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Abstract

This study aimed to determine the physicochemical properties (proximate composition, color, pH, salinity, water holding capacity (WHC), curing yield, and shear force) and sensory properties (electric nose and sensory evaluation) of *Bulgogi* sauce with added crust derived from dry-aged beef loin. Increasing the amount of crust in the *Bulgogi* sauce tended to increase the protein content, fat content, and pH. Uncooked *Bulgogi* also tended to have elevated fat content, ash content, pH, and shear force. Increasing the crust content tended to decrease the water content, lightness, redness, and yellowness of *Bulgogi* sauce. The yellowness of uncooked *Bulgogi* with 6–12% crust in sauce was significantly lower than that of the control (no crust) and the sample with 3% crust in sauce ($p<0.05$). The redness of the cooked control *Bulgogi* was significantly lower than that of the samples with crust in sauce ($p<0.05$). The WHC of uncooked *Bulgogi* with 6–12% crust in sauce was significantly higher than that of the control and the sample with 3% crust in sauce ($p<0.05$). The flavor, texture, and overall acceptability of the *Bulgogi* with 9% crust in sauce were significantly higher than those of the control ($p<0.05$). These findings showed that the crust did not degrade the physicochemical properties of *Bulgogi* sauce and meat. The sensory characteristics of *Bulgogi* marinated with 9% crust in sauce were rated the best as persensory evaluation. Therefore, crust is a suitable flavor enhancer for *Bulgogi* sauce, and a 9% addition amount is optimal in terms of quality.

Keywords: *Bulgogi*, by-product, crust, dry-aged beef, sauce

Introduction

The consumer demand for dry-aged meat with its unique flavor has recently increased, because it is viewed as a high-quality edible meat. Unlike wet-aging, dry-aging is an aging unpackaged, it accelerated the microorganism decomposition of the meat surface (Perry, 2012). This dry-aging process induces a unique flavor that increases the consumer preference for dry-aged meat. (Campbell et al., 2001). However, the crust formed during the dry-aging process is the reason for the high price of dry-aged meat compared to other meat types. The crust is the area of meat formed by surface hardening during the dry-aging process, and its use as edible meat is limited (Dashdorj et al., 2016; Lee and Kim, 2020). Nevertheless, the crust is enriched with flavor components due to surface moisture evaporation (Lee et al., 2019). Its role as a flavor enhancer with high functionality, including anti-oxidant and anti-hypertensive functions, when applied to beef patty has been reported (Park et al., 2018).

The sauce is gives the dish its distinct color and taste; however, one of the most important characteristics of the sauce is its flavor (Mcgee, 2004). Therefore, our research team analyzed the quality characteristics of brown sauce after using crust powder as an additive to enhance the flavor of the sauce, which is widely used in meat dishes (Park et al., 2020). The addition of crust had a positive effect on the viscosity, aromatic component, and sensory characteristics of brown sauce. Accordingly, the suitability of using crust as a flavor enhancer for the sauce has been identified; however, in order to increase the utility of crust as a flavor enhancer, it is necessary to devise a method for using it as a food material in various forms.

In Korea, the export of sauce products has substantially increased in the past five years, with the income generated from exported products rising from $92.63 million in 2013 to $121.68 million in 2017, a 31.4% increase (MAFRA, 2018). This has been

determined to be due to the large increase in the export of mixed sauce products that allow consumers to reproduce the taste of Korean-style food (K-food) in line with the globalization of K-food in recent years (Nam et al., 2010).

Bulgogi is one of the most representative K-foods, as people in countries with meat-eating culture are willing to try it without aversion (Kim et al., 2013a). Accordingly, the export of 'Korean BBQ sauce' to overseas countries has also been robust (MAFRA, 2018). *Bulgogi* sauce removes any off-flavors when added to meat, and imparts the special flavor of *Bulgogi* (Heo and Lee, 2017). One of the most important goals of sauce products, including *Bulgogi* sauce, is to maximize the unique flavor of the sauce (Methven, 2012). However, even though *Bulgogi* sauce belongs to the category of 'Sauce', it is often used as a marinade solution (Heo and Lee, 2017). Therefore, it can be said that *Bulgogi* sauce has characteristics similar to those of a salt solution and different from those of brown sauce, tomato sauce, and hot sauce, which are subsequently added to meat dishes. Accordingly, when crust was added as a flavor enhancer to *Bulgogi* sauce, which is similar to a marinade solution, it was considered that the sauce would exhibit characteristics different from those of sauces used for garnish.

This study aimed to produce a sauce product with crust for addition to *Bulgogi*, to increase the utility of the crust as a flavor enhancer. We prepared sauces with different amounts of crust, and subjected them to quality property analysis to determine the optimum level of crust for the sauce.

Materials and Methods

Crust sample preparation

Beef loin (*M. longissimus dorsi*; I Home Meat Co., Seoul, Korea) samples obtained from six Holstein steer carcasses (Korea quality grade 3) and refrigerated for 24 h after

slaughter were divided into three sections of equal length and width. Divided beef loins were placed in a DA-45 dry-aging fridge (Korea Alesso, Gyeonggi-do, Korea) at 4°C (air velocity: 5±3 m/s; humidity: 80% ±5%) for four weeks. Thereafter, the crust was cut from the outermost edge (height: 0.3–0.7 cm) of the dry-aged loin, to sterilize microorganisms that could cause spoilage, lyophilized in an FDU-1110 freeze-dryer (Eyela, Tokyo, Japan) at −70°C for 15 h, and then stored at −18°C. The physicochemical properties (proximate composition, pH, and color) of the crust are shown in Supplementary Table 1.

