Multivariate analysis of deboning data for classifying Hanwoo (Korean native cattle) by gender

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Gender is an important factor in determining the market price of Hanwoo, but its discrimination is impossible after deboning. This study aims at identifying the variables in Hanwoo deboning data that could be used for gender identification and classification. Deboning data of Hanwoo were analysed by discriminant function analysis. Seven pre-deboning and 24 post-deboning variables were identified and showed 91.3% and 98.9% accuracy in gender identification respectively. Discriminant power was 98.9% on using all 31 deboning variables. This result suggests that physical characteristics of meat parts are suitable factors for classification of beef by gender.

Keywords: Beef gender, discriminant function analysis, gender classification, Hanwoo, deboning data.

BEEF consumption per capita in South Korea has increased because of preference for high-quality food owing to the high standard of living. This has promoted consumer-driven sales and distribution of livestock products[1,2]. The recent trend of preference for high-quality beef along with food safety concerns continuously stimulates consumers' interest in Korean native cattle called Hanwoo. Besides its freshness and short transport route to consumers (as compared to imported beef), Hanwoo has a unique taste suitable for Koreans. It has been reported that Hanwoo has higher protein content in the parts called loin and sirloin, and higher fat, collagen, and mono-unsaturated fatty acid contents when compared to imported beef[3]. However, despite the preference for (and excellent quality of) Hanwoo, the price competitiveness of Hanwoo is not sufficient to catch up with increased meat consumption[4,5]. This is because the pricing of Hanwoo is considerably more sensitive to costs production and management that are much higher than that of other livestock products[6].

Several factors influence the price of Hanwoo, such as carcass characteristics, the number of raised Hanwoo, the amount of imported beef, consumption levels, and cost of feeding[7]. In particular, in individual animals' weight and gender, which are related to beef quality, and carcass composition are the most critical determinants of carcass yield grade, meatiness and consequently the market price[8,9]. For this reason, some studies have been conducted on various quality factors of beef and Hanwoo, such as gender characteristics of a beef carcass[10–12], nutritional effects of forage on meat quality[13], dielectric properties[14,15], comparison of Hanwoo to another variety of meat[16]. The effect of price on various parameters such as dressing percentage, weight, physical condition, breed, sales area, age, etc.[17] and differences in quality factors between the genders and grades[18]. Despite inconsistent results of previous studies, it is true that there is a price difference in Hanwoo meat between genders. A study on the effect of back-fat thickness (BFT) on carcass grade and the price of a female and steer showed that the price gradually increases until 13–15 mm but slowly decreases after that in both female and steer Hanwoo[19]. Another study in US investigated the change in price according to the weight of cows and steers, indicating that carcass price was likely to decrease with heavier weight in both cases[20]. Moreover, the price of a cow was higher than that of a steer, but was lowered after it exceeded a certain weight. As shown in earlier studies, the quality of beef is known to be influenced by various factors, but the data vary among different studies. For this reason, the method of evaluating the grade slightly differs among countries, and sometimes gender is not a practical factor for price estimation. Nonetheless, the actual market price in South Korea tends to reflect the gender, suggesting that the consideration of gender in price estimation is necessary.

To stabilize the Hanwoo price, the Government and stockbreeding farms have invested in relevant efforts, such as providing a subsidy for calf production and various consumption promotion events. The price is still unstable, causing frequent fraudulent sales and illegal distribution. For example, cows are generally assigned a price higher than bulls and steers because of their lower meat production per carcass, lower appearance frequency of high grade, and importance in breeding compared to bulls and steers. As a result, several fraud cases have

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Table 1. General statistics on carcass traits with data on Hanwoo

