

Effects of added cereal fibers on the quality characteristics of black pudding prepared with duck blood

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ABSTRACT We investigated the physicochemical and rheological properties of black pudding prepared with duck blood using various combinations of cereal fiber sources: oat, buckwheat, quinoa, amaranth, and sorghum. The processing yield of black pudding made with duck blood and the cereals was higher than that of the control (without cereals) in all cases ($P < 0.05$). The moisture content of the black pudding was the highest in the buckwheat and amaranth groups ($P < 0.05$). The water activity, pH, and yellowness of the black pudding combined with duck blood and cereals were lower than that of the control ($P < 0.05$). The hardness of the black pudding with duck blood and cereals was higher than that of the control ($P < 0.05$), except for the amaranth group. The cohesiveness, gumminess, and chewiness of

the black pudding with duck blood and cereals were higher than that of the control ($P < 0.05$). Differential scanning calorimetry showed distinct peak points according to treatment at the same temperature, and all treatments exhibited 2 peak temperatures, except for sorghum. The viscosities of all samples, including the control, decreased as the shear rate increased, and the viscosity of the black pudding with oat was slightly lower than that of the other samples. Thus, black pudding prepared with duck blood and cereal fibers showed excellent physicochemical and rheological properties, suggesting an improved processing method. These findings can further the development of products using duck blood as a valuable nutritional source rather than being lost as a by-product during slaughter.

Key words: black pudding, duck blood, cereal, physicochemical property, rheological property

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INTRODUCTION

Along with chicken, duck is a representative and popular poultry meat (Wei et al., 2020), especially in Asia, where it is in high demand as a healthy meat source (Shawkat Ali et al., 2007). In particular, duck meat is rich in essential amino acids and has an excellent fatty acid composition compared with that of other meats (Aronal et al., 2012; Kang et al., 2020). Duck is also used as an excellent raw material for meat processing products (Shim et al., 2018). However, the majority of processing with duck involves the preparation of smoked products, and there has been limited development of various other duck-based products to date (Kim et al., 2017).

Livestock are slaughtered for meat, which results in various by-products, including the bones, skin, tails,

intestines, and blood (Choi et al., 2016; Ranaei et al., 2021), which are typically used as feed or discarded despite their nutritional value (Irshad and Sharma, 2015). In particular, blood accounts for a high proportion of livestock by-products (Sorapukdee and Narunatsopanon, 2017); however, few studies have focused on its potential use as a food source (Choi et al., 2009), mainly owing to the difficulty in its collection from slaughtered livestock. There has been limited research regarding the use of cattle or pig blood (Choi et al., 2015; Kim et al., 2021), whereas almost no studies related to poultry blood as a food resource exist. Thus, further research is needed to develop poultry blood as a food resource.

Black pudding is a blood sausage that is typically made with pork blood as the main ingredient, which is a representative meat product in Europe (Anjos et al., 2019) and has high nutritional value (Fellendorf et al., 2016). Currently, most studies on black pudding have focused on aspects of safety (Adesiyun and Benjamin, 1996), because the hygienic stability of blood resources is poor when used in food science, demonstrating the need for quality improvement research. Because

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high functional properties of grains called “super-grain” on physicochemical properties or biological functionalities, there were many studies were conducted to improve quality properties of meat products (Bejosano and Corke, 1998; Pintado et al., 2018; Poursalehi et al., 2021; Tafadzwa et al., 2021; Xiong et al., 2022). However, these studies were focused on commercial meat products such as sausage. There was no information about the effect of these grains on quality properties of black pudding.

Therefore, the objective of this study was to investigate the quality properties of duck blood with and without the combination of cereal fibers in the preparation of black pudding.

MATERIALS AND METHODS

Preparation of Black Pudding With Duck Blood and Cereals

Duck blood (moisture: 90.71%, crude protein: 8.16%, ash: 0.59%, iron: 190.93 mg/kg) was obtained from Peckin duck of Dasol slaughterhouse (Jangheung, Korea) on the day of slaughter. The duck blood was immediately homogenized for 30 s in a homogenizer to prevent the blood from clotting and temperature of duck blood was monitored at 4°C during transportation to laboratory for 2 h. Black pudding was described by Anjos et al. (2019) was prepared by slightly modifying the manufacturing method. Black pudding was obtained by mixing the duck blood (92.5%), oligosaccharide (5.0%), citric acid (0.1%), carrageenan (0.5%), gelatin (1.5%), and agar (0.4%) using bowl chopper (Bowl Cutter C4, Sirman, Padua, Italy) at high level speed (2,800 rpm) for 1 min. The optimal ratio of the black pudding ingredients was based on the results of several preliminary experiments.

