) from 100 mg of lyophilized muscle and 50 mg of fat by mixing with 1 ml chloroform, 2 ml methanol and 0.8 ml deionized water. After shaking for 2 h, 1 ml of chloroform, 0.5 ml of deionized water and 0.5 ml of 33% KCl in concentrated HCl were added to the mixture resulting in a chloroform:methanol:water ratio of 2:2:1.8. Samples were centrifuged at 800×*g* for 5 min (Sorvall RT 6000B refrigerated centrifuge, DuPont). Water (top layer) was siphoned from the test tubes and the chloroform (bottom layer) containing lipids was pipetted into new test tubes. Two rinses were made with 2 ml chloroform and the chloroform layers were added to the previous washes and evaporated under nitrogen (N_2) flow. After evaporation, 1 ml of 33% KOH solution and 4 ml of 95% ethanol were added and the tubes were placed in an 85°C dry bath for 30 min. At the end of saponification, 3 ml of H_2O were added. The unsaponifiable lipids were extracted with 3 ml of hexane twice. One milliliter of concentrated HCl was added to the final alkaline solution to protonate free fatty acids for subsequent extraction with 3 ml of hexane.

2.5. Cholesterol analysis

Stigmasterol (0.1 ml of 100 μg/ml) was added as an internal standard to the unsaponifiable fraction. Hexane was evaporated under nitrogen and the cholesterol was dissolved in 2 ml of chloroform. Cholesterol samples were analyzed using a flame ionization gas chromatograph (Hewlett-Packard, Model 5890A, Avondale, PA) equipped with a packed stainless steel column (Supelco, Bellefonte, PA; 30 m SP5361, 0.53 mm i.d., 0.10 μm film thickness) maintained at a temperature of 250°C, and an automatic sampler (Hewlett-Packard HP7673A). The injection port and detector were maintained at 300°C. The sample injection volume was 2 μl and the flow rate for the carrier gas (helium) was set at 2.0 ml/min. Cholesterol standards were used to obtain regression equations to quantify cholesterol content, which was adjusted based on the response of the internal standard.

2.6. Fatty acid analysis

Free fatty acids were methylated using the boron trifluoride methanol procedure of Morrison and Smith (1964). Fatty acid methyl esters were analyzed using a flame ionization gas chromatograph (Hewlett-Packard, Model 5890A, Avondale, PA) equipped with a packed stainless steel column (J&W Scientific, Folson, CA; 60 m DB225-30N) and an automatic sampler (Hewlett-Packard HP7673A). The gas chromatograph column oven was programmed to have a temperature of 150° C for 1 min and then increased at a rate of 30°C per min from 150 to 190°C, 5°C per min from 190 to 220°C and then maintained at 220°C for 13 min. The injection port and detector were maintained at 225 and 240°C, respectively. Samples were automatically introduced into the injector port (volume of 2 μl). The flow rate for the carrier gas (helium) was set at 0.5 ml/min. Calibration of the gas chromatograph system was performed with standard fatty acid methylester mixtures (reference standard GLC-68-B, Nu-Check-Prep, Elysian, MN). Chromatograms were recorded with a computer integrator (Hewlett-Packard, Model HP 3396). Identification of the fatty acid methyl esters was determined by running reference standards of known methyl esters (Nu-Check-Prep, Elysian, MN). A total of 18 fatty acid methyl esters was identified and analyzed for each of the fat and muscle samples. They were the following: myristic (C14:0), myristoleic (C14:1), pentadecanic (C15:0), 10-pentadecenoic (15:1), palmitic (C16:0), palmitoleic (C16:1), heptadecanic (C17:0), 10-heptadecenoic (C17:1), stearic (C18:0), oleic (C18:1), linoleic (C18:2), linolenic (C18:3), arachidic (C20:0), eiconosenoic (C20:1), eicosadienoic (C20:2), eicosatrienoic (C20:3), arachadonic (C20:4), behenic (C22:0), and docosenoic (C22:1).

2.7. Ether extractable fat analysis

Samples from each carcass were analyzed for percentage extractable fat following (Association of Official Analytical Chemists [AOAC], 1980) procedures. The *longissimus dorsi* muscle samples (about 1 g each) were placed into prefolded oven-dried filter paper, weighed and placed in a drying oven (100°C) for 24 h. After removal from the oven, samples were reweighed and fat content was determined using the Goldfish diethyl ether extraction method.

2.8. Statistical analysis

Dependent variables were analyzed using a linear model (full model) that included eight sires, three sources of dams (WSU Angus, WSU crossbred and Commercial)

and two sexes (steers and heifers). Two-and three-way interactions of all independent variables (sire*sex; sire*source; sex*source; sex*sire*source) were tested. The only significant interactions were (sire*source) for C16:0 and C18:1 for *longissimus dorsi* muscle and (sex*source) for cholesterol. Since these three interactions represent less than 5% of the total number of interaction tests and they were not highly significant, with P values ranging from 0.019 to 0.036, we decided to ignore these three interactions and not include interactions in the final model. A contrast was computed and tested for a significant difference for each dependent variable between Old and New Wagyu sires using the student-t test. Simple correlation coefficients were computed to evaluate the relative importance of various fatty acids with carcass traits.