Experiment 1. Quality properties of *Bulgogi* sauce with added crust

Manufacturing process of *Bulgogi* sauce

Table 1 shows the ingredients of *Bulgogi* sauce manufactured according to the procedure of Kim et al. (2013a) and Jung et al. (2015) with slight modification. Initially, garlic and ginger were ground in 10% of the amount of water using an MQ 5135 sauce hand blender (Braun GmbH, Kronberg im Taunus, Germany) for 40 s at 200 rpm. Brown sugar, refined rice wine, sesame oil, and black pepper powder were mixed into the solution for 1 min 30 s. The remainder of the water and soy sauce were added to the solution and mixed for 2 min. Samples of this basic *Bulgogi* sauce were added with 0% (control), 3%, 6%, 9%, and 12% crust using the hand blender for 2 min at 100 rpm, passed through an 18-mesh sieve, and then stored at 4°C.

Qualitative properties of sauce

The proximate composition of *Bulgogi* sauce samples was determined using methods in compliance with the AOAC (1990). Moisture and crude protein content were measured using oven-drying and Kjeldahl method, respectively. Crude fat and ash content were measured using Soxhlet and dry-ashing methods.

The CIE general color (lightness: L^*; redness: a^*; and yellowness: b^*) of the *Bulgogi* sauce samples was measured using a CR-10 color reader (Minolta, Tokyo, Japan), with a white standard plate (CIE L^*: +97.83; CIE a^*: -0.43; CIE b^*: +1.98) as reference.

The pH of the *Bulgogi* sauce samples (4 g in 16 mL of distilled water) were homogenized for 1 min using an HMZ-20DN Ultra-Turrax homogenizer (Poolim Tech, Seoul, Korea) at 10,923×*g*, and the pH was measured using a Model S220 pH meter (Mettler-Toledo, Schwerzenbach, Switzerland).

The salinity of the *Bulgogi* sauce samples was measured using an SB-2000PRO salinity meter (HM Digital Inc., Redondo Beach, CA, USA), and the values are presented herein as percentages.

The aroma of the *Bulgogi* sauce samples was analyzed using a Heracles II electronic nose (Alpha MOS, Toulouse, France). The electronic nose headspace conditions were as follows: sample vial, 20 mL; sample volume, 1 mL; heating temperature, 40°C; and incubation period, 20 min. The machine conditions were as follows: injected volume, 5 mL; injection temperature, 200°C; trap ready temperature, 40°C; sampling duration, 4 s; trap desorption temperature, 250°C; injection duration, 1.5 s; column temperature program, 51°C (10 s) to 260°C (4 s); detector temperature, 260°C. Before principle component analysis (PCA), the sensitivity of each electronic-nose sensor was measured to determine the rates of change between resistance values of volatile compounds and the air. Classified aroma profiles were taken as the primary (PC1) and secondary (PC2) component values. These measured sensitivity values were included in the Alpha Soft software (Alpha MOS, Toulouse, France) used for PCA.

Experiment 2. Qualitative and sensory properties of *Bulgogi* marinated

with *Bulgogi* sauce containing crust

Manufacturing process of *Bulgogi*

Raw *Bulgogi* meat comprising beef top round (*Biceps femoris*; *Hanwoo*; Korea quality grade 1) was cut into 5 × 5 × 0.2 cm^3 (length × width × height) pieces. The *Bulgogi* was marinated with a 3:4 ratio of beef top round to *Bulgogi* sauce with crust, at 4°C for 10 h. The uncooked marinated *Bulgogi* samples were stored at 4°C. Marinated *Bulgogi* samples were pan-fried front and back at 80°C for 30 s each.

Qualitative and sensory properties of *Bulgogi*

Proximate composition, color, and pH analyses were performed as described for *Bulgogi* sauce.

The water holding capacity (WHC) of uncooked *Bulgogi* samples was determined using the filter paper press method of Grau and Hamm (1953) with slight modification. Each 300 mg uncooked *Bulgogi* sample was placed on a filter paper (Whatman No.2, GE Healthcare, Chicago, IL, USA) and compressed for 3 min using a filter-press device. The WHC was calculated from the areas of meat and exudation as follows:

$$\text{WHC (\%)} = \frac{Meat\ area\ (mm^2)}{Exudation\ area\ (mm^2)} \times 100$$

The curing yield of *Bulgogi* was determined by calculating the difference in *Bulgogi* weight before and after curing, as follows:

$$\text{Curing yield (\%)} = \frac{Bulgogi\ weight\ after\ curing\ (g)}{Bulgogi\ weight\ before\ curing\ (g)} \times 100$$

The shear force of cooked *Bulgogi* samples (1.0 × 2.0 × 0.2 cm; length × width × height) was measured using a V-blade attached to a TA 1 texture analyzer (Ametek Inc., Berwyn, PA, USA), at a test speed of 3.0 mm/s, distance of 22.0 mm, and force of 5.6 N. The measured values were expressed in *kg*.

For sensory evaluation, fourteen sensory panelists analyzed cooked *Bulgogi* samples in triplicate, using basic taste identification tests. The color, flavor, texture, juiciness, off-flavor, and overall acceptability of the samples were evaluated on a 10-point descriptive scale (1 = extremely undesirable; 10 = extremely desirable). The sensory evaluation was approved by the Kongju National University's Ethics Committee (Authority No: KNU 2020-15).

Statistical analysis

The results of all experiments, except those of the electric nose, were assessed after a minimum of three trials. Data were statistically analyzed with a general linear model, using SAS version 9.3 (SAS Institute, Cary, NC, USA). The significance of differences was verified using Duncan's multiple range tests ($p<0.05$). The data are shown as means±standard deviation.