The resulting black pudding (which served as the control group) was divided into 5 treatment batches to which the following cereals (2.0%) were respectively added: oat, buckwheat, quinoa, amaranth, and sorghum. The selected cereals were easily accessible and were determined to have high dietary fiber and nutritional value. The black pudding mixture was heated at 100°C for 30 min and then placed in a box type mold (15.5 × 4 × 8.6 cm³), cooled at −10°C for 4 h, and used as the experimental material. Each batch was prepared 3 times, and the experiment was carried out in triplicate.

Processing Yield

Processing yield was measured by calculating the weight differences of black pudding with duck blood before and after processing with each cereal as follows:

Processing yield (%) = (weight of black pudding after processing/weight of black pudding before processing) × 100.

Physicochemical Properties

- Moisture content: The moisture content of black pudding with duck blood and cereals was determined by measuring the weight loss after 12 h of drying at 105°C in a drying oven (AOAC 2020).
- Water activity: The water activity of black pudding with duck blood and cereals was measured using a hygrometer (Novasina, Labmaster-aw, Lachen, Switzerland).
- pH: The pH values of the black pudding with duck blood and cereals were determined in a homogenized set with 5 g of the sample and 20 mL of distilled water using a pH meter.
- Color: The color of the black pudding with duck blood cereals was determined with a colorimeter (CR-410, Illuminant C, Minolta Co., Osaka, Japan).

Rheological Property

Texture profile analysis: Samples (2 × 2 × 2 cm³) were prepared to experiments and the textural properties of the black pudding with duck blood and cereals were measured using a texture analyzer (TA-XT2i, Stable Micro Systems, Surrey, UK) with the following conditions: maximum load, 2 kg; force, 10 g; pre-test speed, 3.0 mm/s, post-test speed, 5.0 mm/s; distance, 10.0 mm; and head speed, 3.0 mm/s (Bourne, 1978). The dynamic viscosity of the black pudding with duck blood and cereals was measured using a Physica MCR 102 rheometer (Anton Paar Ltd., Graz, Austria). The flow curve test was conducted in a parallel plate with a diameter of 25 mm and a gap of 1 mm at different shear rates ranging from 0.01 to 100 s^{−1} at 25°C. The storage (G′) and loss (G″) moduli of the samples as a function of frequency were measured using the same equipment at 25°C. The angular frequency ranged from 1 to 100 rad/s at a strain of 0.5%. All data were recorded using RheoCompass v. 1.19 software.

Thermal Stability

- The thermal stability of black pudding with duck blood and cereals (Kim et al., 2020) was evaluated using differential scanning calorimetry (DSC). Well-homogenized samples (30 mg) were placed in an aluminum pan, and an empty pan was used as the reference. The DSC 400 furnace system (PerkinElmer, Waltham, MA) was used to estimate the thermal properties of the samples with heating from 20°C to 100°C at 10°C/min.

Statistical Analysis

All data were obtained from triplicate experiments, and were analyzed using the general linear model procedure in

SPSS 20.0 (SPSS Inc., Chicago, IL). The five cereal types were considered as the main effects, and the replicates and other uncontrollable external factors were considered as randomized effects. Duncan's multiple range test was conducted to investigate significant differences among the samples, assessed at $P < 0.05$. Principal component analysis (PCA) was also performed to explain the association between physicochemical properties and texture profile analysis (TPA) variables according to the type of cereal added to the black pudding.

RESULTS AND DISCUSSION

Cereals Influence the Processing Yield, Moisture Content, Water Activity, pH, and Color of Duck Black Pudding

The processing yield, moisture content, water activity, pH, and color values of black pudding with various cereal fibers are presented in Table 1. The processing yield of black pudding with cereals and duck blood was higher than that of the control (without cereals) ($P < 0.05$). The highest processing yield was 64.58% for the sample to which amaranth was added. In addition, the amaranth-added sample had the highest moisture content among all black pudding samples at 42.61%. Tafadzwa et al. (2021) reported that water-holding capacity was high in amaranth-added beef sausages. It can be explained that the higher the water holding capacity, the less moisture discharged, and thus the higher the moisture content in the amaranth-added sausage. This is in line with the findings of Isleroglu et al. (2015), showing that moisture content is associated with the processing yield of the product and has a significant impact on the quality properties.