Deboning stage	Variables	Bulls (94)	Cows (96)	Steers (75)
Pre-deboning	Cold carcass weight (kg)	346.61 ± 39.94[a]	277.23 ± 46.03[b]	350.70 ± 53.96[a]
	Rib-eye area (cm^2)	87.33 ± 8.31[a]	76.64 ± 9.13[b]	84.04 ± 10.95[a]
	Back-fat thickness (mm)	4.23 ± 2.13[a]	7.75 ± 3.89[b]	7.72 ± 2.95[b]
	Moisture (%)	73.22 ± 2.10[a]	70.73 ± 2.76[b]	66.35 ± 3.19[c]
	Cooking loss (%)	22.57 ± 3.16[a]	19.67 ± 3.80[b]	20.78 ± 3.49[b]
	Shear force (kg/cm^2)	7.73 ± 2.32[a]	7.90 ± 1.83[a]	4.57 ± 1.29[b]
	Water-holding capacity (%)	52.46 ± 3.81[a]	53.09 ± 2.25[a]	56.39 ± 2.17[b]
Post-deboning	Retail cuts weight (kg)	212.99 ± 24.60[a]	157.08 ± 22.08[b]	192.97 ± 29.34[c]
	Body fat (kg)	35.42 ± 11.63[a]	38.63 ± 14.97[a]	58.20 ± 14.80[b]
	Bone (kg)	48.98 ± 5.88[a]	40.05 ± 4.29[b]	44.61 ± 5.12[c]
	Visceral fat (kg)	35.30 ± 21.98[a]	33.64 ± 15.29[a]	36.67 ± 11.48[a]
	Tender loin (kg)	5.86 ± 0.62[a]	5.12 ± 0.72[b]	6.03 ± 0.93[a]
	Hanging tender (kg)	0.97 ± 0.28[a]	0.73 ± 0.17[b]	0.97 ± 0.25[a]
	Strip loin (kg)	7.21 ± 0.91[a]	6.27 ± 1.12[b]	7.78 ± 1.44[c]
	Loin (kg)	41.05 ± 5.02[a]	27.11 ± 5.28[b]	34.02 ± 6.05[c]
	Chuck (kg)	16.51 ± 3.04[a]	8.71 ± 1.64[b]	10.96 ± 2.18[c]
	Top round (kg)	22.99 ± 2.58[a]	18.31 ± 2.28[b]	20.69 ± 2.99[c]
	Bottom round (kg)	34.63 ± 4.11[a]	27.95 ± 3.54[b]	32.47 ± 4.62[c]
	Blade (kg)	28.38 ± 3.32[a]	20.93 ± 3.02[b]	26.31 ± 4.56[c]
	Fore-shank (kg)	7.64 ± 0.87[a]	5.76 ± 0.73[b]	7.38 ± 0.97[a]
	Hind-shank (kg)	7.98 ± 0.98[a]	6.46 ± 0.80[b]	7.79 ± 1.11[a]
	Brisket (kg)	32.38 ± 3.82[a]	22.63 ± 3.79[b]	29.29 ± 4.86[c]
	Flank (kg)	8.78 ± 1.30[a]	7.09 ± 1.36[b]	9.28 ± 1.81[a]
	Rib (kg)	47.29 ± 7.43[a]	41.42 ± 8.91[b]	54.57 ± 10.87[c]
	Fore-leg bone (kg)	7.44 ± 0.76[a]	5.56 ± 0.60[b]	7.04 ± 0.86[c]
	Hind-leg bond (kg)	9.25 ± 0.96[a]	7.46 ± 0.77[b]	9.09 ± 1.00[a]
	Tail (kg)	11.09 ± 1.15[a]	9.32 ± 1.20[b]	9.95 ± 1.49[c]
	Knee bone (kg)	1.42 ± 0.20[a]	1.20 ± 0.20[b]	1.48 ± 0.23[a]
	Doggy bone (kg)	20.02 ± 2.85[a]	16.52 ± 1.89[b]	17.05 ± 1.93[b]
	Flank fat (kg)	34.46 ± 11.57[a]	37.77 ± 14.84[a]	55.65 ± 15.55[b]
	Tail fat (kg)	1.04 ± 0.33[a]	0.86 ± 0.30[b]	1.19 ± 0.49[a]

Results are expressed as mean ± SD. Means with the same letter in the same rows are not significantly different ($p > 0.05$).

been reported where steers are disguised as locally raised cows[21]. Nevertheless, most previous studies have focused on grade, quality, and physicochemical traits of Hanwoo, and only a limited number of studies have addressed the criteria and characteristics of gender classification. This study aims at classifying Hanwoo by gender via statistical management of pre- and post-deboning data. In particular, we first identified effective meat parts or quality factors that can be used as a criteria for gender classification of Hanwoo carcasses. The selected criteria were then applied to classify Hanwoo as male, female and steers. We then proposed statistical algorithms to show accuracy of classification.

Materials and methods

Database description

The database used for the gender classification through multivariate analysis was deboning data on Korean cattle from 2005 to 2008, and this dataset composed of various variables, including weight of a specific part of meat, carcass data, and quality grade. The total number of bulls, cows, and steers were 94, 96, and 75 respectively, while the total number of variables was 31. Because carcass yield and quality grade are determined before deboning, we categorized the database into two categories; pre- and post-deboning data. As a result, there were 7 and 24 variables for pre- and post-deboning datasets respectively. To be precise, pre-deboning data included cold carcass weight, ribeye area, back-fat thickness, moisture, cooking loss, shear force, and water-holding capacity. There were 24 variables in the post-deboning dataset: weight of retail cuts, body fat, bone, visceral fat, tender loin, hanging tender, strip loin, loin, chuck, top round, bottom round, blade, fore-shank, hind-shank, brisket, flank, rib, fore-leg bone, hind-leg bone, tail, knee bone, doggy bone, flank fat and tail fat. The characteristics and comparison of groups by means of each variable, with separation by gender, are presented in Table 1. The comparison in Table 1 was performed by analysis of variance (ANOVA) and Tukey's test.