3. Results and discussion

For *longissimus dorsi* muscle, progeny from Old sires had higher ($P<0.05$) MUFA:SFA ratio than progeny of New sires (1.14, 1.08, respectively, Table 2). These values were similar to those obtained by Xie et al. (1996) who reported a MUFA:SFA ratio of 1.21 for *longissimus dorsi* muscle from Wagyu cross-bred cattle fed a high concentrate barley-based diet. Our results are also similar to those of Sturdivant et al. (1992) who reported that the *longissimus dorsi* muscle of crossbred Wagyu had a MUFA:SFA ratio of 1.19, while they reported a value of 1.66 for purebred Wagyu. The higher MUFA:SFA ratio of progeny from Old Wagyu sires was a result of a higher ($P<0.05$) percentage of C18:1 and lower ($P<0.05$) percentage of C14:0 and C16:0 (Table 2). According to Duckett, Wagner, Yates, Dolezal and May (1993) the neutral lipid and total lipid of *longissimus dorsi* muscle become more unsaturated as time on feed increases, primarily due to a linear increase of oleic (C18:1) acid concentration. In the present study, all cattle were on feed the same time, but progeny from Old sires were fatter externally than progeny of New sires (Elías Calles et al. in press), and thus may have been more physiologically mature. The changes reported by Duckett et al. may have been due to the degree of fattening or stage of physiological maturity and not just to time on feed.

Table 2
Least squares means and standard errors for fatty acids and cholesterol content of *longissimus dorsi* muscle from steers and heifers by New and Old sire groups[a]

Fatty acid %	Group		P-value[b]
	New sires	Old sires	
Number	25	88	
14:0	4.0±0.11	3.7±0.06	0.01
14:1	1.2±0.05	1.1±0.03	0.43
16:0	30.8±0.29	29.7±0.15	0.001
16:1	4.8±0.10	4.6±0.05	0.12
18:0	10.9±0.17	10.2±0.09	0.64
18:1	42.0±0.43	43.4±0.23	0.01
18:2	2.6±0.12	2.9±0.06	0.01
SFA[c]	45.2±0.40	43.9±0.21	0.001
MUFA[d]	48.6±0.40	49.8±0.21	0.01
PUFA[e]	2.7±0.12	3.1±0.06	0.01
MUFA:SFA	1.08±0.02	1.14±0.01	0.01
PUFA:SFA	0.06±0.001	0.07±0.001	0.001
Cholesterol, mg/100g	49.5±0.75	47.7±0.39	0.64
Ether extract fat, %	10.4±1.01	9.2±0.91	0.18

[a] Fatty acids are reported as percentages of total fatty acids.
[b] Significance of contrast between Old and New sires.
[c] Total of 14:0, 16:0, 18:0, 20:0 and 22:0.
[d] Total of 14:1, 16:1, 18:1, 20:1 and 22:1.
[e] Total of 18:2, 18:3, 20:2, 20:3 and 20:4.

Progeny from Old Wagyu sires had a higher PUFA:SFA ratio ($P<0.05$) in the *longissimus dorsi* muscle than progeny from New Wagyu sires (Table 2). This higher ratio resulted mainly from a higher ($P<0.05$) percentage of C18:2. For *longissimus dorsi* muscle, there were also differences ($P<0.05$) among sires for MUFA:SFA and PUFA:SFA (Table 3). MUFA represented the greatest percentage of total fatty acids, with means for sires ranging from 47.7 to 51.0%. The range of sire means for SFA was from 43.3 to 46.4%. These results were in agreement with Eichhorn et al. (1986), who reported similar values for lipid extracts of subcutaneous adipose tissue and triacyglycerol fractions of *longissimus dorsi* and *semitendinosus* muscles from yearling bulls and steers.

There were differences ($P<0.05$) among sources of dam (Table 4) for fatty acids of *longissimus dorsi* muscle. Progeny of WSU Angus cows had lower ($P<0.05$) MUFA:SFA and higher ($P<0.05$) percentage of C16:0 and SFA than progeny of WSU crossbred cows and commercial cows. Progeny of WSU Angus cows had lower ($P<0.05$) PUFA:SFA than progeny of WSU crossbred and commercial cows. *Longissimus dorsi* muscle from steers had lower ($P<0.05$) MUFA:SFA, and higher ($P<0.05$) percentages of C14:0 and SFA than muscle from heifers (Table 5).

For subcutaneous fat, there were no differences ($P>0.05$) in fatty acid percentage between progeny of Old and New Wagyu sires or among sources of dam (data not shown). However, there were differences ($P<0.05$) between sexes (Table 5). Heifers had 0.2% more linoleic acid (C18:2). This higher level could be related to the degree of external fatness, which was higher for the heifers than steers (Elías Calles et al., in press). Link, Bray, Cassens and Kauffman (1970) studied fatty acid composition of bovine subcutaneous adipose tissue at different stages of growth and concluded that increased fatness and/or age altered the proportions of fatty acids in the muscle. Leat (1975) in a similar study, found a greater proportion of unsaturated

fatty acids in subcutaneous fat with increased fatness. In our study, the heifers had a higher PUFA:SFA ratio than steers.

There were differences among sires for percentage ether extractable fat of muscle tissue (Table 3), however, percentage ether extract did not differ ($P<0.05$) between by Old or New Wagyu sires (Table 2). Sine means for percentage of ether extractable fat ranged from 7.6 to 13.1 (Table 3). Progeny from Michifuku and Judo had a higher ($P<0.05$) content of ether extract than the rest of the sires. There was a positive correlation between ether extractable fat and marbling score ($r=0.68$, $P<0.05$) and a negative correlation between ether extractable fat and C18:2 ($r=-0.61$, $P<0.05$). There were differences among sources of dam (Table 4) for ether extract ($P<0.05$). Progeny from WSU Angus cows had more ether extractable fat than progeny from WSU crossbred and commercial cows. There were no differences ($P>0.05$) for ether extract between steers and heifers (data not shown).