Results and Discussion

Experiment 1. Quality properties of *Bulgogi* sauce

Proximate composition

Table 2 shows the proximate composition of *Bulgogi* sauce. The ash content of *Bulgogi* sauce was found to be 2.33–2.50%, although no significant difference was

observed among the treatment groups based on the amount of crust added. The moisture content decreased with an increase in the amount of added crust, whereas the protein content showed a significant increase ($p<0.05$) and the fat content showed an increasing trend. The proximate composition of a sauce depends on the contents of the added ingredients. Consequently, when crust was added to brown sauce, protein and fat content increased while water content decreased with the amount of crust (Park et al., 2020). The differences in the proximate composition of *Bulgogi* sauce based on the amount of crust added are thought to be due to the high protein and fat content in the proximate composition of the crust (fat: 29.81%;protein: 56.25%; Supplementary Table 1), indicating that adding high amounts of crust leads to elevated protein and fat content.

Color, pH, and salinity

Table 3 presents the color, pH, and salinity of *Bulgogi* sauce based on the amount of crust added. The lightness of *Bulgogi* sauce decreased with an increase in the amount of added crust, and the redness and yellowness followed a similar trend. Soy sauce has a significant influence on the primary color formation of *Bulgogi* sauce. The color of soy sauce is reddish brown or dark brown, and mixing with other additives may turn the color cloudy (Yokotsuka, 1986). It was hence presumed that the overall color of the *Bulgogi* sauce was influenced by the salt-soluble proteins released from the crust upon its addition. The pH of *Bulgogi* sauce increased with the amount of crust added. Generally, as the pH of a food product is known to generally decrease with an increase in the salt content (Feiner, 2006a; Park and Kim, 2016). Thus, despite the pH of crust was lower than that of Bulgogi sauce, the increase in pH upon the addition of the crust may be attributed to the relative decrease in the salt content with an increase in the amount of crust added.

The salinity decreased with an increase in the amount of crust added, with no

significant difference observed for the 6–12% crust treatments. This is thought to be due to the relative decrease in the content of soy sauce, which may have an influence on the salinity of the *Bulgogi* sauce. Thus, as the amount of crust added increased, the soy sauce content and salinity decreased. Excessive salt intake has harmful effects on the human body, such as hypertension, cerebral stroke, and kidney function decline (de Wardener and MacGregor, 2002). As the amount of salt in processed meat products is quite high, the consumers' demand for low-salt meat products has been increasing (Morris et al., 2008). Sauce products are mostly high in salt content, and the use of various sauce products in different types of foods is leading to a substantially higher level of salt consumption (Doyle and Glass, 2010). In particular, soy sauce, which accounts for the highest proportion among the additives in *Bulgogi* sauce, has a high salt content, and hence, the need for salt reduction is more prominent (Goh et al., 2011). Therefore, the addition of the crust is advantageous, as it can lower the salinity of *Bulgogi* sauce while enhancing its palatability.

Experiment 2. Qualitative and sensory properties of *Bulgogi* marinated with *Bulgogi* sauce containing added crust

Proximate composition

Table 4 presents the proximate composition of *Bulgogi* marinated with *Bulgogi* sauce containing added crust. The moisture, protein, and ash content among the treatment groups showed no significant differences; however, the fat content increased with the amount of crust added. The crust used in this study was obtained from beef sirloin with the formation of marbling, wherein layers of fat are distributed in the muscle tissue and the fat content is comparatively higher than that in the other meat areas (Corbin et al., 2015). It is hence thought that the fat content of the *Bulgogi* sauce increased with the

amount of crust added (The fat content of the crust: 29.81%; Supplementary Table 1). The fat content of *Bulgogi* was lower than that of *Bulgogi* sauce. The reason for these results was that the part used as raw meat in *Bulgogi* was beef top round, which has a very low fat content compared to other parts. Furthermore, when the raw meat was marinated with *Bulgogi* sauce, the curing yield was 124.57-128.87% in all treatments; however, 0.50-6.82% fat content of *Bulgogi* sauce did not significantly affect *Bulgogi* after curing; hence, it was considered that the fat content of *Bulgogi* after curing was lower than that of *Bulgogi* sauce.

Color and pH

Table 5 presents the color of *Bulgogi* before and after cooking, based on the amount of crust added. Before cooking, the lightness of *Bulgogi* showed no significant difference with up to 6% crust treatment; thereafter, it increased significantly with an increase in the amount of crust added ($p<0.05$). The lightness of *Bulgogi* after cooking, likewise, showed no significant difference up to 6% crust treatment, but the 9% and 12% treatment groups with relatively large amounts of added crust showed significantly higher values ($p<0.05$). The redness of *Bulgogi* did not change significantly with the amount of added crust before and after cooking, whereas the yellowness decreased before cooking and increased after cooking. As shown, the addition of the crust led to a decrease in the lightness and yellowness of *Bulgogi* before cooking. In line with these results, previous studies have reported a reduction in the lightness with increases in the redness and yellowness upon the use of a light-brown colored additive in foods (Choi and Lee, 2016; Kim et al., 2013b). In a study wherein brown mealworm powder, whose color was similar to that of the crust, was added to meat patties, the lightness and yellowness decreased (Kim et al., 2015); this

was attributed to the influence of the additive on the meat color, whereby it reduced the relative content of myoglobin, a pigment in meat (Choi et al., 2019). On the contrary, after cooking, the lightness and yellowness increased, because meat proteins such as those in the crust undergo Maillard browning upon heat treatment (Young and West, 2001). The addition of the crust to *Bulgogi* sauce is hence likely to further preserve the color of the original beef meat in *Bulgogi* after cooking.

