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ORIGINAL ARTICLE

Evaluation of kamaboko quality characteristics when it is produced using sorghum distillers grains

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Abstract

Kamaboko is an important fish product that is consumed in high volumes across the globe. This study investigated whether the amount of sorghum distillers grains (SDGs) contained in kamaboko affected its quality. Kamaboko containing SDG had significantly higher cohesiveness and chewiness, but reduced springiness and gumminess. However, the SDG addition ratio had no significant effect on hardness. The pH value (range, pH 4.98–5.87) and cooking loss (range, 2.54–2.71%) were significantly lower than the control group (5.99 and 5.27%, respectively). The kamaboko's emulsification stability and water loss (range, 1.22–1.59%) decreased with increasing SDG; however, the differences were not significant. The fat loss (range, 0.02–0.10%) and water-holding capacity (WHC) (range, 91.56–95.91%) at high SDG addition ratios (100%) were significantly lower than those in the control group (0.07 and 96.12%, respectively).

Practical applications

The results of this study demonstrate the practical application of sorghum distillers grains (SDG), a byproduct of brewing a famous Taiwanese alcoholic drink, kaoliang liquor. Sorghum distillers grains can replace starch in emulsified seafood products, such as kamaboko, to create products with favorable qualities (texture profile analysis, pH value, cooking loss, and emulsification stability). Ultimately, our findings should serve as a reference for exploring the diverse roles of SDG in food processing, provide a basis for adding value to SDG, and help reduce the waste and the environmental problems caused by leftover distillers grains generated during the alcohol brewing process.

1 | INTRODUCTION

The high nutritional value of seafood and its importance in the human diet have been demonstrated in recent years (Shabanpour & Etemadian, 2016). Seafood products play a key role in maintaining the dietary balance. Kamaboko is made of surimi and is an emulsified seafood product that is generally consumed immediately after preparation (Desai et al., 2006; Yamada et al., 2018). Kamaboko is one of the most popular and important fish products (Hajidoun & Jafarpour, 2013; Mao et al., 2006; Suryaningrum et al., 2015; Yaguchi et al., 2017; Yamada et al., 2018) because of its unique texture and nutritional value. It is made from the highest quality fresh fish and is rich in protein, and low in calories and fat (Mao et al., 2006). Kamaboko is produced in large quantities in Taiwan and has become commercially available worldwide in response to increasing health consciousness among consumers.

The quality of kamaboko depends on a number of factors, including the species and freshness of the fish used, processing methods, and variables such as moisture content, salt, and pH (Jafarpour & Gorczyca, 2012; Mao et al., 2006; Seighalani et al., 2017; Seighalani et al., 2017; Yaguchi et al., 2017). In addition, kamaboko contains surimi as the main ingredient and starch as a filler. It also contains added sugar and salt (Suryaningrum et al., 2015). However, various food additives are commonly used to enhance its quality and reduce production costs. The necessity of these additives has received increasing attention because consumer perception indicates that the use of natural food materials is safer and healthier.

Consumer desire for healthy foods has led to changes in the demand for processed foods and fierce competition in relevant markets. This has prompted the manufacturers of processed fish products to consistently improve their food processing protocols and material processing techniques (Chou, 2020). Functional properties are the major factors affecting the final acceptance of kamaboko by consumers (Fogaça et al., 2013). Therefore, the application of functional materials in the preparation of healthy kamaboko has become a key topic in seafood production.

However, the remaining distillers grains are typically regarded as waste products of the liquor fermentation process. Currently, Taiwan produces a lot of distillers grains annually, which constitutes a serious waste problem as these distillers grains possess a wide range of nutrients. Thus, identifying an appropriate use for distiller grains has become a pressing matter (Chou, 2020).

Sorghum distillers grains (SDGs) are a byproduct generated after brewing a famous Taiwanese alcoholic liquor, kaoliang liquor (Chou, 2020). Numerous studies have reported that distiller grains possess a comprehensive range of nutrients (Awika & Rooney, 2004) and have an excellent water-holding capacity (WHC) (Chou, 2020). Therefore, many food products based on distiller grains, such as biscuits, have been developed over the years. However, the application of SDGs during the processing of fish products is none.