Cholesterol content of muscle tissue in the present study was not influenced by sire ($P>0.05$). However, progeny from Michifuku tended to have a higher content of cholesterol than progeny from the rest of the sires. Sire means for cholesterol content (mg/100 g wet weight) of *longissimus dorsi* muscle ranged from 46.1 to 50.5 (Table 3). These values were lower than the overall mean reported by Eichhorn et al. (1986) of 58.3 and 62.4 (mg/100 g wet weight) reported by Rhee, Dutson, Smith, Hostetler and Reiser (1982) for *longissimus dorsi* muscle. In a study in which cholesterol content of *longissimus dorsi* muscles in seven marbling-score categories was determined, Rhee et al. (1982) observed only one significant difference, i.e. muscles "practically devoid" of marbling had lower cholesterol values than muscles with higher marbling scores. Tu, Powrie and Fennema (1967) reported the cholesterol content of various bovine muscles from three steers ranged from 51.4 to 65.8 mg/100 g wet weight, with an overall mean of about 58 mg/100 g wet weight.

Table 3
Least squares means and standard errors for fatty acids of *longissimus dorsi* muscle and subcutaneous fat from steers and heifers sired by various Wagyu bulls[a]

Fatty acid %	Judo	Mazda	Rueshaw	Fame	Konishiki	Alvin	Haruki II	Michifuku
Number	7	19	10	16	21	15	6	19
Longissimus dorsi *muscle*								
14:0	3.8±0.20	3.9±0.11	4.0±0.15	3.9±0.13	3.5±0.10	3.3±0.13	4.±0.21	3.9±0.12
14:1	1.1±0.11	1.2±0.06	1.1±0.08	1.2±0.07	1.1±0.06	1.0±0.07	1.0±0.11	1.3±0.06
16:0	30.9±0.53	30.1±0.30	30.2±0.41	30.6±0.33	28.7±0.27	29.0±0.35	31.3±0.57	30.6±0.31
16:1	4.5±0.19	4.7±0.11	4.9±0.15	4.6±0.12	4.5±0.10	4.2±0.12	4.7±0.20	4.8±0.11
18:0	10.8±0.33	9.9±0.18	10.3±0.25	9.8±0.20	10.1± 0.17	10.7±0.21	10.8±0.35	9.9±0.19
18:1	42.4±0.83	43.0±0.46	42.2±0.63	42.2±0.52	44.6±0.43	44.7±0.54	41.3±0.88	42.3±0.49
18:2	2.3±0.21	2.8±0.12	2.8±0.16	3.2±0.13	3.2± 0.11	2.9±0.14	2.4±0.23	2.6±0.13
SFA[b]	45.7±0.75	44.2±0.42	44.8±0.57	44.6±0.47	42.5± 0.38	43.3±0.49	46.4±0.79	44.7±0.44
MUFA[c]	48.6±0.77	49.6±0.43	48.8±0.59	48.7±0.48	51.0± 0.39	50.5±0.50	47.7±0.82	49.0±0.45
PUFA[d]	2.5±0.22	2.9±0.12	2.9±0.16	3.3±0.13	3.3±0.11	3.1±0.14	2.6±0.23	2.8±0.13
MUFA:SFA	1.06±0.04	1.13±0.02	1.10±0.03	1.10±0.02	1.21±0.02	1.17±0.02	1.03±0.04	1.10±0.02
PUFA:SFA	0.05±0.001	0.07±0.001	0.07±0.001	0.07±0.001	0.08±0.001	0.07±0.001	0.05±0.001	0.06±0.001
Cholesterol, mg/100g	49.8±1.58	47.8±0.88	47.2±1.20	48.3±0.98	47.1±0.81	47.1±1.03	46.1±1.67	50.5±0.92
Ether extract fat, %	10.91±0.86	9.39±0.75	8.68±0.97	8.65±0.85	7.90±0.68	10.00±0.86	7.58±1.40	13.13±0.79
Subcutaneous fat								
14:0	4.3±0.21	4.1±0.12	4.7±0.16	4.5±0.13	3.9±0.11	3.8±0.14	4.4±0.23	4.2±0.13
14:1	2.3±0.22	2.0±0.12	2.2±0.17	2.5±0.14	1.9±0.11	1.8±0.14	2.00±0.23	2.5±0.13
16:0	29.6±0.51	28.7±0.28	29.6±0.39	29.9±0.32	28.7±0.26	29.7±0.33	28.6±0.54	28.9±0.30
16:1	6.7±0.49	5.9±0.27	7.2±0.37	6.8±0.30	5.9±0.25	5.9±0.32	6.5±0.52	6.8±0.29
18:0	7.0±0.44	7.2±0.25	7.1±0.34	6.7±0.27	7.3±0.23	7.0±0.29	7.5±0.47	6.4±0.26
18:1	43.7±0.82	45.3±0.46	42.5±0.62	42.7±0.51	45.5±0.42	44.7±0.53	44.4±0.87	44.1±0.48
18:2	1.8±0.16	2.2±0.09	1.9±0.12	2.5±0.10	2.3±0.08	2.4±0.10	1.8±0.17	2.4±0.09
SFA[b]	41.1±0.67	40.1±0.37	41.5±0.51	41.1±0.42	40.1±0.34	40.7±0.44	40.6±0.71	39.5±0.39
MUFA[c]	53.2±0.65	53.6±0.36	52.3±0.50	52.3±0.40	53.6±0.33	52.8±0.43	53.3±0.67	53.8±0.38
PUFA[d]	2.0±0.17	2.4±0.09	2.1±0.13	2.7±0.10	2.4±0.86	2.5±0.18	2.00±0.18	2.6±0.10
MUFA:SFA	1.30±0.04	1.34±0.02	1.27±0.03	1.28±0.02	1.34±0.02	1.31±0.02	1.32±0.04.	1.36±0.02
PUFA:SFA	0.05±0.01	0.06±0.01	0.05±0.01	0.06±0.01	0.06±0.01	0.06±0.01	0.05±0.01	0.06±0.01

[a] Fatty acids are reported as percentage of total fatty acids.
[b] Total of 14:0, 16:0, 18:0, 20:0 and 22:0.
[c] Total of 14:1, 16:1, 18:1, 20:1 and 22:1.
[d] Total of 18:2, 18:3, 20:2, 20:3 and 20:4.