The water activity, pH, and yellowness (b^*) of the control black pudding with duck blood were all higher than those with added cereals ($P < 0.05$). The lightness (L^*) of the black pudding ranged from 25.66 to 26.18, with no significant differences found among groups. The redness (a^*) of black pudding was the highest in the sample containing sorghum, followed by the samples with amaranth and quinoa. The increase in redness with the addition of cereals is in line with previous reports, which is attributed to the anthocyanin pigment contained in these cereals (Im et al., 1998; Paško et al., 2009; Sanz-Penella et al., 2013). When cereal was added to meat products, the fiber

and color of cereal were indicated to increase the processing yield and redness. It was found that the high water retention of cereal affects the processing yield, and the redness increases due to the influence of pigments in cereal. In particular, sample added with amaranth was found to have high processing yield and redness.

Cereals Influence the Textural Properties of Duck Black Pudding

As shown in Table 2, the TPA of black pudding with duck blood and cereals displayed significant differences between the control and treatment groups. The hardness of the black pudding with duck blood and cereals was higher than that of the control ($P < 0.05$), except for the samples containing amaranth. The springiness of the black pudding ranged from 0.95 to 0.97, which was the highest for the sample containing quinoa ($P < 0.05$). The cohesiveness, gumminess, and chewiness of the black pudding with duck blood and cereals were higher than that of the control ($P < 0.05$). Fellendorf et al. (2016) reported that the highest hardness and chewiness of black pudding were obtained with samples containing carrageen due to the effects of the dietary fiber. Choi et al. (2009) also reported that the hardness, gumminess, and chewiness of blood sausage were higher in treatments with rice bran than in the control. Garcia et al. (2002) indicated that the textural properties of meat products increased with the addition of cereal fiber. From the above results, it was confirmed that the moisture activity decreased when cereals were added, which may be related to bonding with water. In particular, there is a significant difference in that the TPA value increases as the moisture activity decreases in the oat-added sample compared to the control. Thus, TPA can accurately describe the quality characteristics of meat products to select appropriate ingredients; in this case, the addition of cereal to black pudding appears to result in more desirable textural properties.

Correlations of Physicochemical and Textural Properties

Dimensions 1 and 2 of the PCA plot explained 75.02% of the total variation (47.25 and 27.77%, respectively) in physicochemical properties. Figure 1A shows the correlations with all physicochemical characteristics (processing

Table 1. Effect of cereal fibers on the processing yield, moisture content, water activity, pH, and color values of duck blood black pudding.

Treatments	Control	Oats	Buckwheat	Quinoa	Amaranth	Sorghum	
Processing yield (%)	45.27 ± 0.30 ^d	47.56 ± 1.12 ^c	54.19 ± 0.53 ^b	53.45 ± 1.41 ^b	64.58 ± 1.24 ^a	63.79 ± 1.26 ^a	
Moisture content (%)	39.12 ± 1.05 ^{bc}	38.83 ± 0.96 ^{bc}	41.45 ± 1.23 ^a	40.98 ± 0.14 ^{ab}	42.61 ± 0.41 ^a	37.54 ± 0.67 ^c	
Water activity	0.872 ± 0.003 ^a	0.844 ± 0.001 ^c	7.10 ± 0.01 ^b	7.10 ± 0.01 ^b	7.10 ± 0.01 ^b	0.844 ± 0.002 ^c	
pH	7.73 ± 0.01 ^a	7.10 ± 0.01 ^b	6.90 ± 0.01 ^c	6.78 ± 0.01 ^d	6.72 ± 0.01 ^e	6.63 ± 0.01 ^f	
Color	L^*	25.91 ± 0.29 ^{ab}	25.66 ± 0.18 ^b	26.18 ± 0.30 ^a	26.06 ± 0.13 ^a	26.16 ± 0.08 ^a	26.05 ± 0.20 ^a
	a^*	2.58 ± 0.12 ^d	2.87 ± 0.10 ^d	2.59 ± 0.22 ^d	6.21 ± 0.38 ^c	6.92 ± 0.14 ^b	7.39 ± 0.15 ^a
	b^*	18.88 ± 1.27 ^a	12.26 ± 0.97 ^e	14.05 ± 0.42 ^d	15.75 ± 0.37 ^c	16.95 ± 0.54 ^{bc}	17.35 ± 0.40 ^b

All values are presented as the mean ± standard deviation of three replicates ($n = 3$).