Discriminant function analysis

This is a multivariate statistics method generally used for classifying two or more populations. Discriminant function analysis (DFA) involves discriminant functions (DFs), which are created from a set of a linear combination of independent variables, and they were used to classify data points into corresponding groups[22]. The basic principle behind creation of a DF is to find a new axis that maximizes the variance between groups of dependent variables, meaning that intergroup variance is divided by intragroup variance. The linear discriminant is expressed as

$$z = a + w_1x_1 + w_2x_2 + w_3x_3 + \cdots + w_nx_n, \quad (1)$$

where z is the discriminant score, a the intercept, w_j the discriminant weights of the jth independent variable and x_j is the jth independent variable.

Because of its classification ability, DFA has been widely used in agriculture and food production. For example, DFA has been applied to classify geographic origins of beef on the basis of data acquired by mass spectrometry[23] and was used for analysing image processing to discriminate tough and tender meats in bulls[24]. In addition, DFA was applied to near-infrared spectroscopy data to screen beef hamburgers for defective ones[25]. The taste grade of Hanwoo beef was also classified by DFA[26]. For this reason, we selected DFA to identify the variables effective at gender classification and to develop the DFs that could classify deboning data by gender with high accuracy.

Statistical software

Statistical analysis was performed using the SAS software package (ver. 9.4, SAS Institute Inc., Cary, NC, USA) and SPSS Statistics (ver. 22, SPSS Inc., Chicago, IL, USA). Statistical significance was assumed when the p value was less than 0.05.

Results and discussion

DFA with all variables

Applying DFA to the total of 31 variables, Hanwoo was classified with 98.9% accuracy. The first DF (DF1) and the second DF (DF2) accounted for 61.6% and 38.4% of the total variance respectively. In the case of DF1, the most significant factor was chuck: it was able to correctly identify 192 out of 265 (72.8%) meat samples, including 76 out of 94 bulls and 74 out of 96 cows. For both bulls and cows, the remaining samples (18 bulls and 22 cows) were erroneously identified as steers. This classification resulted from the weight difference in chuck by gender; the weight of chuck was found to be significantly different and can be ranked as follows: bulls ≥ steers ≥ cows. Discriminant power increased up to 74.3% with the addition of loin, whose weight also differs by gender. The loin was the heaviest in bulls, whereas cows had the smallest loin. This gender classification by means of the difference in chuck and loin weights is consistent with the finding that the average carcass weight as well as meat production of bulls is larger than cows and steers[21]. Moreover, meat weight for sale has been reported to be ranked in the order bulls ≥ steers ≥ cows in all market weight data[27], showing consistency with our present finding that the larger the amount of meat, the more likely it is to belong to a bull. Next, fore-leg bone was added to chuck and loin, and this combination correctly classified 222 of 265 Hanwoo meat samples, thus yielding the largest increase in discriminant power (+9.5%). In particular, 90 among 96 cows were correctly discriminated (93.7%), while the accuracy was increased by 10% for steers, at discriminant power of 72%, and 83% for bulls. Other studies indicated that both the weight and ratio of bones in a carcass are higher in bulls than in cows and steers[27]. For this reason, the rationale for the drastic increase in discriminant power (+17.8%) in cows may be due to the large difference in bone weight when compared to bulls and steers (Table 1). Subsequently, weights of brisket and retail cuts were identified as meaningful variables for the first DF by gender. In addition, moisture and shear force were significant factors of DF2, which we will discuss in the results of the analysis of pre-deboning data.

Table 2 shows the structure matrix presenting a correlation between each variable and a standardized canonical DF. The standardized discriminant coefficients can be used to investigate the discriminant power of each independent variable, but the reliability of discriminant power may decrease due to multicollinearity. For this reason, DF loading, representing a correlation between a variable and DF, is more useful in this regard. In general, a variable with DF loading greater than 0.3 is considered significant (effective at discrimination)[28]. Wilks' lambda, another statistical index, is used to determine whether there is a difference between group means when the variance within the group is less than the total variance. Therefore, discriminant power increases as Wilks' lambda of the DF approaches zero. In the case of DF1 and DF2, the values were 0.019 and 0.168 respectively, suggesting that the functions were significant ($p < 0.05$). In addition, canonical correlation coefficients of DF1 and DF2 were 0.943 and 0.912 and were close to 1.0, meaning that the discriminant power exerted by DFs was reliable[29].

In conclusion, discriminant analysis using all variables could derive significant DFs, and this result suggests that the current deboning variables can classify Hanwoo meat by gender. In particular, the main factor that successfully classified the Hanwoo meat by gender is the weight difference between some meat parts.