Table 4
Least squares means and standard errors for fatty acids of *longissimus dorsi* muscle for sources of dam[a]

Fatty acid %	Source of dam			*P*-value[b]
	Commercial	WSU Angus	WSU crossbred	
Number	34	33	46	
14:0	3.6 ± 0.10	3.9 ± 0.10	3.8 ± 0.09	0.07
14:1	1.1 ± 0.05	1.1 ± 0.05	1.1 ± 0.05	0.23
16:0	29.4 ± 0.27	30.9 ± 0.26	30.1 ± 0.23	0.002
16:1	4.54 ± 0.10	4.6 ± 0.09	4.6 ± 0.08	0.76
18:0	10.2 ± 0.17	10.2 ± .16	10.5 ± 0.14	0.21
18:1	43.5 ± 0.42	42.3 ± 0.40	42.8 ± 0.35	0.13
18:2	2.9 ± 0.11	2.6 ± 0.10	2.8 ± 0.09	0.09
SFA[c]	43.6 ± 0.38	45.3 ± 0.36	44.64 ± 0.32	0.02
MUFA[d]	49.9 ± 0.39	48.7 ± 0.37	49.1 ± 0.33	0.11
PUFA[e]	3.1 ± 0.11	2.7 ± 0.10	2.93 ± 0.09	0.07
MUFA:SFA	1.15 ± 0.19	1.08 ± 0.18	1.10 ± 0.02	0.04
PUFA:SFA	0.07 ± 0.001	0.06 ± 0.001	0.07 ± 0.001	0.01
Cholesterol, mg/100g	47.6 ± 0.80	48.4 ± 0.76	48.0 ± 0.67	0.82
Ether extract fat, %	8.7 ± 0.69	10.9 ± 0.64	9.0 ± 0.56	0.02

[a] Fatty acids are reported as percentages of total fatty acids.
[b] Significance of overall *F* ratios from ANOVA.
[c] Total of 14:0, 16:0, 18:0, 20:0 and 22:0.
[d] Total of 14:1, 16:1, 18:1, 20:1 and 22:1.
[e] Total of 18:2, 18:3, 20:2, 20:3 and 20:4.

Table 5
Least squares means and standard errors for fatty acids of *longissimus dorsi* muscle and subcutaneous fat for steers and heifers[a]

Fatty Acid %	Sex		*P*-value[b]
	Heifers	Steers	
Number	51	62	
Longissimus dorsi *muscle*			
14:0	3.7 ± 0.07	3.9 ± 0.06	0.02
14:1	1.1 ± 0.04	1.2 ± 0.03	0.14
16:0	30.0 ± 0.19	30.4 ± 0.17	0.08
16:1	4.7 ± 0.07	4.5 ± 0.06	0.12
18:0	10.3 ± 0.12	10.3 ± 0.10	0.58
18:1	43.2 ± 0.29	42.6 ± 0.26	0.12
18:2	2.8 ± 0.08	2.7 ± 0.07	0.15
SFA[c]	44.2 ± 0.27	44.9 ± 0.23	0.04
MUFA[d]	49.6 ± 0.27	48.9 ± 0.24	0.05
PUFA[e]	3.0 ± 0.08	2.8 ± 0.07	0.10
MUFA:SFA	1.13 ± 0.01	1.09 ± 0.01	0.04
PUFA:SFA	0.07 ± 0.001	0.06 ± 0.001	0.05
Cholesterol, mg/100	47.8 ± 0.56	48.2 ± 0.49	0.61
Subcutaneous fat			
14:0	4.2 ± 0.08	4.3 ± 0.07	0.20
14:1	2.1 ± 0.08	2.2 ± 0.07	0.67
16:0	29.0 ± 0.18	29.5 ± 0.16	0.05
16:1	6.6 ± 0.17	6.4 ± 0.15	0.32
18:0	6.9 ± 0.16	7.2 ± 0.14	0.14
18:1	44.4 ± 0.29	43.9 ± 0.25	0.19
18:2	2.3 ± 0.06	2.1 ± 0.05	0.001
SFA[b]	40.1 ± 0.24	41.0 ± 0.21	0.001
MUFA[c]	53.5 ± 0.23	52.8 ± 0.20	0.03
PUFA[d]	2.4 ± 0.06	2.2 ± 0.05	0.001
MUFA:SFA	1.34 ± .001	1.29 ± 0.01	0.01
PUFA:SFA	0.06 ± .001	0.05 ± .001	0.001

[a] Fatty acids are reported as percentages of total fatty acids.
[b] Level of significance comparing steers to heifers.
[c] Total of 14:0, 16:0, 18:0, 20:0 and 22:0.
[d] Total of 14:1, 16:1, 18:1, 20:1 and 22:1.
[e] Total of 18:2, 18:3, 20:2, 20:3 and 20:4.

4. Conclusions

These results suggest that the observed differences in major fatty acid profiles, MUFA and SFA are related to genetic differences among Wagyu sires, indicating that it may be possible to identify and select individuals capable of transmitting their ability to accumulate tissue with less palmitic acid (C16:0), more oleic acid (C18:1) and a high MUFA:SFA ratio to provide consumers a healthier beef product. However, the effectiveness of selecting for more than one fatty acid simultaneously depends on genetic correlations among these traits within Wagyu sires. Therefore, more research needs to be done in order to evaluate genetic variation for these traits. These data show that Old Wagyu sires may produce progeny with slightly higher MUFA:SFA ratio than progeny of New Wagyu sires.