^{a-c}Means within a row with different letters are significantly different ($P < 0.05$).

Table 2. Texture profile analysis of duck blood black pudding formulated with various cereal fibers.

Treatments	Control	Oats	Buckwheat	Quinoa	Amaranth	Sorghum
Hardness (g)	23.76 ± 0.93 ^c	28.82 ± 0.98 ^a	27.95 ± 0.78 ^{ab}	27.22 ± 0.33 ^b	23.89 ± 0.84 ^c	27.65 ± 1.15 ^{ab}
Springiness	0.95 ± 0.01 ^b	0.96 ± 0.01 ^{ab}	0.94 ± 0.01 ^b	0.97 ± 0.01 ^a	0.95 ± 0.01 ^b	0.96 ± 0.02 ^{ab}
Cohesiveness	0.38 ± 0.03 ^c	0.45 ± 0.03 ^a	0.41 ± 0.03 ^b	0.42 ± 0.02 ^b	0.43 ± 0.02 ^{ab}	0.42 ± 0.03 ^b
Gumminess (g)	9.03 ± 0.28 ^d	12.99 ± 0.92 ^a	11.73 ± 0.78 ^b	11.52 ± 0.57 ^b	10.27 ± 0.27 ^c	11.36 ± 0.66 ^b
Chewiness (g)	8.58 ± 0.27 ^d	12.51 ± 0.89 ^a	11.21 ± 0.74 ^{ab}	11.01 ± 0.54 ^{ab}	9.76 ± 0.22 ^c	10.85 ± 0.70 ^b

All values are presented as the mean ± standard deviation of three replicates (n = 3).

^{a-d}Means within a row with different letters are significantly different ($P < 0.05$).

yield, moisture content, water activity, pH, and color) as the independent variables and TPA factors as the descriptors, whereas Figure 1B shows the individual graphs for each cereal group. According to Shin et al. (2010), variables

closest to each other or farther from the origin in the PCA plot have a positive correlation, and variables further from each other on the plot have a negative correlation. In Dimension 1, TPA and water activity were negatively

