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Prediction of relationships between pork color and muscular texture traits for entrepreneurial decisions

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ABSTRACT

This study was done to examine correlation between pork color and texture traits for entrepreneurial decision-making. Most traits between both factors had significant correlations, but presented low correlation values. The first correlation in the results of canonical correlation analysis (CCA) maintained relatively high values of 47.9. The value was positive and negative contributions for hardness and gumminess, respectively. Loadings of color traits were more influenced by lightness and whiteness. However, influence of variance in texture trait showed only 7.6% with color trait. The result indicates that there is no direct influence between pork color and texture, but an indirect influence. Therefore, we suggest that consumers and distributors as well as producers apply indirect criteria rather than directly assessing texture quality by pork color.

Key words: Canonical correlation, Consumer, Distributor, Marketing, Pork quality traits, Productor.

INTRODUCTION

Quantity and quality of meat determine price of consumers to pay for meat and meat products (Adzitey and Nurul, 2011). Technological quality attributes of meat include pH value, color, texture, water holding capacity (WHC), and chemical composition. These attributes are influenced by various factors such as breed, heredity, feed, pre-slaughter treatment and stunning, slaughter method and chilling and storage conditions (Tomovic *et al*., 2014).

Pork color is an important quality attribute to consumers, and consumers prefer pork with a high intensity of pink color (Lindahl *et al*., 2001). Since consumers routinely determine depending on state of color and appearance for selection of pork or its products, suppliers of muscular food must produce pork to maintain desirable colors (AMSA, 2012; Kim *et al*., 2016a). For this reason, fresh pork color is a major concern to pork industry (Warner *et al*., 1993). Pork color is affected by pigment's content, chemical conformation, and meat structure (Lindahl *et al*., 2001; Kim *et al*., 2017). Low pH and WHC are correlated with decreases of meat tenderness, juiciness and flavor (Jeong *et al*., 2010). However, composition and color of pork *longissimus dorsi* are not affected by age and sex of animal (Radovic, 2015).

Canonical correlation analysis (CCA) is a useful multivariate technique for investigation of relationship between sets of independent and dependent variables, which are composed of one or more variables (Sahin *et al*.. 2011; Kim *et al*., 2016b). Recently, CCA has been performed in livestock field by very few studies (Jaiswal *et al*., 1995; Mendes and Akkartal, 2007; Kabir *et al.*, 2014), including a simultaneous relationship among breeding efficiency and growth and reproductive trait of buffalo (Thomas and Charkravarty, 2000).

In this study, we investigated relationship between sets of variables related to muscle texture and color traits from pigs by CCA. We suggest that demonstration of special relationship between meat color and texture traits is possible to improve production and marketing methods to induce promotion of pork consumption.

MATERIALS AND METHODS

Rearing and sample collection: Berkshire pigs of six month old (n=266, 110±10 kg) were used (Dasan Genetics, South Korea) for this study. Pigs were reared for 6 months by conventional diets in accordance with guide for care and use of laboratory animals (Gyeongnam National University of Science and Technology Animal Care Committee). After slaughter by standard method, *longissimus dorsi* muscle from each pig were collected, transferred under a refrigerated condition in a laboratory and then examined for meat quality traits.

Technological quality measurements: Texture was measured by Instron 3343 (US/MX50, A&D Co., USA). Pork *longissimus dorsi* was heated for 1 h at 80°C, and then stored for 2 h at 4°C. The treated meat was cut to 5cm x

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Table 1: Results of analysis for meat traits employed for this study (n=266).

***X* variable set**		***Y* variable set**	
Texture traits	**mean±SD**	**Color traits**	**mean±SD**
X_1 = Hardness	1.63±0.31	Y_1 = CIE L*	48.60±4.73
X_2 = Surface Hardness	1.63±0.31	Y_2 = CIE a*	7.46±1.73
X_3 = Cohesiveness	0.47±0.06	Y_3 = CIE b*	2.35±0.95
X_4 = Springiness	1.03±0.06	Y_4 = w	41.55±3.81
X_5 = Gumminess	0.77±0.19	Y_5 = c	7.87±1.77
X_6 = Chewiness	0.80±0.22	Y_6 = h	17.62±6.94
X_7 = Adhesiveness	0.22±0.07		

X_1, Hardness; X_2, Surface Hardness; X_3 Cohesiveness; X_4, Springiness; X_5 Gumminess; X_6, Chewiness; X_7, Adhesiveness; Y_1, Lightness (CIE L*); Y_2, Redness (CIE b*); Y_3, Yellowness (CIE b*); Y_4, Whiteness (w); Y_5, Chroma (c); Y_6, Hue angle (h).
* P<0.01.