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Differences among Wagyu sires for USDA carcass traits and palatability attributes of cooked ribeye steaks[1]

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ABSTRACT: The objective of this experiment was to evaluate the effects of various Wagyu sires on carcass quality traits and palatability attributes of cooked ribeye steaks. Wagyu sires were used and grouped as Old (n = 6) or New (n = 2) sires, based on the chronological order in which they were imported into the United States. One hundred thirteen F_1 heifer and steer calves sired by Wagyu bulls out of three different sources of cows were fed a backgrounding diet for 112 d consisting of an 80:20 ratio of roughage:concentrate then grazed on a mixture of orchardgrass and bluegrass pasture for 84 d and finished on a 10:90 ratio of roughage:concentrate diet for 231 d in a feedlot. Progeny from New sires had larger ($P < .05$) ribeye areas, higher ($P < .05$) marbling scores, and lower ($P < .05$) maturity scores than progeny from Old sires. Marbling was positively correlated ($P < .05$) to brightness (r = .56), texture (r = .60), and fat luster (r = .38). Progeny of New sires had lower shear force values ($P < .05$) than progeny of Old sires. These results indicate the superiority of New Wagyu sires to produce progeny with more marbling, lower shear force values, and larger ribeye areas than Old Wagyu sires. Furthermore, there are substantial differences between Wagyu sires for carcass quality traits and palatability attributes.

Key Words: Carcass Quality, Japanese Black Cattle, Palatability, Sires

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Introduction

The improvement of overall eating quality of cooked beef, the reduction of dietary cholesterol, and the contribution of beef to the total intake of saturated fatty acids (**SFA**) have become important issues to consumers and the meat industry (Mattson and Grundy, 1985; Rule et al., 1989; Morgan et al., 1991; Mills et al., 1992). In addition, a desirable beef product must be economically competitive, tender, juicy, and flavorful with an adequate amount of marbling, minimal external fat, and a high ratio of monounsaturated fatty acids to saturated fatty acids (Boylston and Morgan, 1992).

Japanese Wagyu cattle are characterized by their ability to produce very palatable beef containing high amounts of marbling (Yamazaki, 1981). Xie et al. (1996) indicated that the Wagyu genetics available in North America at that time contained highly variable marbling ability. However, that study involved a limited number of progeny, and the marbling ability, fat deposition, and palatability characteristics of newly imported Wagyu sires have not been reported. Therefore, the objective of this study was to evaluate New and Old Wagyu sires on USDA carcass grade traits and palatability attributes of cooked ribeye steaks and to identify Wagyu sires with low shear force values and high marbling scores.

Materials and Methods

Animals. Based on the chronological order in which the Wagyu sires have been imported into the United States, they can be described as Old and New Wagyu sires. Old Wagyu sires used in this experiment include three of the original five full-blood bulls or semen imported into the United States and Canada in 1974 through 1976 (Judo, Mazda, and Rueshaw). Additionally, Alvin, Konishiki, and Fame are in the group of Old sires. Alvin and Konishiki were sired by Mt. Fuji, another bull imported into the United States in 1976 and are considered purebred (containing 15/16 or greater Wagyu influence). Fame, a son of Itotani 7th (whose semen was imported into Canada in 1974) containing 63/64 Wagyu influence, is considered a purebred

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Table 1. Backgrounding and finishing diet composition

Item	Feeding period	
	Backgrounding	Finishing
	% of DM	
Ingredient		
Alfalfa hay cubes	54.5	—
Oatlage	20.0	9.5
Steam-rolled barley	25.0	90
Trace mineralized salt with Se	Ad libitum	Ad libitum
Melengesterol acetate[a]	.5	.5
	%, as Fed	
Chemical composition		
Dry matter, %	69.4	84.5
Crude protein, %	14.3	11.6
Neutral detergent fiber, %	45.1	25.0
Acid detergent fiber	31.3	13.2
Estimated NE_m, Mcal/kg	1.30	1.87
Estimated NE_g, Mcal/kg	.95	1.40

[a]Fed only to the heifers.

by the Canadian Wagyu Association. Sires described as New were imported in 1993. New sires used in this study were Haruki II and Michifuku, both sired by Monjiro. Sixty-two steers and 51 heifers were sired by artificial insemination using semen from these eight Wagyu sires that were randomly mated in 1994 to cows in three different herds, WSU Angus, WSU crossbreds, and commercial crossbreds owned by a private producer. All crossbred cows were combinations of Angus, Hereford, and Simmental breeds. Calves were born in the spring (February to April) of 1995, weaned in the fall (7 to 9 mo of age), and transported to the WSU Cattle Feeding Laboratory in December 1995.

Feeding Phases. Washington State University's Animal Care and Use Committee approved the use of animals in this study. Upon arrival at the cattle feeding facility, steers and heifers were limit-fed on an 80:20 ratio of roughage:concentrate diet for 112 d to achieve an ADG of .7 to .9 kg and then grazed on a mixed orchardgrass and bluegrass pasture for 84 d from April 16 to July 8, 1996. At the end of the grazing period, calves were weighed and allotted to pens by sex. Animals were allocated (six to seven animals/pen) based on full weight, sex, and sire distribution, so that progeny in the different sire groups were distributed equally across pens. Cattle were fed for 231 d (finishing phase) on a 10:90 ratio of roughage:concentrate diet prior to slaughter. In the finishing phase, cattle were initially fed 75% roughage and 25% concentrate. The roughage portion of the diet was decreased in five increments, whereas the concentrate portion was increased in the same manner over a 35-d period until the 10:90 ratio was reached. See Table 1 for composition and chemical analyses of the diets. During the finishing phase, melengesterol acetate was administered to the heifers as a feed additive to suppress estrus; all animals had ad libitum access to the diets. The cattle were fed similar to Japanese methods for producing highly marbled beef; steers weigh approximately 700 kg at slaughter.