In summary, distillers grains are byproducts of alcohol breweries and have a high nutritional value, dietary fiber content, and WHC (Chou, 2020). The second property, dietary fiber, is generally lacking in modern human diets. Surimi is the main ingredient in kamaboko, a product whose production methods and physical properties have been extensively investigated (Desai et al., 2006; Shabanpour & Etemadian, 2016; Yaguchi et al., 2017). However, there have been few reports about how SDG addition affects the characteristics of kamaboko. Kamaboko is produced and consumed in large quantities worldwide, but fish products do not contain dietary fiber. Therefore, we examined the effects of substituting potato flour during kamaboko production with SDG at different proportions (20, 40, 60, 80, and 100%) and investigated the quality characteristics of kamaboko (texture profile analysis, pH value, cooking loss, and emulsification stability). Ultimately, our findings should serve as a reference for exploring the diverse roles of SDG in food processing, and provide a basis for adding value to SDG, and reducing the waste and the environmental problems caused by leftover distillers grains generated during alcohol brewing.

2 | MATERIALS AND METHODS

2.1 | Raw materials

Fresh tilapia (*Oreochromis niloticus*) weighing ~0.5 kg per head was purchased from a local market in Neipu Township, Pingtung County, Taiwan. The fish were packed in ice and transported to the laboratory. After the heads, viscera, tails, bone, and skin were removed, the dorsal muscle was collected and chopped into <3 mm cubes for the preparation of surimi and kamaboko.

Salt, sugar, and potato flour were purchased from a local market in Neipu Township, Pingtung County, Taiwan. The SDGs were purchased from the Pingtung Brewery of the Taiwan Tobacco and Liquor Corporation, Taiwan. Then the SDGs were stored in a freezer at 7°C until needed. Prior to the experiment, the SDGs were removed from the freezer and left to reach room temperature before processing.

2.2 | Preparation of SDGs

The SDGs were prepared according to Chou (2020). They were first placed in a 42°C oven (Constant Temperature Oven DKN 612; Yamoto Company) and dried until the water activity was below 0.3. The dried SDG was pulverized using a grinder (RT-N08; Rong Tsong) and then the SDG powders were sieved through a 30-mesh sieve (Retsch GmbH). Finally, the sifted SDG powder was placed in a sealed container and stored at 18°C.

2.3 | Surimi preparation

The surimi was prepared according to Suryaningrum et al. (2015), Seighalani et al. (2017), and Seighalani et al., (2017), with some modifications. Approximately 500 g of minced fish was weighed and washed three times with cold water (kept below 5°C) at a water/mince ratio of 5:1 for 15 min. After the third wash, 22.5 g NaCl was added. The water was subsequently removed using a dehydrator (SYCY-15-D; Sheng-You Co. Ltd.) for 1 min. The minced fish were ground using a meat mincer (CB-7; K.S.H. Kinn Shang Hoo Iron Works) for 1 min, and then 2.5% NaCl was added and the product was continuously ground for 2 min to obtain surimi. The surimi was packed into a 1 kg pack and kept at −18°C until needed.

2.4 | Proximal analysis of SDG

The moisture, crude protein, crude fat, crude fiber, and ash contents of the SDG were estimated using standard methods of analysis (AOAC, 2012). Total carbohydrate content was calculated using the difference method and the following formula: Total carbohydrate (%) = 100 − [moisture (%) + crude protein (%) + crude fat (%) + total ash (%)]. In addition, the total dietary fiber and insoluble dietary fiber were also estimated using standard methods of analysis (AOAC, 1986 and AOAC, 1994).

The moisture, crude protein, crude fat, crude fiber, ash content, and total carbohydrate contents of the SDG were 8.0, 13.8, 5.3, 17.7, 5.0, and 67.9% (wet weight basis), respectively (data not shown). The total dietary fiber and insoluble dietary fiber of the SDG were 34.08 and 31.68%, respectively (data not shown).

2.5 | Preparation of kamaboko containing SDG

The kamaboko was prepared as described by Chou (2020), Yaguchi et al. (2017), Seighalani et al. (2017), Seighalani et al., (2017), and Suryaningrum et al. (2015), with some modifications. The raw materials for each group were weighed according to a predetermined formula (Table 1). The frozen surimi was thawed and ground with salt in a meat mincer (CB-7; Kinn Shang Hoo Iron Works) to obtain homogeneous surimi. The surimi was stirred until a sticky paste had formed. Then, sugar, ice water, potato starch, and SDG were gradually added and the mix was stirred for 15 min. The resulting dough was shaped into a kamaboko with the following specifications: length = 15 cm, width = 5 cm, and thickness = 1 cm. The shaped kamaboko was then placed in a 100°C gas steamer (CK-485; Chuan Kuel) and steamed for 15 min to fix the shape. Finally, the manufactured kamaboko was removed from the steamer, packed, and stored at −18°C for further analysis.

