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Research Article

Replacement of Potato Starch with Sorghum Distiller Grains Improves the Quality Characteristics of Emulsified Pork Meatballs

Ying-Che Huang[1] **and Chin-Fu Chou**[2]

[1]*Department of Food Science and Nutrition, Meiho University, Pingtung, Taiwan*
[2]*Master Degree Program in Safety and Health Science, Chang Jung Christian University, 1, Changda Road, Tainan City 71101, Taiwan*

Correspondence should be addressed to Chin-Fu Chou; choucf@mail.cjcu.edu.tw

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Taiwanese-style emulsified pork meatballs (EPM) (Kung-wan) are the most popular restructured ready-to-eat meat products in Taiwan. However, the quality of EPM is influenced by numerous factors, especially its nonmeat ingredients. Sorghum distillers grains (SDGs) are a byproduct of Taiwanese alcoholic liquor, kaoliang liquor brewing. SDGs have comprehensive nutrients and good processing properties. However, the application of SDGs in EPM has not been reported. For this purpose, we examined the quality of EPM containing SDGs in this study. EPM containing SDGs showed substantially higher hardness (2126.67 to 3515.50 gf), gumminess (1093.79 to 1532.19 gf), chewiness (395.43 to 501.16 mJf), and lower pH values (4.98 to 5.87) compared to those of control (1917.33 gf, 930.81 gf, 389.83 mJf, and 5.99) ($p < 0.05$); however, EPM did not affect springiness or cohesiveness. Additionally, the control EPM exhibited the highest water-holding capacity (WHC) (94.87%), which did not markedly differ from those of 20% and 40% SDGs ($p > 0.05$). The control EPM (0% SDGs) showed the lowest cooking loss (5.58%), water loss (3.67%), fat loss (1.31%), and L (54.29), a (4.23), and b values (12.62), which substantially increased with increasing SDGs addition ratios (7.42 to 35.16%, 4.27 to 15.30%, 1.31 to 9.73%, 54.87 to 59.20, 4.26 to 5.67, and 13.81 to 18.51). Therefore, sorghum distiller's grains can replace potato starch for emulsified meat products such as tribute balls, and produce high-quality products, and promote the added value of SDGs.

1. Introduction

The consumption of meat products is increasing worldwide. In recent years, processed meat in ready-to-eat form has been demanded by modern consumers to save time and effort. Taiwanese-style emulsified pork meatballs (EPM) (Kung-wan) are restructured ready-to-eat meat products produced from finely ground pork and starch [1, 2] to provide a desirable texture and reduce manufacturing costs. Although EPM is the most popular boiled, fried, or grilled edible meat product in Taiwan, there are some concerns regarding its nutritive value. Studies are needed to improve the nutritive value and functional quality of meat products through addition of functional ingredients from natural sources.

The quality of EPM is remarkably influenced by its nonmeat ingredients, such as flour, starch, soy protein, egg, and whey protein, which are used to modify functional properties and may affect the textural properties, emulsification, and water and fat binding capacity of meat products [3]. The demand for healthier meat products is increasing rapidly, leading to further development of meat products and studies of the nutrition and quality of EPM [2]. Some studies reported health impairments following consumption of synthetic food additives [4], increasing consumer concerns related to the safety of synthetic food additives. Natural food ingredients with functional properties may be a useful alternative to synthetic chemical additives.

Various plant-derived ingredients (wheat, oat, soya, etc.) have been applied in meat product manufacturing to provide beneficial components and decrease formulation costs [5]. Sorghum is one of the most important but least utilized staple crops in Africa, Asia, and America [6]. Additionally, sorghum grains require less water during the growing than corn and higher yield, and have a lower cost of production in comparison to corn [7, 8]. Sorghum grain is a rich in nutrients and phenolic compounds. The phenolic compounds in sorghum are unique and more abundant and diverse than other common cereal grains [9]. Therefore, sorghum grain has been used to develop variety of food and beverages. Besides its use as a food, sorghum is used to produce alcoholic liquor.

Distiller grains, a byproduct of ethanol brewing, hold a high nutritional value because of the removal of starch during the fermentation process [10, 11]. SDGs are a byproduct generated after brewing a famous Taiwanese alcoholic liquor, kaoliang liquor [12]. Some studies reported the higher concentration of protein and fiber [7, 10] and lower lipid content [7] of SDGs when comparing the maize distiller-dried grains [8]. Previous researches also reported that SDGs have a comprehensive nutrients [12, 13] and good processing properties [12].