DFA with variables before deboning

We then subdivided the deboning data into pre- and post-deboning variables as previously mentioned. As a result of the use of seven pre-deboning variables, discriminant power reached 91.3%, and the first discriminant function explained 60.2% of variance caused by gender. Wilks' lambda value was significant (0.151), and the canonical correlation coefficient was 0.811, suggesting that the discriminant ability of DF was high enough. Because a significant correlation was observed among pre-deboning variables, the discriminant function loading in the structure matrix was indexed for selection of variables important for gender discrimination. The meaningful variables of DF1 were moisture, back-fat thickness, shear force, and water-holding capacity, and discriminant power was 69.4% with these variables. Additionally, shear force and water-holding capacity showed higher correlation in DF2 than in DF1 (Table 3). The moisture variable correctly identified 78.7% of bulls, and 73.3% of steers, but the discriminant power involving moisture was only 50% accurate in cows. This problem may be due to the difference in moisture contents. The moisture content was the highest in bulls but lowest in steers. Cows had an intermediate moisture content (between bulls and steers), indicating lower discriminant power in cows. This finding is consistent with one study that revealed a difference in moisture content by gender: bulls (73.23%), cows (70.65%), and steers (62.32%)[11]. Nonetheless, we may need to consider that bulls do not always have the highest moisture content and it is variable depending on the marbling score. In general, beef with a lower marbling score tends to contain more moisture[30–32]. In addition, another study showed a significant correlation between moisture content and fat ($r = -0.92$, and $p < 0.01$)[33]. This finding may be related to back-fat thickness, which is the second significant factor among the predeboning variables, and it was ranked in the order bull ≤ steer ≤ cow. The results of ANOVA indicated that back-fat thickness of bulls was significantly different from that of cows and steers, but it was not significantly different between cows and steers. This is why the discriminant power of bulls increased by 5.3%, when compared to cows (2.1%) and steers (0%) with the addition of back-fat thickness into DFA, and the overall discriminant power increased up to 69.4% (+2.6%). The difference in back-fat thickness resulting in an increase in discriminatory ability was demonstrated in another study showing that average back-fat thickness of Hanwoo steers is ~0.64 mm thicker than that in cows, and that gender affects carcass grade and price[19]. Addition of shear force – the third significant predeboning variable – into DF1, resulted in discriminant power of 75.8%, yielding the largest increment in the overall discriminant power. This is because sheer force in the steer group was significantly different from that in cows and bulls ($p < 0.05$ in ANOVA), facilitating the discrimination of steers from cows and bulls. A study on shear force in beef showed that this force is significantly different in each meat part and tends to decrease with increasing meat quality grade[34]. This result suggests that shear force could be a criterion for gender classification as well as a factor of quality indices. When we added water-holding capacity, which is the fourth significant variable, into DF1, the

Table 2. Significant variables in the structure matrix used for classifying Hanwoo meat by gender

Variables	Discriminant function loading DF1	Discriminant function loading DF2	Discriminant power (%)
Chuck*	0.508	–0.049	72.8
Loin*	0.372	–0.142	74.3
Fore-leg bone*	0.333	–0.283	83.8
Brisket*	0.321	–0.217	83.4
Retail cuts weight*	0.306	–0.186	85.7
Fore-shank	0.282	–0.278	87.2
Blade	0.276	–0.205	89.8
Top round	0.258	–0.104	94.7
Bone	0.250	–0.101	95.5
Doggy bone	0.246	0.018	95.1
Bottom round	0.224	–0.149	95.5
Tail	0.210	–0.039	96.2
Back-fat thickness	–0.190	–0.045	97.0
Rib-eye area	0.154	–0.106	97.4
Cooking loss	0.124	–0.028	97.7
Moisture*	0.230	0.356	98.1
Shear force*	0.066	0.339	99.2
Body fat	–0.104	–0.286	99.6
Rib	0.039	–0.281	99.6
Hind-leg bone	0.246	–0.269	99.6
Flank fat	–0.099	–0.259	99.6
Cold carcass weight	0.177	–0.247	99.6
Flank	0.122	–0.241	99.6
Water holding capacity	–0.089	–0.232	99.2
Strip loin	0.075	–0.221	99.2
Knee bone	0.119	–0.219	99.2
Hind-shank	0.201	–0.206	99.2
Tender loin	0.108	–0.197	98.9
Hanging tender	0.121	–0.151	98.9
Tail fat	0.037	–0.150	98.9
Visceral fat	0.008	–0.031	98.9

*Identified as significant variables yielding the absolute value of discriminant function loading greater than 0.3 in DF1 and DF2.

Table 3. Discriminant loading of the structure matrix and significant variables for pre-deboning

Variables	Discriminant loading DF1	Discriminant loading DF2	Discriminant power (%)
Moisture*	0.655	–0.423	66.8
Back-fat thickness*	–0.384	–0.104	69.4
Cooking loss	0.215	0.172	74.0
Cold carcass weight*	0.177	0.622	86.8
Shear force*	0.337	–0.553	89.1
Rib-eye area*	0.222	0.344	90.2
Water holding capacity*	–0.313	0.335	91.3

*Identified as significant variables yielding the absolute value of the discriminant function loading greater than 0.3 in DF1 and DF2.