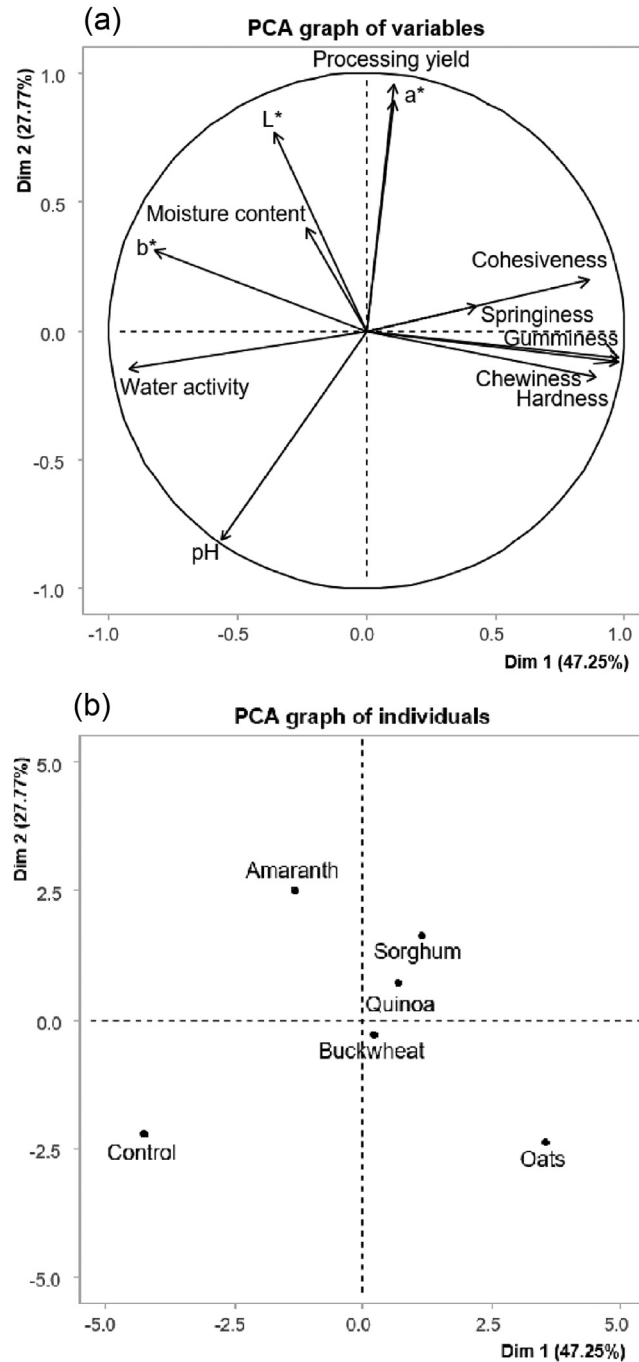


Figure 1. Principal component analysis (PCA) of physicochemical properties and texture profiles for black pudding prepared with and without (control) various cereals.