Water holding capacity and curing yield

Figure 1 shows the WHC and curing yield of *Bulgogi* after curing and before cooking. The WHC values were significantly higher for the 6–12% crust treatment groups than for the control and the 3% crust treatment group ($p<0.05$). For meat and meat products, the WHC is closely associated with the pH, and it is known that an increase in the pH of meat results in a high WHC (Sebranek, 2009). The pH increased with the amount of crust added, which is thought to have led to the relatively high WHC of the treatment groups with high pH. In addition, meat with a high WHC shows a low rate of water separation upon cooking, with a consequent low reduction rate (Siegel et al., 1978). Therefore, it was predicted that the 6–12% crust treatment groups with high WHC would exhibit low cooking loss. The curing yield fell within the range of 124.57–128.87%, and no significant difference was found among the treatment groups with respect to the proportion of crust added to the *Bulgogi* sauce. In general, the curing yield increases after massaging actions such as tumbling (Plimpton et al., 1991). Kim et al. (2003) also reported that pork meat cured in soy sauce after tumbling showed a higher curing yield than the meat subjected to immersion alone during curing, in addition to a more outstanding cooking yield. Hence, the lack of difference in curing yield among the treatment groups in this study, regardless of the proportion of added crust, is thought to

be due to the use of immersion alone during the curing process.

Warner-Bratzler shear force (WBSF)

Figure 2 shows the WBSF of marinated *Bulgogi* after cooking, based on the amount of crust added. The WBSF of the different treatment groups exhibited a range (0.40–0.61 kg), and increased with the amount of crust added. The reason for increased shear force is related to a decrease in the salt concentration of *Bulgogi* sauce. In meat, salt is dispersed in the water added to the meat. The salt then penetrates into the muscle tissue and structurally swells the meat, resulting in extraction of salt-soluble protein (Feiner, 2006a). When the meat tissue is swollen in this way, the texture of the tissue softens. Hence, the salt concentration decreases upon addition of crust, while the degree of softening of the meat tissue is relatively reduced. Among the sensory properties of meat products, the physical properties are a major determinant of consumer preference (Guerrero et al., 1999), and when meat powder is added to a food product, the binding strength can increase (Lu and Chen, 1999). This increase in binding strength may promote binding among the proteins or between the proteins and fats in meat, which in turn may further increase the binding strength. In addition, for thin-sliced meat products, a certain level of binding strength is required for enhancing the texture. Hong et al. (2011) reported that the panelists that evaluated the sensory properties of their *Bulgogi* gave outstanding results to the meat with a level of texture that was neither too soft nor too hard. The *Bulgogi* produced in this study was thin-sliced to 0.2 cm thickness, and it is likely that the use of *Bulgogi* sauce with added crust would have enhanced the texture of the *Bulgogi*.

Electronic nose

To examine the differences in the aroma of *Bulgogi* sauce and *Bulgogi* samples, the

volatile components were analyzed with respect to retention time using PCA, the results of which are shown in Fig. 3. Fig. 3-a is the plots for the different samples indicated that, compared to the control, the 3% crust treatment group had a clearly differentiated flavor, and the 6% crust treatment group had a flavor distinguishable from those of the control and 3% crust treatment groups. On the contrary, the 9% and 12% crust treatment groups shared similar flavors, implying that adding amounts exceeding 9% would not lead to a significant difference in the flavor. Figure 3-b shows the PCA plot of different *Bulgogi* samples. The samples treated with 3% crust showed distinctly different flavor compared to the control, but showed similar flavor to those treated with 3-9% crust. However, the 12% crust treatment group showed significantly different flavor compared to the 3-9% crust treatment groups. In this study, among the major aroma volatile compounds changes due to the increase in the amount of crust in Bulgogi sauce and Bulgogi, the Nonan-2-one component increased in either. Nonan-2-one is a component commonly detected in fermented cheese products, it has unique flavors such as 'buttery', ‘cheese', 'fatty', and 'milk-like' flavors (Mallia et al., 2005). One of the representative characteristics of dry-aged beef is that it forms a unique flavor due to proteolysis of meat and microbial decomposition on the meat surface, which is known to have a “cheesy” or “buttery” flavor (Dashdorj et al., 2016). Accordingly, it was found that the addition of crust on the Bulgogi sauce could give a flavor similar to that of dry-aged beef to some extent. In addition, according to Motono (2012), inosine monophosphate (IMP) or monosodium glutamate (MSG) can be substituted with beef stock powder, as the latter contains a certain amount of IMP or MSG that can increase palatability, and the addition of a set amount of such ingredients is recommended for adding flavors to and enhancing the palatability of sauce products. As described above, the addition of crust to *Bulgogi* sauce leads to a change in flavor, but when the amount of crust added exceeds 9%, it appears to lead to a distinctly

different flavor; thus, adding excessive crust may contribute to an off-flavor in *Bulgogi*.