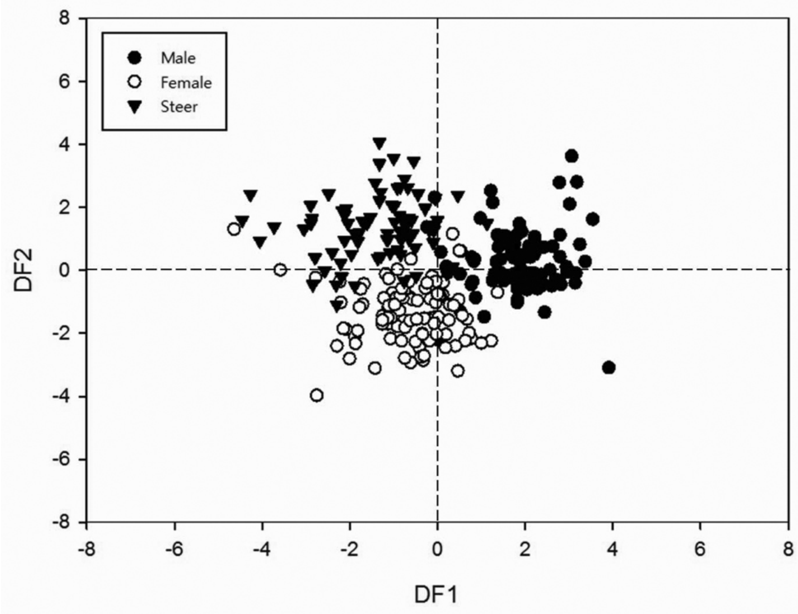

Figure 1. Scatter plot of gender classification by using DFA applied for pre-deboning variables.

Table 4. Discriminant loading of the structure matrix and significant variables for post-deboning

Variables	Discriminant loading DF1	Discriminant loading DF2	Discriminant power (%)
Chuck*	0.536	–0.092	72.8
Loin*	0.409	0.060	74.3
Fore-leg bone*	0.391	0.240	83.8
Brisket*	0.368	0.164	83.4
Retail cuts weight*	0.347	0.132	85.7
Fore-shank*	0.338	0.250	87.2
Blade*	0.320	0.163	89.8
Hind-leg bone	0.299	0.250	90.2
Top round	0.285	0.047	94.7
Bone	0.276	0.047	96.6
Bottom round	0.256	0.112	97.7
Doggy bone	0.252	–0.095	97.4
Hind-shank	0.242	0.187	97.4
Tail	0.225	–0.016	97.4
Hanging tender	0.150	0.145	97.7
Body fat*	–0.063	0.374	98.5
Flank fat*	–0.061	0.340	98.9
Rib	0.084	0.296	98.5
Flank	0.165	0.252	98.9
Strip loin	0.114	0.243	98.9
Knee bone	0.158	0.227	98.9
Tender loin	0.144	0.204	99.2
Tail fat	0.062	0.169	98.9
Visceral fat	0.013	0.034	98.9

*Identified as significant variables yielding the absolute value of discriminant function loading greater than 0.3 in DF1 and DF2.

total discriminant power did not change and remained at 75.8%. In particular, the number of discriminated individuals slightly changed, but the number of individuals discriminated into correct gender stayed the same. Based on the results of ANOVA, the average water-holding capacity and shear force in steers was significantly different from those in bulls and cows, in agreement with a study by Lee *et al.*[11] suggesting that water-holding capacity in steers is the highest but is not different between cows and bulls. Consequently, the effect of water-holding capacity on the gender classification algorithm of DFA was similar to that of shear force, probably resulting in unchanged discriminant power. Furthermore, the first meat quality grade of steers showed the highest water-holding capacity index, indicating that water-holding capacity may be more effective at assessing meat quality within the gender because of its positive correlation with the marbling score[17].

Overall, it is conclusive that moisture, back-fat thickness, shear force, and water-holding capacity among pre-deboning variables were identified here as significant factors in DF1 for gender classification of Hanwoo meat. Additional variables, such as rib-eye area, cooking loss, and cold carcass weight were less significant in DF1 as compared to the aforementioned variables, but they could increase the discriminant power up to 85.3%, 87.9% and 91.3% respectively. Cold carcass weight, shear force, moisture, rib-eye area, and water-holding capacity were meaningful variables in DF2. That is, all the pre-deboning variables except cooking loss were effective in the DFs. Specifically, variables' shear force and water-holding capacity were effective in DF1, and both had a higher correlation in DF2. Their low significance in DF1 could be explained by the results of ANOVA, which revealed that the three above-mentioned variables did not differ by gender. Figure 1 shows a scatter plot of the pre-deboning variables with coordinates constructed by DF