2.6 | Texture profile analysis

Texture profile analysis was conducted using an EZ Test-500N texture analyzer (TAXTZ-5, Shimadzu Co.) as previously described by Chou (2020), Jin et al., (2016), and Suryaningrum et al. (2015), with some modifications after calibrating the accuracy. The samples were sliced into pieces (3 cm ×3 cm ×1 cm). For each set of samples, two compression testing sessions were conducted at a compression speed of 60 mm/min with a 1 cm rounded probe, a 500 N load cell, and a compression height that was set to 50% of the height of the original sample. Three measurements were performed for each sample set.

2.7 | Determination of the pH value

The pH value was analyzed using a calibrated digital pH tester (PL 700PV(s); Great Tide Instrument Co., Ltd.) as previously described by Chou (2020), Seighalani et al. (2017), Seighalani et al., (2017), and Park and Kim (2016), with some modifications. A 10% (wt/vol) suspension was homogenized using a food processor (CP-75S; Ladyship Co., Ltd.) for 5 min and allowed to stand for 30 min. Three measurements were performed for each sample set.

2.8 | Cooking loss analysis

The cooking loss analysis was performed according to Chou (2020). A total of 2 g of each sample and 20 ml of distilled water were measured out. Then, the distilled water was placed in a crucible (W) with a constant weight and heated to boiling using a heating plate (HP-303D; NewLab). The weighed sample was added to the boiled distilled water and heated for 5 min before removal. Then, the remaining liquid was then placed in an oven (DKN 612; Constant Temperature Oven, Yamoto Company) at 105°C and dried to a constant weight (W1). The cooking loss rate was calculated using the following formula: cooking loss rate = (W1 − W)/X × 100. Three measurements were performed for each sample set.

2.9 | Emulsified stability and WHC analysis

The emulsified stability and WHC analysis procedures were conducted as described by Chou (2020), Park and Kim (2016), and Hajidoun and Jafarpour (2013), with some modifications. Each sample (20 g) was weighed and suspended in a beaker and covered with aluminum foil. The beaker was then placed in a circulating bath (BH-230D; Yihder) at 75°C for 30 min before being removed and set aside to cool. The cooled beaker was then weighed and placed in a drier (DV453; Channel model) at 60°C for 6 hr to remove the moisture. The dried beaker was weighed again and the obtained values were substituted into the following formulas to calculate the water loss and fat loss ratio. Three measurements were performed for each sample set.

$$\text{Water loss }(\%) = (\text{water weight}/\text{sample weight}) \times 100 \tag{1}$$

$$\text{Fat loss }(\%) = (\text{oil weight}/\text{sample weight}) \times 100 \tag{2}$$

$$\text{WHC }(\%) = (\text{water content} - \text{water loss lrb}\%)/\text{water content} \times 100 \tag{3}$$

2.10 | Statistical analysis

The collected data were organized by Microsoft Excel 2010 and evaluated using analysis of variance (ANOVA) and Statistical Analysis System statistical software (Windows V9.1, SAS Institute

TABLE 1 Kamaboko composition (g) according to the SDG ratio

	Category					
Ingredient	Control group	20%	40%	60%	80%	100%
Surimi	1,500	1,500	1,500	1,500	1,500	1,500
Salt	22.5	22.5	22.5	22.5	22.5	22.5
Sugar	30	30	30	30	30	30
Ice water	375	375	375	375	375	375
Potato starch	300	240	180	120	60	0
SDG	0	60	120	180	240	300

Inc.). Differences between the mean values were evaluated using Duncan's multiple range test ($p < .05$).