5 cm x 5cm (horizontal x vertical x height) to be equilibrium with direction of muscle. Hardness, surface hardness, cohesiveness, springiness, gumminess, chewiness and adhesiveness were assayed at a state maintained with right angle with muscle. Measurement conditions were done by load cell 10 kg, adapter area 28 mm^2.

Meat and fat lightness were recorded after 30 min blooming at 1°C using a Minolta Chromameter (CR400; Minolta, Japan). To compare correlation between texture and color trait sets in pork, as shown in Table 1, muscular texture traits were selected from hardness, surface hardness, cohesiveness, springiness, gumminess, chewiness, and adhesiveness, whereas color traits were adopted by lightness (CIE L*), redness (CIE a*), yellowness (b*), whiteness (w), chroma (c), and hue angle (h), respectively.

Applications of CCA: CCA was applied for examination of relationships between two sets of color and texture traits in pork. This analysis was performed by using PROC CANCORR procedure of SAS 9.1 statistical package (SAS, 2009).

RESULTS AND DISCUSSION

Relation between meat color and muscle texture variables: Pearson correlations between texture (*X* set) and color traits (*Y* set) of pork examined from 266 pigs were able to analyze degree of correlation between two data sets (Table 2). Most of correlations between texture and color traits were significant (P<0.01), but showed lower values. Relationships between pork texture traits and lightness (CIE L*) were higher than those of the other color traits such as redness (CIE a*), yellowness (CIE b*), whiteness (w), chroma (c), and hue angle (h).

CIE L*, CIE b* and whiteness (w) showed a similar pattern as negative correlations with hardness, surface hardness, gumminess and chewiness (P<0.01). CIE b* and chroma c had negatively significant correlations with cohesiveness, springiness, gumminess, and chewiness. Hue angle (h) had negatively significant correlation with hardness and surface hardness. When compared with correlation values using cooked ham (Valkova *et al*., 2007), their values in this study exhibited higher correlations. Therefore, it was assumed that their differences were owing to differences in specific properties of Berkshire breed.

Summary of canonical correlation analysis: CCA is able to predict simultaneously relationship between two sets of variables which consist of one or more variables associated with each other (Akbas and Takma, 2005). In order to predict simultaneously relationship between texture and color trait sets, CCA were done for six pairs of canonical variate due to variables of six color traits in the smaller variable set (Table 3). The 1st canonical correlation was 0.479, which represented the highest possible correlation between any linear combinations of the texture trait (V_1) and color trait (W_1) in pork (P<0.01). The 2nd pairs of canonical correlation coefficients were 0.284. It was indicated that these results had significant relationship between the canonical variables (P<0.01). However, we found only the 1st and 2nd significant coefficients (P<0.01) among all the estimated canonical correlation coefficients from likelihood ratio test (Table 3). Therefore, we considered only the 1st and 2nd pairs having a

Table 2: Correlation matrix between color and texture traits in pork.

	Y_1	Y_2	Y_3	Y_4	Y_5	Y_6
X_1	**-0.350***	-0.076	**-0.295***	**-0.214***	-0.119	**-0.243***
X_2	**-0.350***	-0.078	**-0.296***	**-0.213***	-0.120	**-0.243***
X_3	0.126	**-0.220***	-0.057	-0.114	**-0.208***	0.104
X_4	0.116	**-0.192***	0.008	0.138	**-0.173***	0.152
X_5	**-0.332***	**-0.167***	**-0.254***	**-0.221***	**-0.193***	-0.133
X_6	**-0.263***	**-0.198***	**-0.219***	**-0.162***	**-0.212***	-0.074
X_7	-0.017	-0.142	-0.145	0.087	-0.156	-0.041

* P<0.01.

Variables are described by the same symbols as shown in Table 1.