Sensory evaluation

In this study, the crust separated from dry-aged beef loin was freeze-dried at −70 °C to sterilize microorganisms that could cause spoilage (total bacteria count was used in lieu of microbial colony detection). The results of the sensory evaluation of *Bulgogi* after cooking, based on the amount of crust added to the *Bulgogi* sauce, are presented in Table 6. In various food products, the addition of a flavor enhancer may not induce a significant change in flavor beyond a certain level, or may negatively affect the sensory properties upon reaching an excessive level; hence, it is crucial to identify the optimum amount of enhancer to be added (Methven, 2012). The color, juiciness, and off-flavor elements of the sensory evaluation showed no significant differences across the treatment groups; however, a significantly higher score was given for flavor to the treatment groups with 9% or higher amounts of added crust, in comparison to that of the control ($p<0.05$). These differences in the evaluation of flavor appeared similar to the results of the electronic nose analysis of *Bulgogi* sauce. The 3% and 6% crust treatments showed different PCA results compared to the control, but they did not receive a significantly higher evaluation scores than the control. The 9% and 12% crust treatment groups received higher evaluation than the control, but there was no difference between them. Accordingly, it is thought that *Bulgogi* marinated using *Bulgogi* sauce prepared by adding 9% and 12% crust relatively high evaluation score for flavor due to its meaty flavor. Similar to the results of this study, it has been shown that flavor evaluation increased with the amount of crust added in brown sauce, and there was no difference in sensory properties when the amount of crust added exceeded a certain level (Park et al., 2020). For texture, the 6% and 9% crust treatment groups received significantly higher scores in comparison to the control

($p<0.05$). As texture is one of the determinants of food sensory properties in meat products, an excessively soft or hard texture that is unsuitable for the given food product is likely to reduce consumer preference (Szczesniak and Khan, 1971). Hence, to control the texture, which is a critical factor in determining the sensory properties of meat products, a texture enhancer, such as isolated soy protein, egg protein, and gelatin, may be added to the meat (Fernández-Ginés et al., 2005; Saranya et al., 2016). In this study, the addition of crust to *Bulgogi* sauce increased the shear-force of the *Bulgogi*, and in contrast to the 6% and 9% crust treatment groups, the 12% crust treatment group did not differ significantly from the control, i.e., the shear-force (texture) with acceptable sensory properties could be achieved using 6% or 9% crust treatments. For overall acceptability, the 9% crust treatment group earned a significantly higher evaluation result compared to the control and the 3% treatment group. Therefore, with respect to the specific items of sensory evaluation, 9% crust treatment of *Bulgogi* sauce is likely to be the suitable level for use as a flavor enhancer.

Conclusion

We applied crust derived from by-products of dry-aged beef as a natural flavor-enhancer for *Bulgogi* sauce. The crust added to *Bulgogi* sauce exerted positive effects on the WHC of cured *Bulgogi*. The results of electronic nose and sensory evaluation of *Bulgogi* samples treated with 9% and 12% crust had more positive characteristics than those of the other samples. However, the texture and overall acceptability of *Bulgogi* samples containing 9% crust were better than those of control. On the contrary, the characteristics of *Bulgogi* samples containing 12% crust were non-significant compared with the control. These results suggest that the addition of 9% crust to *Bulgogi* sauces as a flavor-enhancer can improve several physicochemical factors and sensory properties.

Conflict of Interest

The authors declare no potential conflict of interest.

Acknowledgements

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Ethics Approval

The experiment was approved by the Kongju National University's Ethics Committee (Authority No: KNU2020-15).

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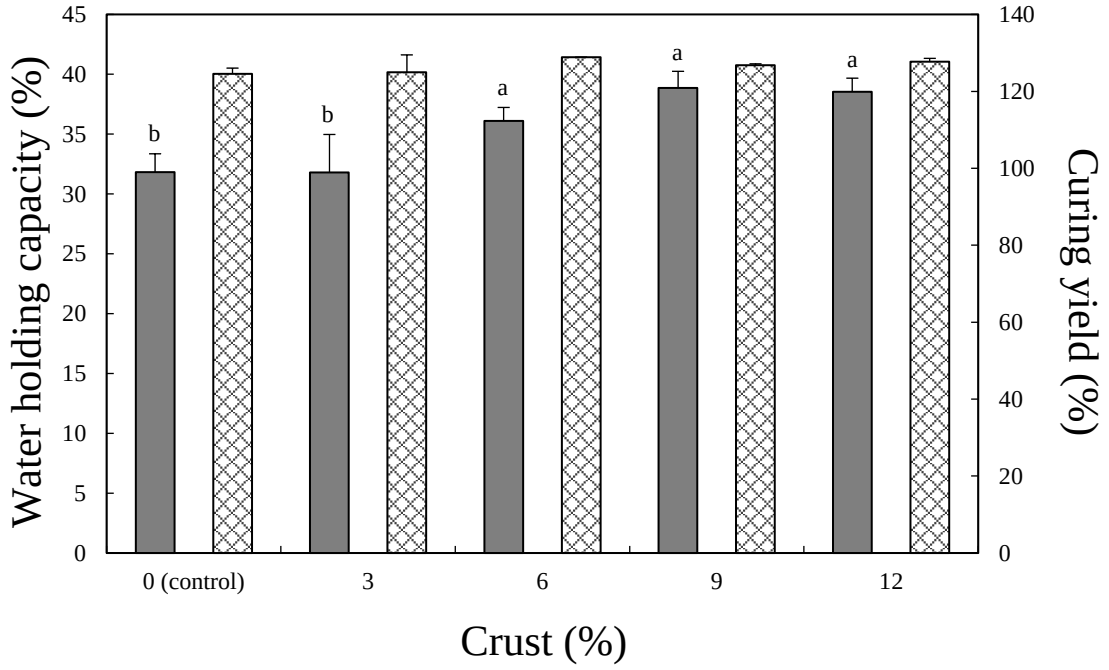

508

509 Fig. 1. Curing yield and water holding capacity of *Bulgogi* marinated with *Bulgogi*

510 sauce containing added crust. [a-b]Means on the same bar with different letters are

511 significantly different ($p<0.05$).