3 | RESULTS AND DISCUSSION

3.1 | Texture profile analysis

The effects of different ratios of SDG addition on the texture of kamaboko are summarized in Table 2. The texture profile analysis indicated that kamaboko supplemented with SDG had higher levels of cohesiveness and chewiness ($p < .05$) than the kamaboko in the control group. The hardness analysis indicated that the hardness of the produced kamaboko ranged from 1.22 to 1.59 kgf, and the addition of SDG to kamaboko did not significantly affect its hardness ($p > .05$). A higher SDG addition ratio corresponded to a lower hardness level for the manufactured kamaboko. It is probable that the gel strength of kamaboko decreased because the SDG contained starch (Yaguchi et al., 2017). The gel-forming (gelation) process for myofibrillar proteins in fish muscle is the most important step in the formation of unique and gel-like textures. It is caused by heating after the kamaboko is ground with salt (Do & To, 2017; Hajidoun & Jafarpour, 2013; Hosseini-Shekarabi et al., 2015; Shabanpour & Etemadian, 2016; Uzzaman et al., 2018). Depending on the type of additive applied and the preparation method (Hosseini-Shekarabi et al., 2015; Seighalani et al., 2017; Seighalani et al., 2017), starch promotes the formation of a continuous matrix by interacting with water and protein in the fish paste and plays an important role in improving the mechanical and functional properties of kamaboko (Fogaça et al., 2013). The decreased hardness of kamaboko at higher SDG addition ratios may be due to excessive cross-linking, which lowers the gel strength and hardness by impeding protein intermolecular aggregation, which reduces gel network formation (Seighalani et al., 2017; Seighalani et al., 2017). However, the finding of this study was not statistically significant ($p > .05$) among the different experimental variables, but the result was in agreement with Hajidoun and Jafarpour (2013), who found that the hardness of common carp surimi gels was not affected by different levels (0.5, 1.0, and 1.5%) of added chitosan. Our results showed that the different SDG addition ratios had no significant effects on kamaboko.

The springiness analysis indicated that the springiness of the kamaboko produced ranged from 0.29 1.67. The results presented in Table 2 indicate that increasing SDG addition led to a lower level of springiness in the manufactured kamaboko, and some of these results were statistically significant ($p < .05$). Uzzaman et al. (2018) demonstrated that the springiness of red tilapia mince gel (*Oreochromis sp.*) supplemented with chitosan and phosphate salts ranged from 0.3 to 0.9. Hajidoun and Jafarpour (2013) also demonstrated that the elasticity of common carp surimi with various concentrations of chitosan ranged from 0.96 to 0.99, which was similar to the results obtained in this study. Yen and Anh (2018) found that the texture of a product is determined by the gel-forming process, which involves the myofibrillar proteins in fish muscle. Kamaboko has an elastic texture (springiness) owing to its protein gel availability (Suryaningrum et al., 2015). The formation of a fish protein gel matrix in kamaboko is affected by pH and water availability because the interaction between protein and water affects springiness (Suryaningrum et al., 2015). According to Suryaningrum et al. (2015), the optimal pH for strong gelation was approximately pH 7.0–7.5 for kamaboko, while the pH value of kamaboko after the addition of SDG ranged from 4.98 to 5.99 (Table 3). These results indicate that a higher SDG addition ratio leads to a lower pH value and springiness in kamaboko.

The cohesiveness analysis indicated that the cohesiveness of kamaboko ranged from 0.11 to 0.43. Furthermore, after the addition of SDG, kamaboko had significantly higher cohesiveness than that of the control group (0.04) ($p < .05$). Hajidoun and Jafarpour (2013) demonstrated that the cohesiveness of common carp surimi with various concentrations of chitosan ranged from 0.65 to 0.80. Similarly, Uzzaman et al. (2018) also demonstrated that the cohesiveness of red tilapia mince gel (*Oreochromis* sp.) with chitosan and phosphate salts ranged from 0.10 to 0.55, which was similar to the results obtained in this study. The cohesiveness of kamaboko is affected by pH and water availability and depends on the interaction between protein and water (Suryaningrum et al., 2015). A higher