Table 3: Summary of results obtained from canonical correlation analysis.

Canonical Variate Pair	Canonical Correlation	Squared Canonical Correlation	Eigen-value	Degree of Freedom	Likelihood Ratio	Pr > F
V_1W_1	0.479	0.230	0.298	35	0.649	<0.0001
V_2W_2	0.284	0.081	0.088	24	0.843	<0.0071
V_3W_3	0.251	0.063	0.068	15	0.917	<0.0958
V_4W_4	0.142	0.020	0.021	8	0.978	<0.6930
V_5W_5	0.036	0.001	0.001	3	0.999	<0.9527
V_6W_6	0.000	0.000	0.000	-	1.000	-

V_1; *i*th pork texture trait variables, W_1; *i*th pork color trait variables.
Variables are described by the same symbols as shown in Table 1.

significant value that describes relationship between the two groups (P<0.01). Since correlation matrix for the color traits was less than full rank, sixth canonical correlations and coefficients were probably induced into zero (Table 3).

Canonical correlations measures only correlations between linear combinations of variables rather than direct measurement of correlations between two sets of variables (Kim *et al*. 2016b). Thus, in this work, the numbers of dimension explaining relationships between pork traits were reduced from 13 to 2 by CCA (Fig 1). The first canonical correlation between texture traits (V_1) and color traits (W_1) was 0.479. However, canonical correlations tend to appear in very high association between the two original sets of variables which was sometimes exaggerated (Laessig and Duckett, 1979). Furthermore, since the squared values of canonical variate pairs were ratio of variance to be explained by a linear combination of variables, these were interpreted that 23% of variation in (V_1) was explained by variation in (W_1), but only 8.1% of variation in (V_2) was explained by (W_2). These results indicated that only the first canonical correlation was important.

The standardized canonical coefficients were shown in 1st and 2nd pairs of canonical variables in Table 4. The canonical variates representing optimal linear combinations of dependent and independent variables are defined by the standardized canonical coefficients for the first pair of canonical variables (V_1 and W_1) as follows;

$$V_1 = -3.22X_1 - 0.75X_2 - 1.77X_3 + 0.76X_4 + 3.0X_5 - 1.03X_6 + 0.47X_7$$

$$W_1 = 1.16Y_1 + 5.04Y_2 - 0.17Y_3 - 4.64Y_5 + 0.67Y_6$$

Magnitudes of canonical coefficients are significant for relative contributions to correlated variate (Cankaya and Kayaalp, 2007). In this study, the coefficients for variables of texture traits showed that the magnitudes of hardness (X_1), gumminess (X_5), and cohesiveness (X_3) have relatively large contributes to the 1st canonical variable (V_1), as -3.22, 3.0, and -1.77, respectively. Hence, if the values of gumminess are increased, texture traits are increased owing to the trend. Otherwise, if the values of hardness are increased, the texture traits are decreased. On the contrary, the coefficients for pork color traits showed that the magnitudes of lightness (Y_1), redness (Y_2), and chroma (Y_5) contribute largely to the 1st canonical variable (V_1), as 1.16, 5.04 and -4.64, respectively. Accordingly, if the values of lightness and redness are increased, the color traits are increased. Otherwise, when the values of chroma are increased, the color traits are decreased.