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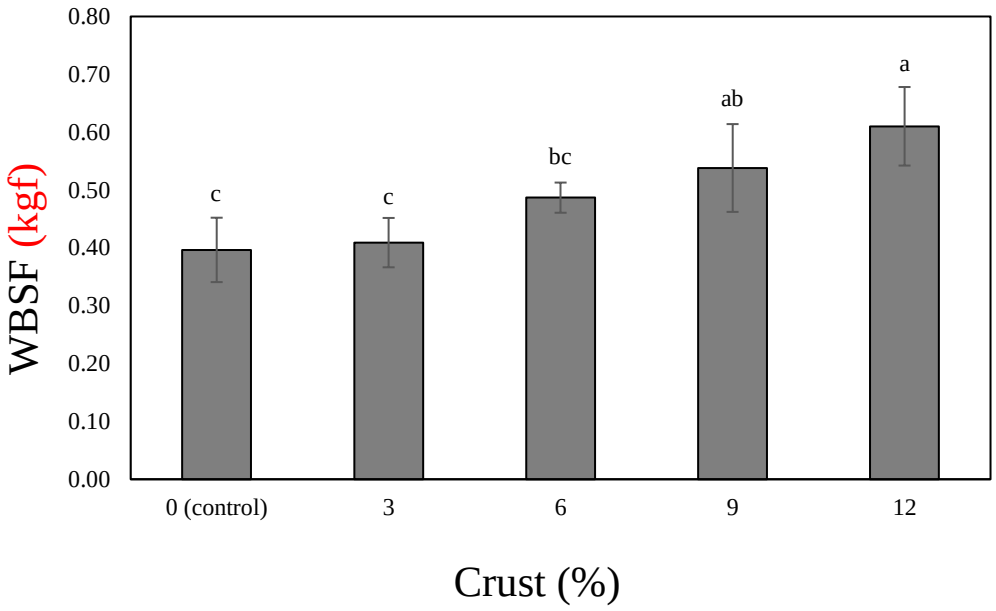

513

514 Fig. 2. Warner-Bratzler shear force (WBSF) of cooked *Bulgogi* marinated with *Bulgogi*

515 sauce containing added crust. [a-c] Significantly different means on same bar ($p<0.05$).

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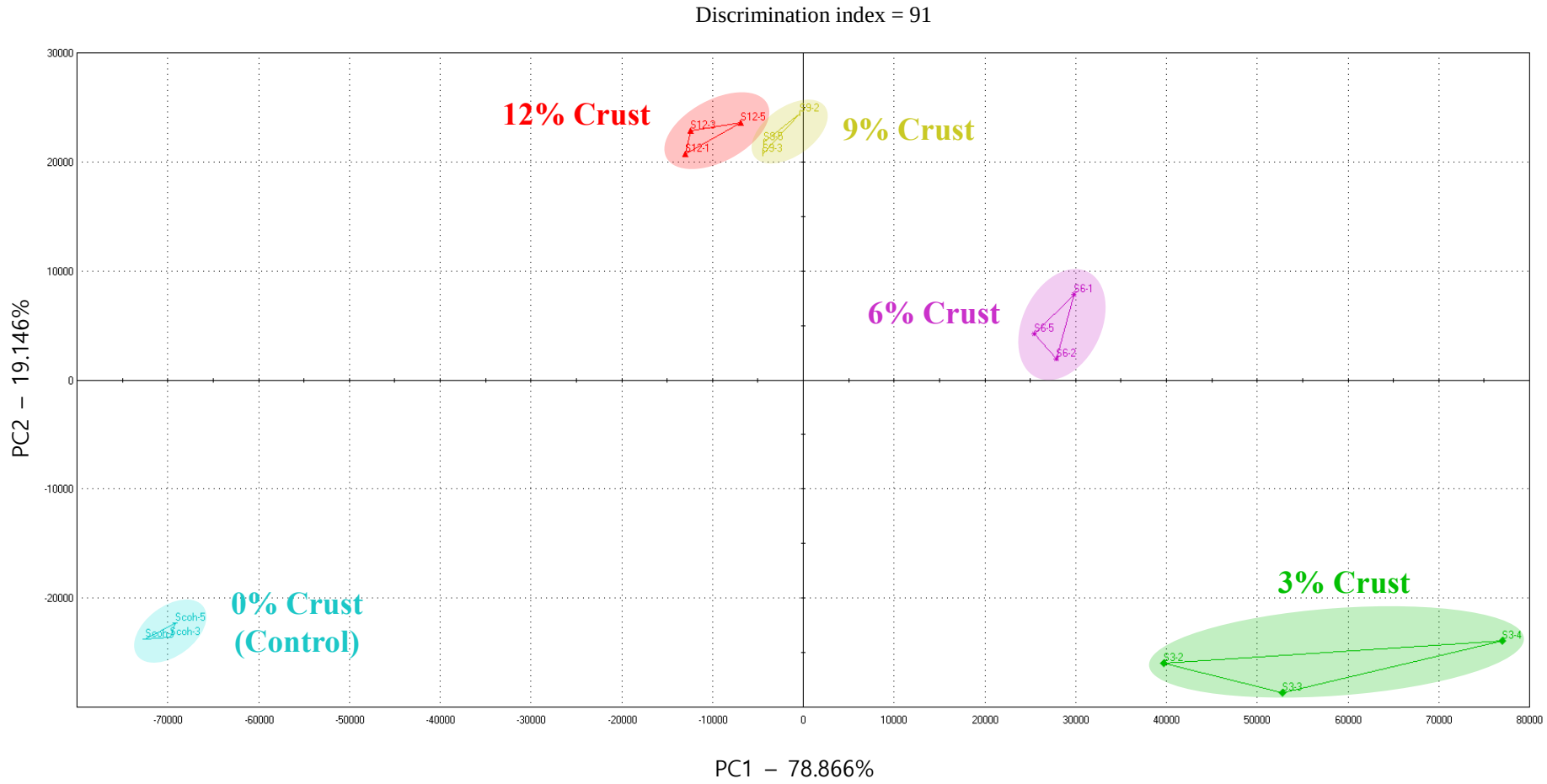

Fig. 3-a. Principal component analysis of *Bulgogi* sauce containing various amounts of dry-aged beef crust.