TABLE 2 Effects of different SDG ratios on kamaboko texture

Experimental group	Hardness (kgf)	Springiness	Cohesiveness	Gumminess (gf)	Chewiness (gf)
Control					
	1.44 ± 0.03^{a}	2.17 ± 0.23^{a}	0.04 ± 0.01^{e}	112.98 ± 4.96^{a}	15.53 ± 3.79^{e}
20%	1.59 ± 0.06^{a}	1.67 ± 0.33^{b}	0.11 ± 0.01^{d}	93.15 ± 2.25^{b}	16.63 ± 2.55^{de}
SDG					
40%	1.49 ± 0.01^{a}	0.94 ± 0.02^{c}	0.20 ± 0.04^{c}	63.69 ± 4.83^{cd}	23.39 ± 1.74^{cd}
60%	1.30 ± 0.03^{a}	0.75 ± 0.02^{cd}	0.23 ± 0.02^{c}	65.14 ± 3.32^{c}	24.53 ± 3.51^{c}
80%	1.28 ± 0.01^{a}	0.54 ± 0.06^{de}	0.31 ± 0.06^{b}	57.60 ± 2.20^{de}	35.70 ± 2.67^{b}
100%	1.22 ± 0.07^{a}	0.29 ± 0.02^{e}	0.43 ± 0.01^{a}	53.84 ± 3.15^{e}	50.41 ± 6.95^{a}

Note: Different superscript letters in the same column are significant differences ($p < .05$). Values are means ($n = 3$).

TABLE 3 Effects of different SDG ratios on kamaboko pH

Experimental group	pH
Control	
	5.99 ± 0.04^{a}
20%	5.87 ± 0.02^{b}
SDG	
40%	5.78 ± 0.02^{c}
60%	5.69 ± 0.02^{d}
80%	5.50 ± 0.01^{e}
100%	4.98 ± 0.03^{f}

Note: Different superscript letters in the same column are significant differences ($p < .05$). Values are means ($n = 3$).

SDG addition ratio led to a higher level of cohesiveness in manufactured kamaboko, and some of the results were statistically significant ($p < .05$). A possible explanation for the improved texture of kamaboko after the addition of different ratios of SDG is the slight reduction in the myosin heavy chain content via polymerization, which enhances the formation of cross-linked myosin heavy chain components (Hajidoun & Jafarpour, 2013; Seighalani et al., 2017; Seighalani et al., 2017). The results from this study indicate that the use of SDG in the preparation of kamaboko significantly affects the cohesiveness of the manufactured products.

The gumminess analysis indicated that the gumminess of the produced kamaboko ranged from 53.84 to 93.15 gf, and samples with added SDG had a significantly lower level of gumminess than the control group (112.98 gf) ($p < .05$). Yaguchi et al. (2017) reported that the texture decreases with increasing vegetable and fruit powder concentrations. In another study, Uzzaman et al. (2018) demonstrated that adding chitosan and phosphate salts to red tilapia mince gel (*Oreochromis* sp.) altered its gumminess (gumminess range: 0.10–0.55 kgf), which could be attributed to the gelation of kamaboko being either inhibited or enhanced. This means that the gel texture of the products can be very different from gels formed by the food components (Uzzaman et al., 2018).

The chewiness analysis indicated that the chewiness of the produced kamaboko ranged from 16.63 to 50.41 gf, and the added SDG products had a significantly higher level of chewiness than the control group (15.57 gf) ($p < .05$). A higher SDG addition ratio increased the chewiness of the kamaboko. It is possible that the chewiness of kamaboko increases because the SDG contains starch (Yaguchi et al., 2017). The heating process used during the production of kamaboko can cause several changes to the starch characteristics, such as the swelling of starch granules and water absorption, both of which improve texture and chewiness (Suryaningrum et al., 2015).

Texture is the most important factor when evaluating the quality of kamaboko (Do & To, 2017). According to Choe et al. (2013), emulsified products with greater levels of cohesiveness and chewiness show greater emulsification stability. The results of the present study indicate that the addition of SDG generally resulted in higher levels of cohesiveness and chewiness in kamaboko than in the control group ($p < .05$). No negative effects were observed when different amounts of SDG were added to the kamaboko.

Ultimately, these results indicate that the addition of SDG may enhance the emulsification stability of kamaboko, which is crucial when attempting to enhance its texture and increase consumer acceptance of kamaboko.