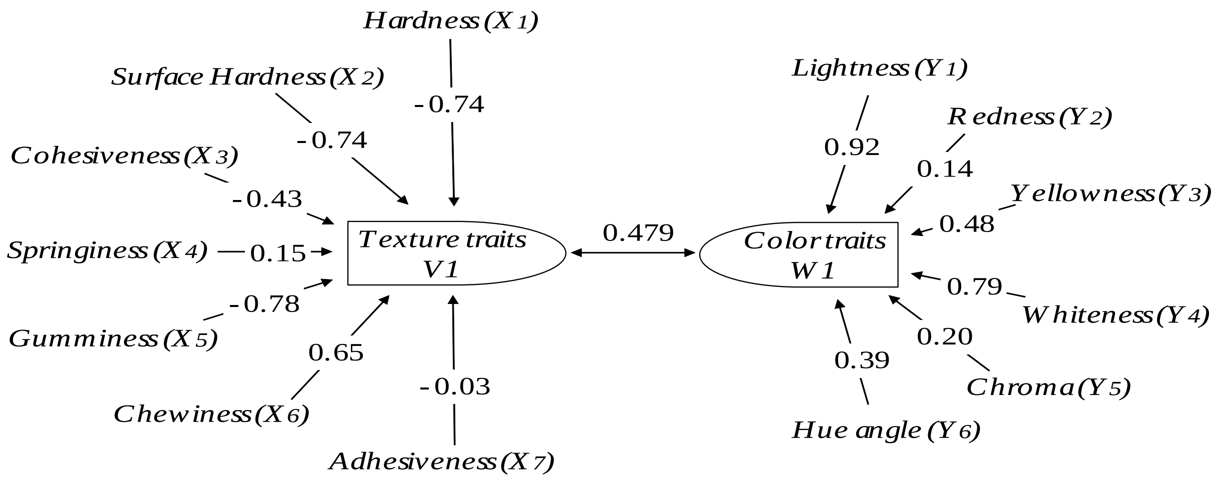

Fig 1: Correlations between the pair of canonical variables V_1 and W_1, and their canonical variables and original variables.

Table 4: Canonical coefficients standardized for canonical variables.

	X variable set								*Y* variable set					
	X_1	X_2	X_3	X_4	X_5	X_6	X_7		Y_1	Y_2	Y_3	Y_4	Y_5	Y_6
V_1	-3.22	0.75	-1.77	0.76	3.00	-1.03	0.47	W_1	1.16	5.04	-0.17	0.00	-4.64	0.67
V_2	0.10	-0.11	1.06	0.27	-0.22	-0.37	0.3	W_2	-0.29	6.01	0.18	0.00	-6.55	1.75

V_1; 1st texture trait variables, W_2; 1st pork color trait variables.
Variables are described by the same symbols as shown in Table 1.

Analysis of canonical loadings: The canonical loadings of original variables with their canonical variables were shown in Table 5. A canonical loading indicates Pearson product-moment correlation between original variable and its corresponding canonical variate. The value reflects degree to which a variable is represented by a canonical variate (Yaprak *et al*., 2008; Tahtali *et al*., 2012). In terms that variables with larger canonical loadings indicate more contributions to multivariate relationships between variables of texture and color traits in pork, the loadings for color traits suggest that lightness (L*) and whiteness (w) are more influence in variables of the texture traits (W_1) compared to the other color traits (a*, b*, c and h). Furthermore, the loadings for hardness, surface hardness, and gumminess are negative effects more than the other texture traits in variables of the color traits (V_1), except for springiness.

The canonical loadings exhibited correlations between original variables and their canonical variables, whereas the cross loadings represented correlations between original variables and opposite canonical variables. According to cross loading, the first pair of canonical variables for lightness (L*) and whiteness (w) exhibited higher relative contributes than those of the other color traits, to W_1, whereas hardness, surface hardness, and gumminess had an inverse relationship to V_1 (Table 6). If the value of lightness is increased, it is suggested that the values of gumminess, hardness, and surface hardness are decreased from results of the first canonical function. In addition, when the value of hue angle (W_1) is increased, it is assumed that the values of cohesiveness and springiness are increased from the second canonical function (Table 6).

Analysis of canonical redundancy index: Redundancy index (RI) indicates total proportion of variance to be shared by two sets of original variables. RI is designed to overcome the inflated correlations (Laessig and Duckett, 1979). The results of canonical redundancy analysis showed that 33.1% of total variation in texture trait (*X* set) is explained by 1st pair of canonical variable V_1 (Table 7). The shared variance (SV_x) of 33.1% was indicated by a proportion of the standardized variance of the texture traits explained by their own canonical variables. In particular, contribution of gumminess was the highest, whereas contribution of adhesiveness was the lowest. Otherwise, the shared variance (SV_y) of 31.8% was marked by ratio of total variance in the dependent variable set *Y* (the color trait). In other words, 31.8% for the 1st canonical variable was explained by W_1. These values were added by canonical loadings of the original variables with their canonical variables (Table 5) as follows;

$$SVx_1 = [0.74^2 + 0.74^2 + 0.43^2 + 0.15^2 + 0.78^2 + 0.65^2 + 0.03^2]/7 = 0.331$$