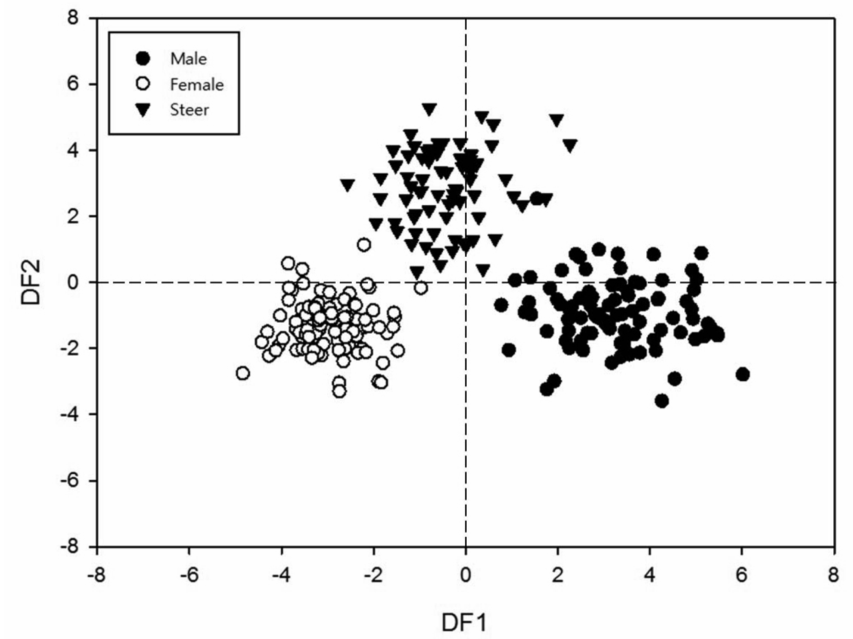

Figure 2. Scatter plot of gender classification by using DFA applied for post-deboning variables.

Table 5. Discriminant power when we used significant variables in DF1 and DF2

	DF1		DF2		
	Significant variables	DP[a]	Significant variables	Total DP[b]	Total variables
Total	Chuck, loin, fore-leg bone, brisket, retail cuts weight	85.7%	Moisture, shear force	93.6%	98.9%
Pre-deboning	Moisture, back-fat thickness, shear force, water holding capacity	75.8%	Cold carcass weight, shear force, moisture, rib-eye area, water holding capacity	91.3%	91.3%
Post-deboning	Chuck, loin, fore-leg bone, brisket, retail cuts weight, fore-shank, blade	89.8%	Body fat, flank fat	92.1%	98.9%

[a]DP, Discriminant power. [a]Total DP, Accumulated discriminant power for both DF1 and DF2.

loadings in the structure matrix, revealing that Hanwoo was classified successfully by pre-deboning variables, but there were some instances of misclassification.

DFA with variables after deboning

DF loading in the structure matrix was compared among post-deboning variables because of multicollinearity (Table 4). The DFA result on post-deboning variables was the same as the result on all variables in terms of the identified significant variables. Among the post-deboning variables comprising divided meat, bone, and fat, DFA indicated that chuck was the most significant variable for gender classification, explaining 72.8% of variation caused by gender. With chuck, 80.9% of bulls were classified correctly, while the remaining meat samples were incorrectly assigned to steers. For cows, 77.1% of samples were adequately discriminated, but 22.9% were misclassified as steers. The addition of the second variable, i.e. loin, increased discriminant power by 1.5%, to 74.3%. This small increase might be explained as follows: the weight difference in loin by gender has a tendency similar to that observed in chuck: meat with higher weight is likely to be classified as bulls whereas lower-weight meat is considered to come from cows. The discriminant power was increased by 10% to 83.8% after fore-leg bone was added. There was large increment in cow discrimination (18% increase), and steers also showed a 10% increase in discriminant power. This large improvement in discriminant power was due to a large difference in the average weight of fore-leg bone between bulls and steers. Addition of the next variable, which was brisket, reduced the overall discriminant power by 0.4%. However, subsequent addition of weight of retail cuts increased the discriminant power only by 2.3%, and a 3% increment was seen after addition of fore-shank and blade, yielding the overall discriminant power of 89.8%.

Table 6. Gender classification results when we used all available deboning data

	Bulls (94)			Cows (96)			Steers (75)		
	A	B	C	A	B	C	A	B	C
Total variables	93	1	98.9	96	0	100	74	1	98.7
Before deboning	86	8	91.5	89	7	92.7	67	8	85.3
After deboning	93	1	98.9	95	1	98.9	74	1	98.7

A, Correctly classified number; B, Misclassified number; C, Discriminant power (%).

This result was the same as the finding on the discriminant power for all variables, suggesting that gender discrimination is possible only with significant variables.

Among post-deboning variables, the significant variables in DF1 were chuck, loin, fore-leg bone, brisket, weight of retail cuts, fore-shank, and blade for DF loading, but brisket reduced the overall discriminant power. The significant variables in DF2 were body fat and flank fat. The accuracy of gender classification was 89.8% with these variables, and yielded 98.9% accuracy when we used all 24 post-deboning variables. Figure 2 shows a scatter plot of the post-deboning variables with coordinates constructed by means of DF loadings in the structure matrix, indicating that Hanwoo was successfully classified by gender using post-deboning variables.