3.2 | pH

The effects of different SDG addition ratios on the pH value of kamaboko are summarized in Table 3. The pH value of the kamaboko with added SDG ranged between pH 4.98 and 5.87, which was significantly lower than the pH value of the kamaboko in the control group (5.99) ($p < .05$). These results indicate that a higher SDG addition ratio corresponds to a lower pH value for kamaboko. Chou (2020) demonstrated that the pH of emulsified pork sausages prepared with different SDG addition ratios (0, 20, 40, 60, 80, and 100%) ranged from 6.21 to 6.43. Seighalani et al. (2017) and Seighalani et al. (2017) demonstrated that the pH of kamaboko from red tilapia ranged from 6.60 to 6.67, and Seong et al. (2017) reported that the pH values of emulsified pork sausages prepared with *Monascus* powder ranged from 6.63 to 6.57. Another study (Jin et al., 2014) substituted nitrite with beetroot in the preparation process for emulsified pork sausages and found that the pH of the sausages produced ranged from 6.03 to 6.30. These results are similar to those produced by the present study. Generally, the pH values of kamaboko and surimi products depend on the ingredients, water-soluble acid elements (free amino acids, lactic acid, and free fatty acids), and additives, which are removed by washing during preparation, resulting in only slight differences in pH (Pietrasik, 1999; Seighalani et al., 2017; Seighalani et al., 2017; Yaguchi et al., 2017). These factors, in turn, affect the quality of kamaboko and surimi products, including their WHC, freshness, color, and texture (Jin et al., 2014). The results of the present study are consistent with those of Pietrasik (1999).

3.3 | Cooking loss

The results for the effects of different SDG addition ratios on kamaboko cooking losses (Table 4) indicated that cooking loss ranged between 2.54 and 2.71%, which was significantly lower than the kamaboko cooking loss in the control group (5.27%) ($p < .05$). However, the addition of 20 and 100% SDG did not significantly affect the kamaboko cooking losses ($p > .05$). This is probably because the SDG contains crude fiber (17.7%), total dietary fiber (34.08), and insoluble dietary fiber (31.68%). Chou (2020) demonstrated that the cooking losses for emulsified pork sausages prepared with different SDG ratios (0, 20, 40, 60, 80, and 100%) ranged from 4. to 6.39%. Ham et al. (2017) indicated that an increase in the lotus root addition ratio during the production of pork sausages led to an increase in crude fiber and ultimately a reduction in the sausage cooking loss (range: 5.89–7.31%), which is similar to the results obtained in the present study. Similarly, Lee et al. (2017) reported that crude fiber in raw ingredients can effectively reduce cooking losses.

3.4 | Emulsification stability: water loss

The results for the effects of different SDG addition ratios on water loss from kamaboko (Table 5) revealed that the water loss ranged between 1.22 and 1.59%. The addition of SDG to kamaboko did not significantly affect water loss from kamaboko ($p > .05$). Chou (2020) showed that the water loss from emulsified pork sausages prepared with different SDG addition ratios (0, 20, 40, 60, 80, and 100%) ranged from 1.83 to 3.00%. Lee et al. (2017) reported that a higher wheat flour addition ratio during the production of emulsified pork sausages reduced the water loss rate (range: 2.50–7.19%), which was similar to the results obtained in the present study. The different SDG ratios did not have any negative effects on kamaboko in the present study.

TABLE 4 Effects of different SDG ratios on cooking loss rate for kamaboko

Experimental group	Cooking loss (%)
Control	
	5.27 ± 0.23^{a}
20%	2.71 ± 0.43^{b}
SDG	
40%	2.54 ± 0.08^{b}
60%	2.64 ± 0.04^{b}
80%	2.57 ± 0.25^{b}
100%	2.55 ± 0.60^{b}

Note: Different superscript letters in the same column are significant differences ($p < .05$). Values are means ($n = 3$).

TABLE 5 Effects of different SDG ratios on water loss rate for kamaboko

Experimental group	Water loss (%)
Control	
	1.44 ± 0.33^{a}
20%	1.59 ± 0.21^{a}
SDG	
40%	1.28 ± 0.40^{a}
60%	1.49 ± 0.21^{a}
80%	1.30 ± 0.08^{a}
100%	1.22 ± 0.11^{a}

Note: Different superscript letters in the same column are significant differences ($p < .05$). Values are means ($n = 3$).

3.5 | Emulsification stability: fat loss

The analysis results for the effects of different SDG addition ratios on fat loss from kamaboko (Table 6) indicated that fat loss ranged from 0.02 to 0.10%. Fat loss decreased as the SDG addition ratio increased and was lowest (0.02%) at the 100% addition ratio. However, the addition of 20 and 80% SDG did not significantly affect fat loss from kamaboko ($p > .05$). Chou (2020) demonstrated that the fat loss from emulsified pork sausages prepared with different SDG addition ratios (0, 20, 40, 60, 80, and 100%) ranged from 0.05 to 0.10%. Ham et al. (2017) reported that the fat loss from emulsified pork sausages tended to decrease as the lotus root powder addition ratio (0, 1, 2, and 3%) increased, which was similar to the results obtained in the present study.