Modern human diets generally lack dietary fiber, and meat contains no dietary fiber. However, the research and application of SDGs in meat processing are rarely discussed, especially the use of emulsified meat is worthy of further research. In addition, the effects of SDGs on the quality of EPM have not been reported. Thus, in this study, we substituted potato flour with SDGs to evaluate the effects of SDGs on the quality properties of EPM. This study provides a reference for exploring the potential of using SDGs in meat industry and waste and manufacturing cost reduction.

2. Materials and Methods

2.1. Raw Materials. Pork forelegs, phosphate, potato starch, sugar, salt, lard, and egg white were bought from a local market in Pingtung County, Taiwan. SDGs were bought from the Pingtung Brewery (Taiwan Tobacco and Liquor Corporation, Taiwan). Finally, the pork forelegs, lard, and egg white were stored at 7°C, and the sifted SDGs powder was placed in a sealed container and stored at -18°C.

2.2. Preparation of SDGs. The SDGs powder was taken out from the -18°C freezer and thawed it at room temperature (30°C). The SDGs samples were first placed in a DKN 612 oven (Yamoto Company, Tokyo, Japan) and dried at 45°C for 10 h. The dried SDGs were pulverized using a RT-N08 grinder (Rong Tsong, Taichung, Taiwan) and then sieved through a Retsch GmbH sieve (550 μm, Haan, Germany). The SDG powder was placed in a sealed container and stored at 7°C [12]. Proximal analysis of SDGs was estimated according to the standard methods of analysis [14]. A graphical abstract of this study is shown in Figure 1.

2.3. Preparation of EPM. The materials for each treatment were weighed according to the formulations listed (Table 1). The pork forelegs and lard were ground with a DH802S grinder (Ding-Han Machinery Co., Ltd., Taiwan) using a grinder plate with 4 mm diameter holes) to obtain a homogeneous mixture. The mixture was minced using a CB-7 meat mincer (K.S.H. Kinn Shang Hoo Iron Works, Taiwan) for 5 min. Other raw materials were added, kept the temperature below 15°C, and mixed using a meat mincer to make uniformly shaped meatballs weighing 20 ± 2 g (approximately 30 mm diameter), which were boiled for 15 min, cooled in water, packed in nylon bags, and stored at 4°C [2, 4, 12]. Appearance of EPM supplemented with SDGs is shown in Figure 2.

2.4. Texture Profile Analysis. An EZ Test-500 N texture analyzer (TAXTZ-5, Shimadzu Co., Kyoto, Japan) was employed to measure the textural properties of EPM. Samples were cut into cubes (11.5 cm^3) [[12, 15]]. Two sessions of compression testing were conducted. The specifications of the tests were a 60 mm/min compression speed, use a rounded probe (diameter = 10 mm), and compression height equal to 50% of the sample's height.

2.5. pH Value Analysis. The pH of the EPM was analyzed using a PL 700PV(s) pH tester (Great Tide Instrument Co., Ltd., Taipei, Taiwan) [12, 15, 16]. 10 g of sample with 90 mL of distilled water was blended for pH value analysis.

2.6. Cooking Loss Analysis. Cooking loss of the EPM was analyzed according to Chou [12], Parvin et al. [1], and Al-Mamun et al. [3]. 20 mL of distilled water in a constant weight (W) crucible was boiled using a HP-303D heating plate (NewLab, Taipei, Taiwan). 2 g of each sample were added and heated for 5 min. The remaining liquid was left in the crucible was baked at 105°C in a DKN 612 oven (Yamoto Company, Tokyo, Japan) to a constant weight (W1). Cooking loss was calculated as follows:

$$\textbf{Cooking loss}\,(\%) = \frac{\mathrm{W}\mathbf{1} - \mathrm{W}}{\mathbf{X}} \times 100\%. \tag{1}$$