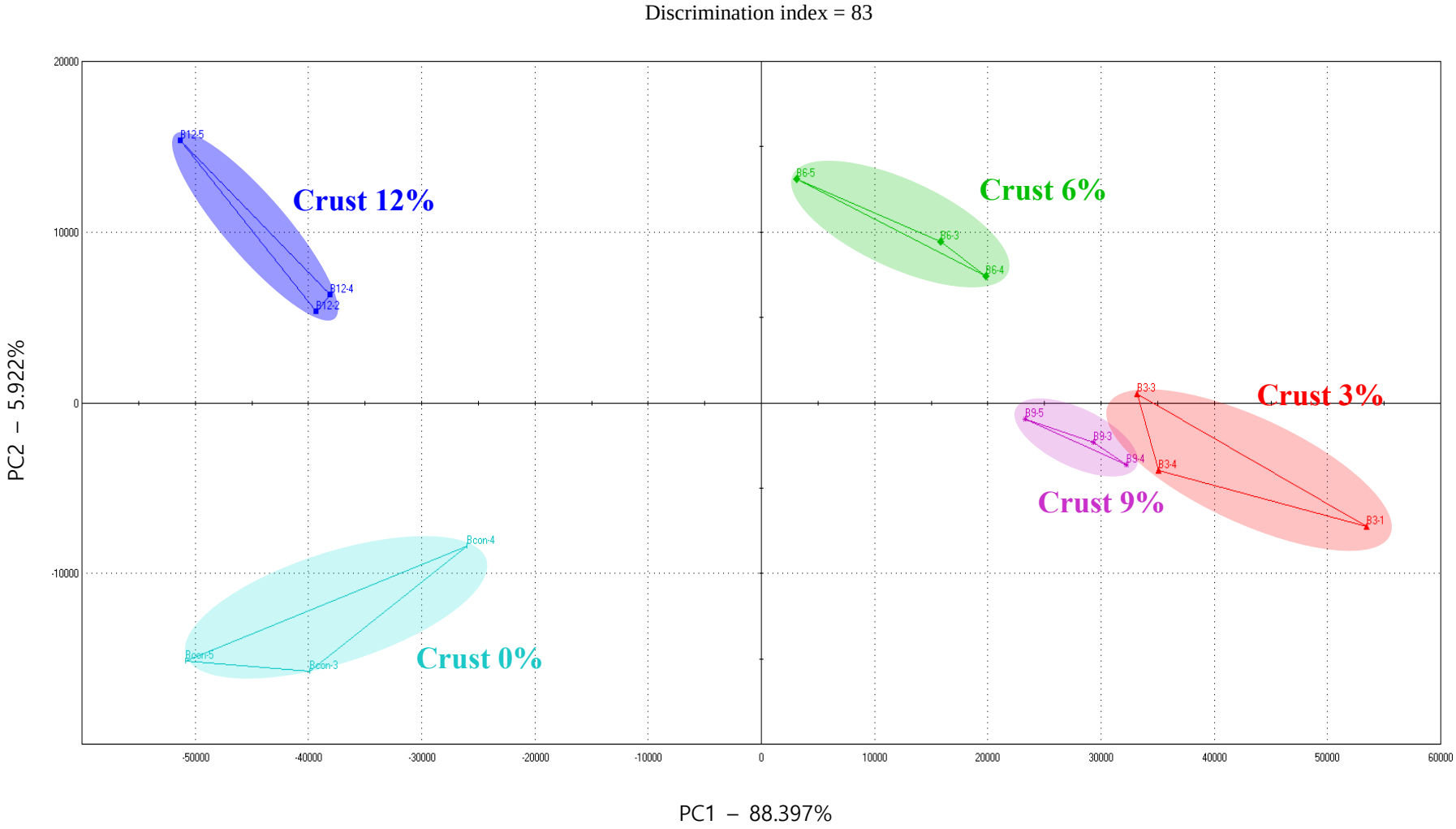

Fig. 3-b. Principal component analysis of *Bulgogi* marinated with *Bulgogi* sauce containing added crust

522 Table 1. Ingredients of *Bulgogi* sauce containing various amounts of crust from dry-aged

523 beef loin.

Ingredients (%)	Dry aged beef crust (%)				
	0 (control)	3	6	9	12
Water	74.7	74.7	74.7	74.7	74.7
Soy sauce	16.6	16.6	16.6	16.6	16.6
Garlic	2.5	2.5	2.5	2.5	2.5
Ginger	0.3	0.3	0.3	0.3	0.3
Brown sugar	3.3	3.3	3.3	3.3	3.3
Refined rice wine	1.7	1.7	1.7	1.7	1.7
Sesame oil	0.8	0.8	0.8	0.8	0.8
Whole black pepper	0.1	0.1	0.1	0.1	0.1
Crust	-	3	6	9	12
Total (%)	100	103	106	109	112
Total (g)	800	824	848	872	896

524

525

526 Table 2. Proximate composition of *Bulgogi* sauce containing different amounts of dry-
527 aged beef crust.

Traits	Dry-aged beef crust (%)				
	0 (control)	3	6	9	12
Water (%)	92.12±1.93^{a}	90.87±2.02^{ab}	90.04±1.38^{ab}	90.72±1.86^{ab}	88.70±0.77^{b}
Protein (%)	1.19±0.03^{e}	1.78±0.14^{d}	2.16±0.05^{c}	2.39±0.11^{b}	3.06±0.27^{a}
Fat (%)	0.50±0.26^{d}	1.49±0.37^{c}	3.71±0.51^{b}	5.39±0.57^{b}	6.82±0.23^{a}
Ash (%)	2.46±0.04	2.33±0.12	2.41±0.12	2.50±0.15	2.44±0.09

528 Data are shown asmeans±SD.

529 $^{a-e}$Means on the same row with different letters are significantly different ($p<0.05$).