3.6 | Water-holding capacity

The WHC of kamaboko after the addition of different amounts of SDG indicated that the WHC of kamaboko ranged from 91.06 to 95.91% (Table 7). In addition, a higher SDG addition ratio corresponds to a lower WHC for kamaboko. The lowest WHC (91.06%) was obtained with an addition ratio of 100%. However, the addition of between 20

TABLE 6 Effects of different SDG ratios on fat loss by kamaboko

Experimental group	Fat loss (%)
Control	
	0.07 ± 0.03^{ab}
20%	0.10 ± 0.05^{a}
SDG	
40%	0.05 ± 0.00^{ab}
60%	0.05 ± 0.00^{ab}
80%	0.04 ± 0.00^{ab}
100%	0.02 ± 0.00^{b}

Note: Different superscript letters in the same column are significant differences ($p < .05$). Values are means ($n = 3$).

TABLE 7 Effects of different SDG ratios on the water-holding capacity (WHC) of kamaboko

Experimental group	WHC (%)
Control	
	96.12 ± 0.14^{a}
20%	95.91 ± 0.04^{a}
SDG	
40%	95.88 ± 0.72^{a}
60%	95.79 ± 0.40^{a}
80%	95.76 ± 1.04^{a}
100%	91.06 ± 0.22^{b}

Note: Different superscript letters in the same column are significant differences ($p < .05$). Values are means ($n = 3$).

and 80% SDG did not appear to significantly affect the WHC ($p > .05$). Chou (2020) demonstrated that the WHC of emulsified pork sausages prepared with different SDG addition ratios (0, 20, 40, 60, 80, and 100%) ranged from 95.88 to 97.16%, but these differences were not statistically significant ($p > .05$), which was similar to the results obtained in the present study. Suryaningrum et al. (2015) reported that the WHC of protein gels was significantly different at a pH of ~6. Water-holding capacity is defined as the ability of fish muscle to retain water in surimi gels (kamaboko). A higher WHC value indicates that the gel has an improved ability to bind to water. The WHC of kamaboko is related to myofibrillar proteins and interactions between proteins and water affect the texture of kamaboko. During kamaboko manufacturing process, proteins become denatured and gradually form a network that can absorb water. However, higher SDG ratios have been associated with a decrease in WHC. Jin et al. (2014) found that the WHC of a meat product is influenced by the interactions between its composition components, wherein the influence of non-meat components is especially strong. Furthermore, SDG, which contains crude fiber (17.7%), affected WHC in food products.

4 | CONCLUSIONS

In the present study, the effects of different SDG ratios (20, 40, 60, 80, and 100%) on the quality of kamaboko were evaluated. The texture profile analysis indicated that kamaboko with added SDG had higher levels of cohesiveness and chewiness compared to the control group, but not springiness or gumminess. However, the experimental and control kamaboko did not differ significantly in terms of hardness. The kamaboko's pHs and cooking losses tended to decrease with increasing SDG; however, the changes in cooking loss were not significant. In terms of the kamaboko's emulsification stability, the lowest fat loss and WHC were observed at the highest SDG addition ratio (100%). These results demonstrate that the addition of SDG could effectively affect the quality of emulsified seafood products (e.g., kamaboko). This strongly suggests that SDG could replace starch in the manufacture of emulsified seafood products, and can enhance the favorable qualities of the final products, including improved texture and emulsification stability. Furthermore, the results obtained in the present study highlight the diverse applications of SDG in the field of food processing. They can be used to promote the added value associated with SDG, and provide an effective solution for the waste and the environmental problems caused by distillers grains generated during alcohol brewing, all of which will ultimately enhance the value of SDG.

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CONFLICT OF INTEREST

The authors declare no potential conflict of interest with respect to the research, authorship, and/or publication of this article.

AUTHOR CONTRIBUTIONS

Chin Fu Chou: Conceptualization; Project administration; Supervision; Validation; Writing—original draft; Writing—review & editing. **Shu Chen Hsu:** Data curation; Formal analysis. **Ying Che Huang:** Supervision; Writing—review & editing.

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