2.7. Emulsified Stability and WHC Analysis. The emulsified stability and WHC of EPM were analyzed according to Chou [12]. 20 g of sample was suspended in a beaker, heated by a BH-230D water bath (Yihdder Company, New Taipei City, Taiwan) at 75°C for 30 min, and then cooled. The beaker was dried using a DV453 dryer at 60°C (Channel model, New Taipei City, Taiwan). The dried beaker was weighed, and the following formulas were used to calculate the water and fat loss ratios.

$$\textbf{Water loss}\,(\%) = \frac{\textbf{water weight}}{\textbf{sample weight}} \times 100, \tag{2}$$

$$\textbf{Fat loss}\,(\%) = \frac{\textbf{oil weight}}{\textbf{sample weight}} \times 100, \tag{3}$$

$$\textbf{WHC}\,(\%) = \frac{\textbf{water content} - \textbf{water loss\%}}{\textbf{water content}} \times 100. \tag{4}$$

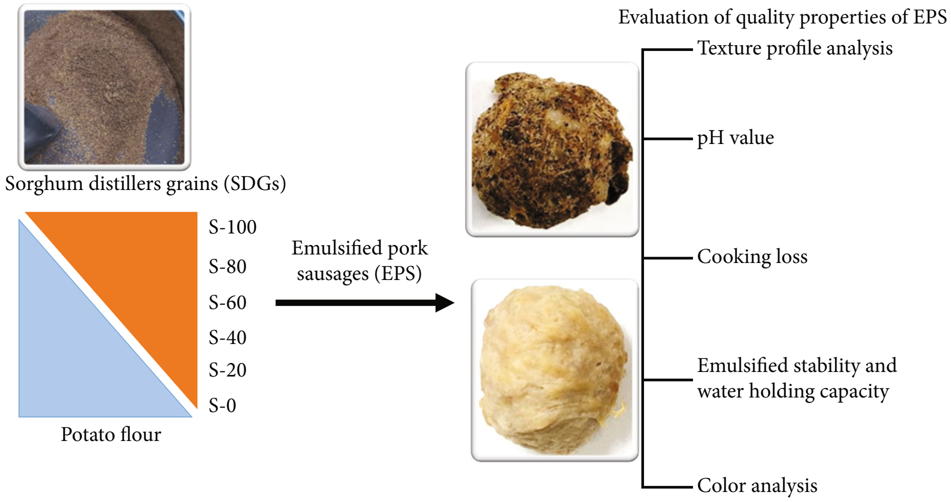

Figure 1: Graphical abstract of this study.

Table 1: Composition (in g) of the SDGs emulsified pork meatballs in each treatment.

Ingredient	Treatments					
	0% SDGs (S-0)	20% SDGs (S-20)	40% SDGs (S-40)	60% SDGs (S-60)	80% SDGs (S-80)	100% SDGs (S-100)
Pork foreleg	600.0	600.0	600.0	600.0	600.0	600.0
Ice water	150.0	150.0	150.0	150.0	150.0	150.0
Phosphate	1.8	1.8	1.8	1.8	1.8	1.8
Potato starch	30.0	24.0	18.0	12.0	6.0	0.0
Salt	12.0	12.0	12.0	12.0	12.0	12.0
Sugar	30.0	30.0	30.0	30.0	30.0	30.0
Lard	60.0	60.0	60.0	60.0	60.0	60.0
Egg white	30.0	30.0	30.0	30.0	30.0	30.0
SDGs	0	6.0	12.0	18.0	24.0	30.0

2.8. Color Analysis. A colorimeter (Hunter Lab Color Quest XE, Hunter Associates Laboratory, Reston, VA, USA) was employed to determine the color properties of the EPM (1 cm in thickness and 3 cm in diameter) [1, 12, 15]. The test results revealed the following color properties of the samples: L value ("100" represents full brightness, and "0" represents full darkness); a value ("+" represents red, "0" represents gray, and "-" represents green); and b value ("+" represents yellow, "0" represents gray, and "-" represents blue). Three measurements were performed for each set of samples.

2.9. Statistical Analysis. The experiments were carried out in triplicate. Data were statistically analyzed using the SAS software (SAS Institute, Cary, NC, USA). The mean values in the various groups were compared using Duncan's multiple range test. The differences were considered to be statistically significant at $p < 0.05$.