Analysis of gender classification by all or significant variables

Table 5 shows significant variables used in either DF1 or DF2 with good discriminant power. The result suggests that significant variables among all, pre-deboning, or post-deboning variables could classify the Hanwoo gender with 93.6%, 91.3% and 92.1% discriminant power, respectively. This result suggests that the use of significant variables may be more effective than the use of all variables because there was only a ~6% difference in discriminant power between all variables and significant variables. Table 6 shows the results of individual classification by gender with discriminant power, i.e. classification accuracy, when we used all available variables. Finally, post-deboning variables showed higher classification accuracy than pre-deboning variables, and the result was consistent with the data from application of both pre- and post-deboning variables simultaneously. These results suggest that post-deboning variables, i.e., the beef part in the market, are more useful than physicochemical properties evaluated before deboning.

Conclusion

It has been reported that consumers prefer Hanwoo to imported beef, and cows to steers and bulls because of the recent increase in high-quality beef consumption. As a result of high-quality fattening in Hanwoo, the appearance ratio of the 1+ grade is expected to increase, but illegal distribution of Hanwoo via gender fraud may continue because of the high price of Hanwoo. On the other hand, it is possible to weaken the quality and price competitiveness of Hanwoo as high-quality, low-price beef continues to be imported. This means that strict classification by gender and quality control are urgently needed. Besides, it is necessary to strategically solve the supply and consumption of Hanwoo by improving the structure of beef distribution. For example, intensification of the beef traceability system would help acquire the trust of consumers. To provide basic information and to demonstrate the possibility of gender discrimination of meat by means of various deboning variables, in this study, we classified Hanwoo by gender using features of deboning parts and an appropriate statistical algorithm. Gender discrimination reached 98.9% using only the simple deboning parts, suggesting that deboning data and DFA could be used for gender classification of Hanwoo instead of expensive analytical tools, such as an electronic nose, PCR, or DNA analysis. However, a more accurate and significant DF is necessary that involves not only the carcass and meat features but also factors that affect the quality grade and sensory characteristics.

Conflict of interest: The authors declare that there is no conflict of interest.

1. Kim, G. J., Byun, G. I. and Jung, W. S., A study on the potential effects of consumer preference for beef and involvement in the attributes of beef selection on consumers' purchase intentions. *Korean J. Culin. Res*., 2009, **15**, 286–298.
2. Han, S. W. and Lee, B. O., A study on the purchaing behaviour of consumers for domestic and imported beef in Korea. *J. Agric. Life Sci*., 2010, **22**, 73–89.
3. Cho, S. H. *et al*., Meat quality and nutritional properties of Hanwoo and imported Australian beef. *Korean J. Food Sci. Anim. Resour*., 2011, **31**, 772–781.
4. Jeong, S. B., In Proceedings the KSAM '97 Summer Conference, The Korean Society for Agricultural Machinery, 1997.
5. Yang, S. Y., Lim, S. D., Jeon, K. H., Nam, K. B., Kwon, S. A. and Park, J. E., Comparison of vitamin A, E, and cholesterol contents and the sensory properties of chilled Hanwoo and Australian beef. *Korean J. Food Sci. Anim. Resour*., 2007, **27**, 262–266.
6. Statistics Korea, 2015 Investigation in Animal Cost of Production, 2016; http://kostat.go.kr