Slaughter Process and Carcass Traits. The cattle were transported 192 km to a commercial plant for processing and were graded 48 h postmortem. The average weight of the F_1 steers and heifers at the time of slaughter was 707 and 651 kg, respectively. A total of 113 cattle were slaughtered using humane slaughter procedures and carcasses were evaluated according to the USDA quality grade factors (USDA, 1989). Percentage of kidney, pelvic, and heart fat and yield grades were not obtained because kidney fat was removed from the carcasses prior to inspection in order to speed up the cooling time. Meat quality attributes were also estimated based on standard procedures of the Japan Meat Grading Association (JMGA, 1988). Meat color and fat color were evaluated using the 7-point Beef Color Standard and 7-point Beef Fat Standard, respectively. Meat brightness, meat firmness, meat texture, and fat luster were evaluated according to 5-point descriptive scales.

Steaks (3.2 cm thick) of longissimus dorsi muscle (ribeye) were removed from each carcass between the 12th and 13th ribs 48 h postmortem. On the same day, steaks were transported to the Washington State University Meat Laboratory and cut to a final thickness of 2.5 cm, individually vacuum-packaged, and then aged at 2° ± 1°C for 14 d. After aging, steaks were frozen at −40°C until sensory evaluation and Warner-Bratzler shear force determination.

Cooking Process. Steaks (n = 113) were thawed at 2 to 5°C for 36 h and weighed (net weight, g) before they were broiled on Farberware Open Hearth grills (Model R4550; Farberware, Bronx, NY) to a final internal temperature of 71°C. During cooking, the steaks were turned when they reached an internal temperature of 35°C. Temperature was monitored with a scanning thermocouple thermometer (Digi-Sense, Cole Parmer, Vernon Hills, IL) equipped with copper-constant thermocouple wires (diameter < .05 cm, error < 2°C), which were inserted into the geometric center of each steak. Initial temperature of the steaks, cooking time, and cooked weight were recorded to obtain cooking loss percentage and rate of cooking (AMSA, 1995).

Warner-Bratzler Shear Force Determination. Cooked ribeye steaks (n = 113) were cooled at room temperature (23°C) for 4 h and then weighed. Nine cores (1.3 cm diameter) were removed parallel to the orientation of the muscle fibers with a manual coring device. Only cores that were uniform in diameter, without connective tissue abnormalities and other structure problems, were used. A Texture Analyzer (TA-XT2, Texture Technologies, Scarsdale, NY) equipped with a Warner-Bratzler shear attachment was used to shear each core. Cores were sheared once in the center in order to maintain accuracy. Peak shear force was recorded. Crosshead speed was set at 20 cm/min.

Sensory Evaluation. Forty of the 113 ribeye steaks were randomly selected to represent each of the eight Wagyu sires (five per sire) for sensory panel evaluation

and cooked as previously described for shear force determination. After cooking, each steak was cut into cubes (1.3 × 1.3 × 2.5 cm) and served at 32 to 35°C for sensory evaluation. One sample was served at a time, and 12 steaks were served at each session, which was held midmorning each day. A 10-member descriptive attribute sensory panel was trained and tested according to methods described by Cross et al. (1978) and AMSA (1995). Panelists in individual booths evaluated the steak samples for tenderness, flavor, and juiciness using 10-point descriptive scales (10 = extremely tender, extremely flavorful, and extremely juicy and 1 = extremely tough, extremely bland, and extremely dry).

Statistical Analysis. Dependent variables were analyzed using a linear model that included eight sires, three sources of dam (WSU Angus, WSU crossbred, and commercial) and two sexes (steers and heifers) (SAS, 1996). Two- and three-way interactions of all independent variables (sire × sex; sire × source; sex × source; sex × sires × source) were tested. The only significant interaction was sire × sex for ribeye area ($P < .04$). Because this interaction represented less than 5% of the total number of interaction tests, and because it was not highly significant, we decided to ignore it and not include interactions in the model. Differences between means for sire and cow herds were tested using least significance difference. A contrast was computed and tested for a significant difference for each dependent variable between Old and New Wagyu sires using the Student's *t*-test. Simple correlation coefficients were computed to evaluate the relative importance of various carcass traits on palatability attributes.

Results and Discussion

Differences were observed ($P < .05$) for several carcass traits between Old and New Wagyu sires (Table 2). The mean marbling score for progeny of New sires (900) was 1.29 of a USDA marbling degree higher ($P < .05$) than the mean (771) for progeny of Old sires. Moreover, progeny of New sires had 10.9% larger ribeye areas (98.8 vs 89.5 cm^2) and tended to have less external fat than progeny of Old sires. In addition, progeny of New sires had younger maturity scores, brighter, firmer texture of lean, and more desirable fat luster ($P < .05$). These results indicate that recently imported sires are superior to those imported earlier. The superiority of the newly imported sires indicates that genetic improvement has been made by Japanese producers during the last 20 yr; American producers have not made the same amount of progress in the Old sires. This gives a rough estimate of improvement in carcass quality from 1975 to 1991. Progeny of New and Old sires did not differ in growth rate, but the New sires excelled in marbling, which is an extremely important economic trait, especially for the U.S. and Japanese markets. In both countries, marbling plays a central role in determining quality grade and is related to meat palatability (Covington et al., 1970; Parrish, 1974; Jennings et al., 1978; Davis et al., 1979).