3. Results and Discussion

3.1. Texture Profile Analysis. We observed higher hardness, gumminess, and chewiness ($p < 0.05$) of EPM supplemented with SDGs when compared with S-0 (Table 2), which were similar to the results obtained by Chou [12]. The hardness (2126.67 to 3515.50 gf) of EPM (S-20, S-40, S-60, S-80, and S-100) was significantly higher than S-0 (1917.33 gf) ($p < 0.05$). Furthermore, a higher SDG addition ratio corresponds to a higher hardness of EPM. However, the lowest hardness (2126.67 gf) was obtained in S-20 (20% SDGs), which did not significantly differ from that of the S-0 (1917.33 gf) ($p > 0.05$). Yeung and Huang [17] reported that the hardness of EPM prepared using protein materials (soy protein, casein, whey, and milk) ranged from 1379 to 2374 gf. Another study reported that the hardness of pork meatballs prepared with chitosan in combination with phosphate was 1290–2630 gf [4]; similar results were also found in our previous study. Ham et al. [18] found that the hardness of EPM would be affected by dietary fiber of materials.

The springiness of EPM (S-20, S-40, S-60, S-80, and S-100) was 0.32–0.35. As shown in Table 2, a higher SDGs corresponded to lower springiness of EPM. However, this finding was not significant ($p > 0.05$). Rungraung et al. [19] demonstrated that the springiness of pork meatballs ranged from 0.35 to 0.57. Wang et al. [6] showed that the springiness of emulsified pork sausages prepared with distillers' grains ranged from 0.44 to 0.47, and this range is similar to the values we obtained.

0% SDGs (S-0) 20% SDGs (S-20) 40% SDGs (S-40)

60% SDGs (S-60) 80% SDGs (S-80) 100% SDGs (S-100)

Figure 2: Appearance of EPM supplemented with SDGs.

Table 2: Effects of different SDGs ratios on emulsified pork meatball texture.

Experimental group	Hardness (gf)	Springiness	Cohesiveness	Gumminess (gf)	Chewiness (mJf)
0% SDGs (S-0)	1917.33^{e}	0.37^{a}	0.87^{a}	930.81^{c}	389.83^{c}
20% SDGs (S-20)	2126.67^{de}	0.35^{ab}	0.83^{a}	1093.79^{c}	395.43^{c}
40% SDGs (S-40)	2610.83^{cd}	0.34^{ab}	0.82^{a}	1321.79^{b}	401.02^{bc}
60% SDGs (S-60)	2881.00^{bc}	0.32^{b}	0.82^{a}	1532.19^{a}	436.75^{b}
80% SDGs (S-80)	3453.33^{ab}	0.32^{b}	0.79^{a}	1532.18^{a}	491.07^{a}
100% SDGs (S-100)	3515.50^{a}	0.32^{b}	0.80^{a}	1455.70^{a}	501.16^{a}

Different superscript letters in the same column indicate significant differences with $p < 0.05$.

The cohesiveness of EPM (S-20, S-40, S-60, S-80, and S-100) ranged from 0.79 to 0.83. Addition of SDGs to EPM did not significantly affect cohesiveness ($p > 0.05$). Peetitungwong et al. added rice bran flour and pea protein to pork meatballs and found that cohesiveness ranged from 0.48 to 0.61 [20]. Jantapirak et al. reported that the cohesiveness of pork meatballs prepared with chitosan in combination with phosphate ranged from 0.56 to 0.77 [4]. Yeung and Huang added protein materials (soy protein, casein, whey, and milk) to EPM and observed cohesiveness values of 0.71–0.77 [17]. Mad-Ali and Benjakul reported that the cohesiveness of goat meatballs ranged from 0.79 to 0.83 [21], and this range is similar to the values we obtained.

The gumminess (1093.79 to 1532.19 gf) of EPM (S-20, S-40, S-60, S-80, and S-100) was higher than S-0 (930.81 gf) ($p < 0.05$). Mad-Ali and S. Benjakul reported that the gumminess of goat meatballs was between 53.79 and 113.70 N [21]. Jantapirak et al. reported that the gumminess of pork meatballs prepared with chitosan in combination with phosphate was between 732 and 2003 gf [4]. Yeung and Huang reported that the gumminess of EPM prepared with protein materials (soy protein, casein, whey, milk) was 1052–1806 gf [17], and this range is similar to the values we obtained.