$$SVy_1 = [0.92^2 + 0.14^2 + 0.48^2 + 0.79^2 + 0.2^2 + 0.39^2]/6 = 0.318$$

Thus, the shared variance (SV) explained by a canonical variate set was calculated by sum of the squared loadings divided by the number of variables in the set. In this process, contribution of lightness was the highest, but contribution of redness was very weak. Redundancy index (RI) of 0.076 for 1st canonical variable indicated that 7.6% of the standardized variance was explained by canonical variate.The value indicated proportion of the standardized variance of the texture traits (*X* set) explained by color trait (*Y* set), where RI of the canonical variate (0.076) was percentage of variance explained by its own of variables (0.331) multiplied by the squared canonical correlation for the pair of variate (0.23). In addition, RI values (0.076) were added by cross loadings of the original variables with opposite canonical variables (Table 6) as follows:

$$RIx_1 = [0.35^2 + 0.35^2 + 0.21^2 + 0.07^2 + 0.37^2 + 0.31^2 + 0.01^2]/7 = 0.076$$

$$RIy_1 = [0.44^2 + 0.06^2 + 0.23^2 + 0.38^2 + 0.1^2 + 0.19^2]/6 = 0.073$$

Therefore, the results of canonical redundancy analysis to explain 7.6% and 7.3% of variance showed that the pairs of canonical variables did not well predict overall for the opposite set of variables. Furthermore, as canonical of canonical variate between the color traits (*Y* set) and texture

Table 5: Canonical loadings of the original variables with their canonical variables.

	X variable set								*Y* variable set					
	X_1	X_2	X_3	X_4	X_5	X_6	X_7		Y_1	Y_2	Y_3	Y_4	Y_5	Y_6
V_1	-0.74	-0.74	-0.43	0.15	-0.78	-0.65	-0.03	W_1	0.92	0.14	0.48	0.79	0.20	0.39
V_2	-0.20	-0.20	0.89	0.74	0.29	0.45	0.27	W_2	0.24	-0.77	0.14	0.19	-0.67	0.70

V_1; 1st texture trait variables, W_1; 1st pork color trait variables.
Variables are described by the same symbols as shown in Table 1.

Table 6: Canonical loadings of the original variables with their canonical variables.

	X variable set								*Y* variable set					
	X_1	X_2	X_3	X_4	X_5	X_6	X_7		Y_1	Y_2	Y_3	Y_4	Y_5	Y_6
W_1	-0.35	-0.35	-0.21	0.07	-0.37	-0.31	-0.01	V_1	0.44	0.06	0.23	0.38	0.10	0.19
W_2	-0.06	-0.06	0.25	0.21	0.08	0.13	0.08	V_2	0.07	-0.22	0.05	0.05	-0.19	0.20

V_1; 1st texture trait variables, W_1 ; 1st pork color trait variables.
Variables are described by the same symbols as shown in Table 1.

Table 7: Redundancy analysis for the pair of canonical variables.

	X variable set					*Y* variable set		
	Shared Variance		Redundancy Index	Canonical R^2		Shared Variance		Redundancy Index
V_1	0.331	W_1	0.076	0.230	W_1	0.318	V_1	0.073
V_2	0.254	W_2	0.021	0.081	W_2	0.275	V_2	0.022

V_1; 1st texture trait variables, W_1; 1st pork color trait variables.

traits (*X* set) of pork were assessed as 23%, this result represented a low predictability of each other. It is assumed that pork has not a direct influence between meat color and texture, but have an indirect effect on each other. Therefore, we suggest that it is difficult to predict meat quality via correction between meat color and texture.

CONCLUSION

Since consumer uses discoloration as an indicator of freshness and wholesomeness, the decision of pork purchase is influenced by color more than any other quality. As CCA was analyzed between pork color and texture, there was a significant correlation between both factors, but showed a low correlation. Since the variables had low values of correction, it was found to provide indirect effect, instead of giving a directly mutual effect. Therefore, we suggest that it is difficult to predict meat quality by correlation between pork color and texture. This result means that it is necessary for consumers and distributors as well as productors to utilize indirect reference conditions rather than judging direct characteristics of texture by meat color.

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