Table 2. Least squares means and standard errors for average daily gain, carcass weight, and yield and grade traits, comparing Old and New Wagyu sires

	Group		
Carcass trait	New sires	Old sires	*P*-value
Number	25	88	—
ADG, kg	1.32 ± .03	1.31 ± .02	.90
Hot carcass wt, kg	415 ± 6.6	407 ± 3.5	.24
Dressing %	60.2 ± .34	60.4 ± .17	.08
Ribeye area, cm^2	98.8 ± 3.2	89.5 ± 2.5	.001
Fat thickness, cm	2.21 ± .13	2.44 ± .08	.19
Adjusted fat thickness, cm	2.34 ± .13	2.62 ± .08	.17
Maturity[a]	87.0 ± 5.9	100.1 ± 3.1	.03
Lean color[b]	3.15 ± .17	3.77 ± .09	.02
Brightness[b]	4.06 ± .15	3.35 ± .08	.01
Firmness[b]	4.06 ± .16	3.47 ± .08	.09
Texture[b]	4.02 ± .14	3.40 ± .07	.02
Fat color[b]	2.81 ± .10	2.89 ± .05	.37
Fat luster[b]	4.23 ± .13	3.69 ± .06	.01
Marbling[c]	900 ± 26.7	771 ± 13.9	.001

[a]USDA maturity score: 0–99 = A; 100–199 = B.
[b]Japan Meat Grading Association, 1988.
[c]USDA marbling score: 400–499 = slight; 500–599 = small; 600–699 = modest.

Other quality attributes such as beef brightness and texture scores were higher for New sires. The larger ribeye areas of the New sires and the tendency for them to have a lower adjusted fat thickness is also a positive and somewhat unusual attribute, because selection for increased muscling and decreased subcutaneous fat is often antagonistic to selection for marbling (Dunn et al., 1970).

The score for meat color was higher ($P < .05$) for Old sires than for New sires (Table 2). Marbling was positively correlated to firmness (r = .59), brightness (r = .56), texture (r = .60) and fat luster (r = .38) ($P < .05$), which enhance meat quality.

Least squares means for carcass traits as shown in Table 3 further illustrate the differences between Old and New sires but also illustrate important differences between sires within those groupings. Progeny from Michifuku, one of the New sires, had the most marbling and largest ribeye areas ($P < .05$). Progeny of Haruki II and Judo had lower ($P < .05$) shear force values than progeny from other sires (Table 4). These results indicate the superiority of New Wagyu sires to produce progeny with more marbling, lower shear force values, larger ribeye areas, and less external fat than Old Wagyu sires. Furthermore, there are substantial differences between Wagyu sires for carcass quality traits and palatability attributes.

There were differences between cow herds for marbling, fat luster, and meat firmness ($P < .05$). Marbling score for progeny of WSU Angus cows (902) was 100 and 162 points higher ($P < .05$) than the means for

Table 3. Least squares means and standard errors for average daily gain, carcass weight, and yield and grade traits for eight Wagyu sires

	Old sires						New sires	
Carcass trait	Judo	Mazda	Rueshaw	Fame	Konishiki	Alvin	Haruki II	Michifuku
Number	7	19	10	16	21	15	6	19
ADG, kg	1.31 ± .01	1.30 ± .03	1.31 ± .05	1.32 ± .04	1.22 ± .06	1.32 ± .05	1.33 ± .01	1.30 ± .04
Hot carcass wt, kg	374 ± 13.2	421 ± 7	427 ± 1.2	403 ± 8.3	396 ± 7.2	406 ± 9.3	415 ± 14	414 ± 8.2
Dressing %	60.1 ± .68	61.5 ± .37	61.2 ± .52	59.9 ± .43	60.5 ± .35	59.2 ± .45	60.1 ± .72	60.2 ± .40
Ribeye area, cm^2	85.3 ± 3.4^{ef}	92.3 ± 2.2^{efg}	92.1 ± 2.3^{efg}	91.1 ± 2.3^{ef}	88.4 ± 2.0^{efg}	88.1 ± 2.5^{efg}	97.5 ± 4.1^{d}	100.1 ± 2.3^{d}
Fat thickness, cm	2.26 ± .25	2.46 ± .15	2.31 ± .20	2.34 ± .15	2.08 ± .13	3.23 ± .18	2.36 ± .28	2.11 ± .15
Adjusted fat thickness, cm	2.26 ± .25	2.64 ± .13	2.49 ± .18	2.51 ± .15	2.36 ± .13	3.38 ± .15	2.56 ± .25	2.26 ± .15
Maturity[a]	90.0 ± 13.4^{f}	88.3 ± 6.7^{f}	104.2 ± 9.6^{e}	93.1 ± 7.8^{f}	104.0 ± 6.4^{e}	123.2 ± 8.1^{d}	75.1 ± 13.2^{g}	92.4 ± 7.3^{f}
Color[b]	3.42 ± .34^{eg}	3.54 ± .18^{g}	3.45 ± .26^{g}	3.33 ± .21^{e}	4.28 ± .18^{f}	4.23 ± .22^{f}	3.28 ± .36de	3.09 ± .20^{d}
Brightness[b]	3.85 ± .30^{f}	3.56 ± .16^{f}	3.61 ± .23^{f}	3.57 ± .19^{f}	3.01 ± .15^{e}	3.01 ± .19^{e}	3.67 ± .32^{f}	4.20 ± .17^{d}
Firmness[b]	3.84 ± .33	3.24 ± .18	3.79 ± .26	3.20 ± .21	3.60 ± .17	3.56 ± .22	3.59 ± .35	4.19 ± .20
Texture[b]	4.01 ± .29^{d}	3.41 ± .16^{eg}	3.57 ± .22^{e}	3.62 ± .18^{e}	3.24 ± .15^{h}	3.04 ± .19^{f}	3.66 ± .31^{e}	4.14 ± .17^{d}
Fat color[b]	3.00 ± .21	2.86 ± .12	2.82 ± .16	2.69 ± .13	3.06 ± .11	2.92 ± .14	2.68 ± .23	2.86 ± .13
Fat luster[b]	3.42 ± .26^{g}	3.81 ± .14^{ef}	3.93 ± .20^{e}	3.66 ± .17^{f}	3.66 ± .14^{f}	3.73 ± .17^{f}	3.86 ± .28^{e}	4.40 ± .16^{d}
Marbling[c]	903 ± 48.2^{d}	807 ± 26.5^{g}	827 ± 37.1^{g}	751 ± 3.2^{f}	703 ± 24.9^{h}	757 ± 31.5^{f}	863 ± 51.3^{e}	907 ± 28.5^{d}

[a]USDA maturity score: 0–99 = A; 100–199 = B.
[b]Japan Meat Grading Association, 1988.
[c]USDA marbling score: 400–499 = slight; 500–599 = small; 600–699 = modest; 700–799 = moderate; 800–899 = slightly abundant.
[d,e,f,g,h]Means with different subscript in the same row differ ($P < .05$).