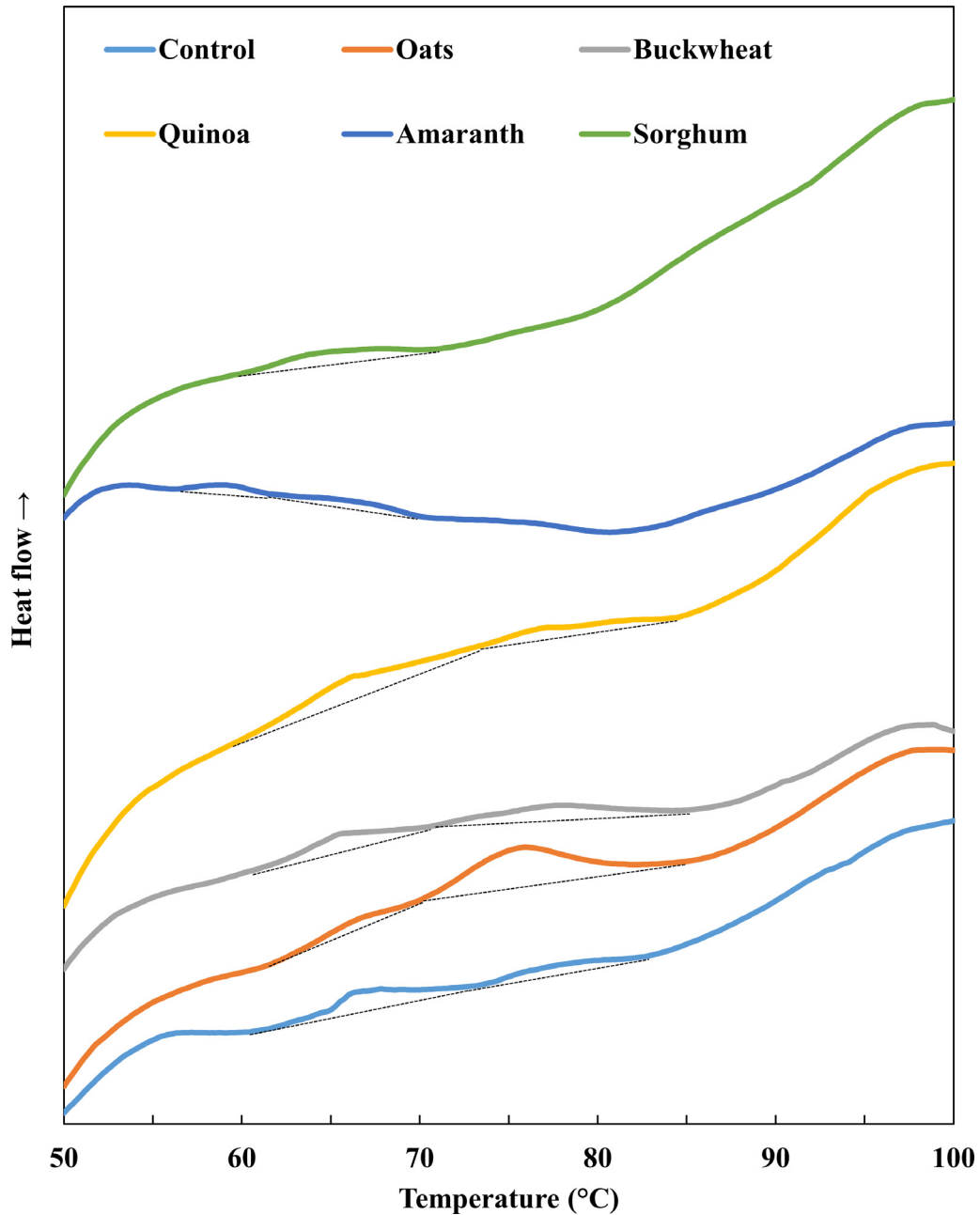


Figure 2. Differential scanning calorimetry (DSC) curves of black pudding formulated with and without (control) various cereal fibers.

correlated, indicating that the value of TPA increased as the water activity decreased. This correlation was further confirmed since the oat sample, which had low water activity and a high TPA value, was the furthest from the control sample along Dimension 1. In Dimension 2, the processing yield and redness were positively correlated, indicating a proportional relationship. Indeed, amaranth was plotted the furthest from the control sample along Dimension 2, representing the processing yield value. No significant differences were found for the remaining treatments.

Effect of Cereals on the Thermal Stability of Duck Blood Pudding

The structure of proteins and addition of non-protein ingredients could affect the thermal properties of protein

heat-induced gelation in food processing owing to changes in protein-protein or protein-water interactions (Parniakov et al., 2018). The changes in the slope of the DSC graph indicate changes in enthalpy, which can be used to predict the thermal reaction of food materials (Heussen et al., 2011). As shown in Figure 2, the temperature with a clear peak point differed according to the treatment. Except for the sorghum treatment, all treatments had 2 distinct peak temperatures. According to Dávila et al. (2007), thermal stability can be affected by pH, and blood ingredients that are more alkaline have relatively higher peak temperatures and enthalpies. In this study, the pH of the black pudding samples varied according to the addition of different cereal fibers, with the sorghum treatment exhibiting the lowest pH value, indicating easy aggregation. These results might be due to the decreased ionic strength of the blood protein.