7. Choi, N. H., Causal loop analysis and policy simulation on the fluctuation of Korean cattle price. *Korean Syst. Dyn. Rev*., 2013, **14**, 135–163.
8. Farrow, R. L., Loneragan, G. H., Pauli, J. W. and Lawrence, T. E., An exploratory observational study to develop an improved method for quantifying beef carcass salable meat yield. *Meat Sci*., 2009, **82**, 143–150.
9. Sami, A. S., Augustini, C. and Schwarz, F. J., Effects of feeding intensity and time on feed on performance, carcass characteristics and meat quality of Simmental bulls. *Meat Sci*., 2004, **67**, 195–201.
10. Garcia, L. G. *et al.*, National Beef Quality Audit–2005: Survey of targeted cattle and carcass characteristics related to quality, quantity, and value of fed steers and heifers. *J. Anim. Sci*., 2008, **86**, 3533–3543.
11. Lee, J. M. *et al.*, Effect of sex on quality grade factors, Physicochemical and sensory traits of longissimus dorsi in Hanwoo. *Korean J. Food Sci. Anim. Resour*., 2010, **30**, 321–327.
12. Choat, W. T., Paterson, J. A., Rainey, B. M., King, M. C., Smith, G. C., Belk, K. E. and Lipsey, R. J., The effects of cattle sex on carcass characteristics and longissimus muscle palatability. *J. Anim. Sci*., 2006, **84**, 1820–1826.
13. Aldai, N., Aalhus, J. L., Dugan, M. E. R., Robertson, W. M., McAllister, T. A., Walter, L. J. and McKinnon, J. J., Comparison of wheat- versus corn-based dried distillers grains with solubles on meat quality of feedlot cattle. *Meat Sci*., 2010, **84**, 569–577.
14. Hoque, M. A., Hosono, M., Oikawa, T. and Suzuki, K., Genetic parameters for measures of energetic efficiency of bulls and their relationships with carcass traits of field progeny in Japanese Black cattle. *J. Anim. Sci*., 2009, **87**, 99–106.
15. Park, C. J. and Park, Y. I., Estimation of genetic correlations for the growth and carcass traits in Hanwoo. *J. Anim. Sci. Technol*., 2002, **44**, 685–692.
16. Hwangbo, S., Rhim, T. J. and Chung, K. Y., Identification of species-specific components between Hanwoo and Aberdeen angus meat. *J. Anim. Sci. Technol*., 2001, **43**, 941–948.
17. Mintert, J., Blair, J., Schroeder, T. and Brazle, F., Analysis of factors affecting cow auction price differentials. *J. Agric. Appl. Econ*., 1990, **22**, 23–30.
18. Kim, J. W., Cheon, Y. H., Jang, A. R., Lee, S. O., Min, J. S. and Lee, M. H., Determination of physico-chemical properties and quality attributes of Hanwoo beef with grade and sex. *J. Anim. Sci. Technol*., 2002, **44**, 599–606.
19. Lee, J. M. *et al.*, Effect of backfat thickness on the carcass grade factors and carcass price in Hanwoo cows and steers. *Korean J. Food Sci. Anim. Resour*., 2011, **31**, 280–289.
20. Faminow, M. D. and Gum, R. L., Feeder cattle price differentials in Arizona feeder cattle price differentials in Arizona auction markets. *Western J. Agric. Econ*., 1986, **11**, 156–163.
21. Cho, S. H. *et al.*, Nutritional composition and physico-chemical meat quality properties of Korean Hanwoo bull beef. *J. Anim. Sci. Technol*., 2007, **49**, 871–880.
22. Afifi, A., May, S. and Clark, V. A., *Practical Multivariate Analysis*, CRC Press, 2011, 5th edn.
23. Lim, C. L., Son, H. J., Hong, E. J. and Noh, B. S., Discrimination of geographical origin of beef using electronic nose based on mass spectrometer. *Korean J. Food Sci. Technol*., 2008, **40**, 717–720.
24. Li, J., Tan, J. and Shatadal, P., Classification of tough and tender beef by image texture analysis. *Meat Sci*., 2001, **57**, 341–346.
25. Ding, H. B. and Xu, R. J., Near-infrared spectroscopic technique for detection of beef Hamburger adulteration. *J. Agric. Food Chem*., 2000, **48**, 2193–2198.
26. Cho, S. H., Seo, G., Kim, D. H. and Kim, J. H., Palatability grading analysis of Hanwoo beef using sensory properties and discriminant analysis. *Korean J. Food Sci. Anim. Resour*., 2009, **29**, 132–139.
27. Lee, J. M. *et al.*, Study on the carcass yield grade traits and prediction of retail product weight in Hanwoo beef. *Korean J. Food Sci. Anim. Resour*., 2008, **28**, 607–609.
28. Kim, C. G., A comparative study on the business groups classified by the Internet export marketing performance level of Korean small and medium enterprises. *J. Korea Trade*, 2008, **33**, 25–52.
29. Kirkpatrick, L. A. and Feeney, B. C., *A Simple Guide to IBM Spss Statistics For Version 23.0*, Cengage Learning, 2015.
30. Lee, J. M. *et al.*, Effect of quality grades on carcass characteristics, physico-chemical and sensory traits of Longissimus Dorsi in Hanwoo. *Korean J. Food Sci. Anim. Resour*., 2010, **30**, 495–503.
31. Lee, J. M. *et al.*, Effect of marbling score on carcass grade factors, physico-chemical and sensory traits of *M. longissimus dorsi* in Hanwoo. *Korean J. Food Sci. Anim. Resour*., 2012, **32**, 659–668.
32. Lee, Y. J. *et al.*, Chemical composition, cholesterol, trans-fatty acids contents, pH, meat color, water holding capacity and cooking loss of Hanwoo beef (Korean Native Cattle) quality grade. *Korean J. Food Sci. Anim. Resour*., 2010, **30**, 997–1006.
33. Lee, J. M. *et al.*, Effect of marbling degrees on the meat quality of Hanwoo. *Korean J. Food Sci. Anim. Resour*., 1999, **19**, 339–345.
34. Lee, Y. J. *et al.*, Warner-Bratzler shear force, sarcomere length, total collagen contents and sensory characteristics of Hanwoo beef (Korean native cattle) quality grade. *Korean J. Food Sci. Anim. Resour*., 2009, **29**, 726–735.

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