Table 4. Least squares means and standard errors for sensory panel traits, Warner-Bratzler shear force, cooking rate, and cooking loss by eight Wagyu sires[a]

	Old sires						New sires		Old vs New
Trait	Judo	Mazda	Rueshaw	Fame	Konishiki	Alvin	Haruki II	Michifuku	*P*-value
Number	5	5	5	5	5	5	5	5	—
Tenderness	6.71 ± .60	6.59 ± .38	7.04 ± .58	5.59 ± .59	5.25 ± .39	5.62 ± .59	6.37 ± .60	7.01 ± .59	.25
Juiciness	6.21 ± .58	6.64 ± .36	7.13 ± .56	6.50 ± .57	5.89 ± .37	6.21 ± .57	5.80 ± .58	7.25 ± .57	.82
Flavor	6.50 ± .39	6.57 ± .24	6.88 ± .38	6.01 ± .38	5.99 ± .25	5.81 ± .38	6.05 ± .39	6.84 ± .38	.58
Number	7	19	10	16	21	15	6	19	—
Cooking loss, %	23.46 ± 2.26	24.47 ± 1.26	25.19 ± 1.72	24.30 ± 1.41	24.06 ± 1.16	22.80 ± 1.47	25.37 ± 2.39	23.79 ± 1.32	.50
Cooking rate, min	31.90 ± 1.63	28.48 ± .91	27.99 ± 1.24	25.40 ± 1.01	28.21 ± .83	26.53 ± 1.06	30.94 ± 1.72	26.15 ± .95	.64
Shear force, kg	3.34 ± .30	3.90 ± .16	3.89 ± .22	4.06 ± .18	3.87 ± .15	3.70 ± .20	3.33 ± .31	3.43 ± .17	.02

[a]Palatability characteristics: 10 = extremely tender, extremely juicy, extremely flavorful, and extremely acceptable; 1 = extremely tough, extremely dry, extremely unflavorful, and very unacceptable.

progeny of WSU crossbred (802) and commercial crossbred cows (740), respectively (data not shown). The offspring of the commercial crossbred cows had higher ($P < .05$) mean fat luster scores (4.0) than the mean of progeny of WSU crossbred cows (3.6). The progeny of the WSU Angus cows had higher ($P < .05$) average meat firmness scores (4.0) than the mean of offspring of the WSU crossbred and commercial crossbred cows (3.4).

Results for heifers (average weight, 393 kg) and steers (average weight, 421 kg) were generally as expected (Hendrick et al., 1989). Heifers grew more slowly and had higher dressing percentage (61%), lower carcass weights (178 kg), older maturity scores (116), and greater fat thickness (2.8, cm) than steers, which had means of 60%, 191 kg, 76, and 2.3 cm for dressing percentage, hot carcass weight, maturity score and fat thickness, respectively ($P < .05$). The color scores and the brightness scores were higher for heifers than for the steers ($P < .05$). Color scores for both sexes were very acceptable, indicating dark-cutting beef was not a problem.

Shear Force and Palatability Characteristics. Least squares means of sires for palatability characteristics from steers and heifers are presented in Table 4. New sires had lower shear force values than Old sires ($P = .02$) (Table 4). Shackelford et al. (1991a) reported that threshold levels of consumer dissatisfaction for Warner-Braztler shear force were 4.6 kg for retail beef and 3.9 kg for food-service beef. Old Wagyu sires had 67% and New Wagyu sires had 100% of the values below the 3.9-kg threshold, and Old and New sires had 100% of the values below the 4.6-kg threshold.

The difference in shear force values between the Wagyu sires was related to the amount of marbling. When including marbling as a covariate there were no significant differences between sires. In our study, marbling was negatively correlated to shear force ($r = -.31$, $P < .05$). There is evidence suggesting that marbling (Gilpin et al., 1965; Breidenstein et al., 1968; Parrish, 1974; Miller et al., 1996) may be associated with beef tenderness and palatability. One of the largest studies on the relationship between marbling and beef longissimus dorsi muscle tenderness was reported by Shackelford et al. (1991b). This study involved 1,602 calf-fed steers of different cattle types, and it clearly showed that Warner-Bratzler shear force decreased ($P < .05$) and sensory panel tenderness increased ($P < .05$) with increases in degree of marbling.

In the present study, marbling was also positively correlated ($P < .05$) to flavor ($r = .41$), tenderness ($r = .36$), and juiciness ($r = .21$). Our correlation of flavor with marbling was higher than that reported by Seideman et al. (1988) ($r = .16$, $P < .05$) and lower for tenderness than that indicated by the same author ($r = .59$, $P < .05$). In addition, the correlation for juiciness ($r = .16$, $P < .05$) reported by Seideman et al. (1988) was lower than that obtained in our study.

Implications

Genetic differences in carcass characteristics between Old and New Wagyu sires show that it is possible to identify sires that excel in marbling and ribeye area with less subcutaneous fat. The sires with the most desirable carcass characteristics also had excellent palatability attributes. However, the effectiveness of selecting for more than one trait simultaneously depends on genetic correlations between traits within Wagyu sires; therefore, more research has to be done to evaluate genetic correlations for these specific traits. This study clearly indicates the genetic superiority of New Wagyu sires to produce progeny with lower shear force values, larger ribeye areas, and more marbling compared to Old Wagyu sires.

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