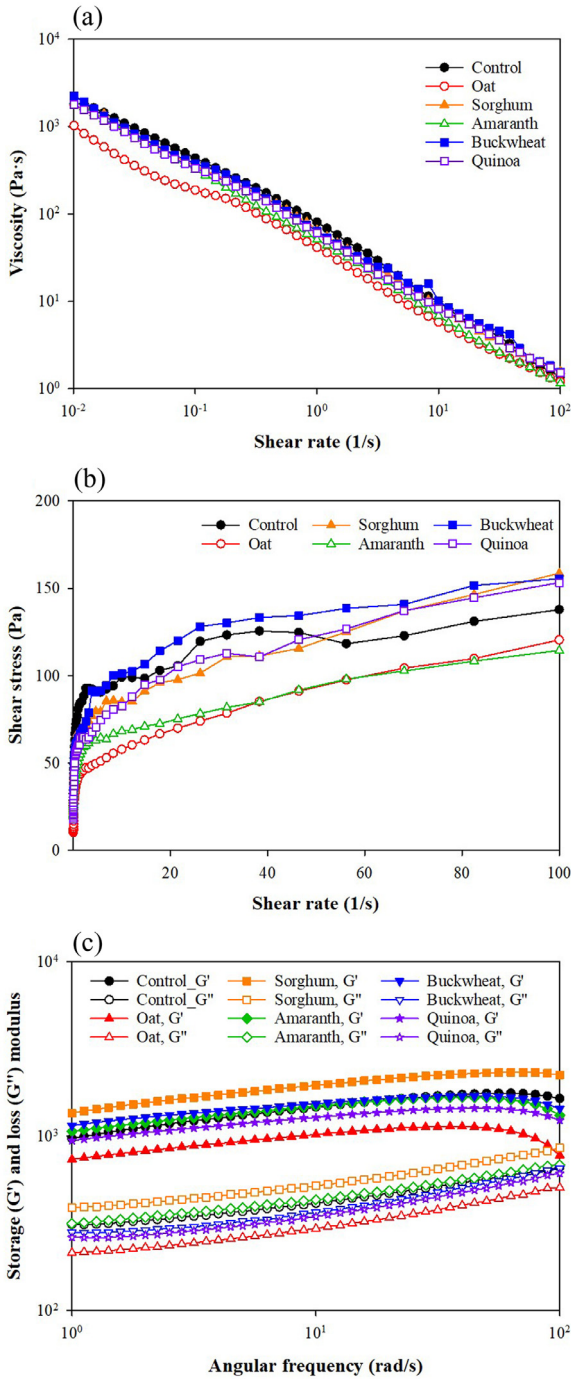


Figure 3. Effect of various cereal fibers on the dynamic viscosity parameters of black pudding: (A) viscosity, (B) shear stress, and (C) storage (G') and loss (G'') moduli.

Proteins with low thermal stability can undergo excessive aggregation, and heating can cause further aggregation to induce poor quality properties of black pudding (Zayas, 1997). In addition, the thermal stability of blood protein can be reduced with an increase in the water-holding capacity because hydrophilic and ionic bonds can become easily disconnected during heating (Gomez-Guillen et al., 1997). However, we found that the moisture content of the buckwheat and amaranth treatments was higher than that of the control ($P < 0.05$), whereas the quinoa and sorghum treatments had a similar moisture content as the control ($P > 0.05$). This result might

be due to differences in the water-holding capacity of the fiber contents in the various cereals (Choi et al., 2011). Thus, although the addition of cereal fiber could induce decreased thermal stability with a decrease in pH, the high water-holding capacity of the fiber could result in decreased quality properties.

Dynamic Viscosity

The changes in viscosity as a function of shear rate (from 10^{-2} to 10^2 s^{-1}) of black pudding with duck blood and different cereals are shown in Figure 3A. The viscosity of all samples, including the control (without cereals), decreased as the shear rate increased, indicating non-Newtonian fluids. In addition, although the viscosity of black pudding with oat was slightly lower than that of the others, the values were overall similar among samples. As shown in Figure 3B, the shear stress of all samples sharply increased in the low shear rate range, and the increment gradually increased in the range of higher shear rates. In general, most food materials exhibit shear-thinning behavior. Consistently, the viscosity profiles of all samples in the present study indicate that the black pudding prepared with duck blood, namely the control, and different cereals, namely oat, sorghum, amaranth, buckwheat, and quinoa, are shear-thinning fluids with flow behavior indices (n) of 0.1924, 0.2647, 0.2058, 0.1792, 0.2158, and 0.2175, respectively, which are all substantially lower than 1 (Gomathy et al., 2015). However, the shear stress values of black pudding samples with oat and amaranth were slightly lower than that of the others. This could be explained by the differences in the composition of these cereals. Oat and amaranth are cereals with a relatively high fat content (especially unsaturated fatty acids, including oleic acid and linoleic acid) of approximately 8 and 7%, respectively (Welch, 2011; Mburu et al., 2011). However, the fat content of quinoa is approximately 5.7% and is even lower for sorghum and buckwheat at approximately 3.3 and 2.8%, respectively (Nowak et al., 2016; Welch, 2011; Zhu, 2016). Figure 3C shows the storage (G') and loss (G'') moduli of the black pudding samples. In the angular frequency range of 1 to 100 rad/s, the G' values of all samples are always higher than the G'' values, indicating that the black puddings exhibit a solid-like behavior. In general, $\tan \delta (= G''/G')$ smaller than 1 indicates that the fluid exhibits solid-like behavior (Lee et al., 2018). This may be due to denaturation of the protein in duck blood induced by heat during preparation of the black pudding.

CONCLUSIONS

This study investigated the effect of using various cereals such as oats, buckwheat, quinoa, amaranth, and sorghum on quality characteristics for the development of black pudding. This analysis showed that the addition of various cereal types significantly improved the physicochemical and rheological properties of black pudding

made with duck blood. It can be seen that the quality of the sample applied with amaranth was improved in processing yield, and the quality of the sample applied with oat was improved in terms of texture profile. These results suggest that black pudding with duck blood and cereal fiber may have excellent processing characteristics superior to those of black pudding without added cereals. This study therefore provides a foundation for further development of black pudding products with duck blood to improve infant and age-friendly foods.

DISCLOSURES

The authors declare no conflicts of interest.

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