The chewiness (395.43 to 501.16 mJf) of EPM (S-20, S-40, S-60, S-80, and S-100) was higher than S-0 (389.83 mJf) ($p < 0.05$). Higher SDGs corresponded to higher chewiness of EPM. Lee et al. reported that the chewiness of emulsified meat products increase with increasing wheat flour content [22]. This trend is similar to the values we obtained.

Our results indicate that EPM containing SDGs (S-20, S-40, S-60, S-80, and S-100) generally had higher hardness, gumminess, and chewiness compared to S-0. According to Choe et al. [23], emulsified meat products with higher hardness, gumminess, and chewiness showed higher emulsification stability. These results indicate that addition of SDGs enhanced the emulsification stability of EPM.

3.2. pH Analysis. We obtained the pH of 4.98 to 5.87 for EPM (S-20, S-40, S-60, S-80, and S-100) produced in this study (Table 3); it was significantly lower than S-0 (5.99) ($p < 0.05$). Higher SDGs corresponded to a lower pH value for the EPM. Essa and Mostafa [24] reported that the pH of cooked meatballs containing sugar beet pulp ranged from 5.93 to 6.05 [24]. Another study showed that when using corn flour to prepare sausages, the pH ranged from 5.33 to 6.09 [3]. Jantapirak et al. reported that the pH of pork meatballs prepared with chitosan in combination with phosphate ranged from 5.7 to 5.9 [4]. The results of our study are similar to those reported by Essa and Mostafa [24], Al-Mamun et al. [3], and Jantapirak et al. [4]. The pH of meat products

Table 3: Effects of different SDGs ratios on emulsified pork meatballs pH and cooking loss.

Experimental group	pH	Cooking loss (%)
0% SDGs (S-0)	5.99^{a}	5.58^{e}
20% SDGs (S-20)	5.87^{b}	7.42^{de}
40% SDGs (S-40)	5.78^{c}	9.41^{d}
60% SDGs (S-60)	5.69^{d}	18.35^{c}
80% SDGs (S-80)	5.50^{e}	29.68^{b}
100% SDGs (S-100)	4.98^{f}	35.16^{a}

Different superscript letters in the same column indicate significant differences with $p < 0.05$.

Table 4: Effects of different SDGs ratios on water loss, fat loss, and WHC of emulsified pork meatballs.

Experimental group	Water loss (%)	Fat loss (%)	WHC (%)
0% SDGs (S-0)	3.67^{d}	1.31^{e}	94.87^{a}
20% SDGs (S-20)	4.27^{d}	1.31^{e}	93.54^{a}
40% SDGs (S-40)	4.34^{d}	2.64^{d}	93.14^{a}
60% SDGs (S-60)	8.30^{c}	4.69^{c}	91.69^{b}
80% SDGs (S-80)	13.07^{b}	7.35^{b}	89.77^{c}
100% SDGs (S-100)	15.30^{a}	9.73^{a}	86.19^{d}

Different superscript letters in the same column indicate significant differences with $p < 0.05$.

depends on the ratio of each component in meat products [25]. The pH values decreased when SDGs were increased in the formulation. Similar results were reported by Rungraung et al., who found that the pH decreased when glycogen in the muscles was transformed from an anaerobic state to lactic acid after slaughter [19].

3.3. Cooking Loss Analysis. Different addition ratios of SDGs to EPM (Table 4) led to cooking losses of 7.42–35.16%. Addition ratios of SDGs of 40–100% significantly increased the cooking loss of EPM ($p < 0.05$). The lowest cooking loss (7.42%) was obtained in the sample containing 20% SDGs, which was not significantly different from that of the S-0 (5.58%) ($p > 0.05$). This is likely because SDGs contain 17.7% crude fiber (data not shown), which reduced interactions between protein molecules [22, 26] with increasing addition ratios of SDGs and ultimately increased cooking loss. Parvin et al. reported that cooking loss for emulsified beef meatballs prepared with nutmeg extract ranged from 14.52 to 16.07% [1]. Al-Mamun et al. found that the cooking loss of emulsified chicken meatballs prepared with corn flour ranged from 25.54% to 27.54% [3], which is similar to our results.