530

531

532 Table 3. Color, pH, and salinity of *Bulgogi* sauce containing different amounts of dry-
533 aged beef crust.

Traits		Dry-aged beef crust (%)				
		0 (control)	3	6	9	12
Color	CIE L*	43.78±0.11^{a}	43.70±0.22^{a}	43.16±0.26^{b}	42.22±0.04^{c}	42.38±0.13^{c}
	CIE a*	4.48±0.26^{a}	0.72±0.04^{b}	0.62±0.11^{bc}	0.52±0.04^{cd}	0.40±0.10^{d}
	CIE b*	6.70±0.16^{a}	4.20±0.07^{b}	3.54±0.05^{c}	3.26±0.09^{d}	3.28±0.13^{d}
pH		5.34±0.02^{c}	5.38±0.01^{b}	5.40±0.01^{ab}	5.42±0.01^{a}	5.42±0.01^{a}
Salinity		2.15±0.03^{a}	2.10±0.03^{b}	2.08±0.01^{bc}	2.07±0.03^{bc}	2.06±0.01^{c}

534 Data are shown as means±SD.

535 $^{a-e}$Means on the same row with different letters are significantly different ($p<0.05$).

536

537 Table 4. Approximate composition of *Bulgogi* marinated with *Bulgogi* sauce containing

538 added crust.

Traits	Dry-aged beef crust (%)				
	0 (control)	3	6	9	12
Water (%)	77.26±1.32	76.78±1.81	78.48±3.56	76.21±1.01	77.21±2.60
Protein (%)	16.75±0.15	17.02±0.08	16.93±0.62	17.74±0.28	18.36±1.72
Fat (%)	1.57±0.51^{c}	2.13±0.76^{b}	3.20±0.11^{a}	3.67±0.21^{a}	3.94±0.26^{a}
Ash (%)	1.81±0.05	1.79±0.04	1.81±0.03	1.79±0.05	1.81±0.06

539 Data are shown as means±SD.

540 $^{a-e}$Means on the same row with different letters are significantly different ($p<0.05$).

541

542 Table 5. Color and pH of *Bulgogi* marinated with *Bulgogi* sauce containing added crust.

Traits			Dry-aged beef crust (%)				
			0 (control)	3	6	9	12
pH	Uncooked		5.12±0.08^{c}	5.15±0.01^{bc}	5.18±0.02^{abc}	5.24±0.01^{ab}	5.27±0.06^{a}
	Cooked		5.65±0.02^{c}	5.67±0.01^{b}	5.69±0.01^{a}	5.69±0.01^{a}	5.68±0.01^{ab}
Color	Uncooked	CIE L*	43.45±0.35^{a}	43.55±0.49^{a}	42.80±0.52^{a}	41.64±0.69^{b}	40.62±0.19^{c}
		CIE a*	8.70±0.20	8.87±1.10	9.10±0.46	9.37±0.59	8.97±0.21
		CIE b*	15.60±0.17^{a}	14.67±0.99^{b}	13.32±0.18^{c}	12.75±0.07^{c}	12.83±0.12^{c}
	Cooked	CIE L*	49.33±0.12^{b}	49.30±0.01^{b}	49.45±0.07^{b}	51.34±0.30^{a}	51.12±0.28^{a}
		CIE a*	5.77±0.06	5.98±0.27	6.06±.36	5.95±0.26	6.05±0.07
		CIE b*	9.02±0.22^{d}	9.50±0.32^{c}	9.96±0.15^{b}	10.54±0.24^{a}	10.62±0.15^{a}

543 Data are shown as means±SD.

544 $^{a-e}$Means on the same row with different letters are significantly different ($p<0.05$).

545

546 Table 6. Sensory evaluation of *Bulgogi* marinated with *Bulgogi* sauce containing added

547 crust.

Traits	Dry-aged beef crust (%)				
	0 (control)	3	6	9	12
Color	8.40±0.55	8.43±0.79	8.40±0.89	8.50±1.00	8.50±1.29
Flavor	8.29±0.95^{b}	8.71±0.76^{ab}	9.14±0.69^{ab}	9.57±0.53^{a}	9.29±0.95^{a}
Texture	8.14±0.69^{b}	8.43±0.98^{ab}	9.14±0.90^{a}	9.29±0.76^{a}	9.00±0.82^{ab}
Juiciness	8.40±0.55	8.67±1.03	8.80±0.45	8.80±0.45	9.00±0.89
Off-flavor	8.75±0.96	8.86±1.21	8.80±1.10	9.00±0.71	8.80±1.30
Overall acceptability	8.14±0.69^{b}	8.14±0.69^{b}	9.00±1.00^{ab}	9.29±0.76^{a}	8.71±1.11^{ab}

548 Data are shown as means ± SD.

549 $^{a-e}$Means on the same row with different letters are significantly different ($p<0.05$).

550