3.4. Emulsification Stability: Water Loss. Adding different SDG ratios to EPM (Table 4) resulted in water loss ranging from 4.27% to 15.30%. The water loss increased significantly ($p < 0.05$) as the SDG addition ratio was between 40% (S-40) and 100% (S-100). The lowest water losses of 4.27% and 4.34% were obtained with 20% (S-20) and 40% SDGs (S-40), respectively, and did not significantly differ from the S-0 (3.67%) ($p > 0.05$). Essa and Mostafa [24] reported that the cooking properties and water loss of the final product were affected by the functional characteristics of nonmeat ingredients [24]. The water loss ranged from 1.83% to 3.00% of emulsified pork sausages prepared with distillers' grains were observed by Chou [12]. Lee et al. reported that the water loss from emulsified pork sausages containing wheat flour ranged from 2.50% to 7.19% [22], which is similar to our results.

3.5. Emulsification Stability: Fat Loss. We obtained the fat loss of 1.31% to 9.73% for EPM (S-20, S-40, S-60, S-80, and S-100) produced in this study (Table 4). When the SDG addition ratio was between 20% and 100%, fat loss from the EPM increased significantly ($p < 0.05$). The lowest fat loss (1.31%) was obtained with addition of 20% SDGs (S-20), which did not significantly differ from the S-0 (1.31%) ($p > 0.05$). Ikhlas et al. demonstrated that fat retention from quail meatballs using different types of flour ranged from 82.58% to 85.91% [27] which is similar to our results. Suksomboon and Rawdkuen reported that muscle protein gelation contributes to desirable texture and fat-water emulsion stabilization in processed meat [26]. These findings indicate that addition of SDGs enhances the emulsification stability of emulsified meat products such as EPM.

3.6. WHC Analysis. The WHC of EPM containing different ratios of SDGs was 86.19–93.54% (Table 4). The significantly decreased were found at S-40, S-60, S-80, and S-100 (40% to 100% SDGs), and the lowest WHC (93.54% and 93.14%) was obtained at S-20 and S-40 (20% and 40% SDGs), respectively, which did not significantly differ compared to the S-0 (94.87%) ($p > 0.05$). In addition, a higher SDG addition ratio corresponded to a lower WHC for the EPM. Chou demonstrated that the WHC of emulsified pork sausages prepared with distillers' grains ranged from 95.88% to 97.16% [12], which is similar to our results. Suryaningrum et al. reported the significantly differed WHC of protein gels at a pH of approximately 6 [28], which also agrees with our results. A higher WHC value of muscle indicates a stronger ability to bind water. The WHC of the EPM is related to the interactions between myofibrillar proteins and water. During the manufacture of EPM, proteins are denatured and gradually form a network that can absorb water. However, a higher SDG addition ratio corresponded to a lower WHC. Moreover, Lee et al. found that the dietary fiber of materials can affect the WHC [22]. In our study, the WHC of EPM was the highest (93.54% and 93.14%) when the SDG addition ratios were 20% and 40% (S-20 and S-40), respectively. Jin et al. found that the WHC of meat product is particularly influenced by interactions of nonmeat components [29, 30]. Furthermore, SDGs contain crude fiber (17.7%), which is enhances the WHC of EPM.

3.7. Color Analysis. EPM in the S-0 exhibited the lowest *L*, *a*, and *b* values (54.29, 4.23, and 12.62, respectively) (Table 5). The SDG ratio (S-20, S-40, S-60, S-80, and S-100) significantly influenced the EPM color. The *L* values were 54.87–59.20 for the EPM (Table 5). Mir et al. reported an *L* value range of 42.34–54.90 for mutton meatballs during refrigeration [16].

Table 5: Analysis results of examining the effects of different addition ratios of SDGs on the color analysis of emulsified pork meatballs.

Experimental group	L	a	b
0% SDGs (S-0)	54.29^f	4.23^f	12.62^f
20% SDGs (S-20)	54.87^e	4.26^e	13.81^e
40% SDGs (S-40)	55.79^d	4.65^d	13.83^d
60% SDGs (S-60)	56.97^c	4.92^c	14.52^c
80% SDGs (S-80)	57.56^b	5.29^b	16.85^b
100% SDGs (S-100)	59.20^a	5.67^a	18.51^a

Different superscript letters in the same column indicate significant differences with $p < 0.05$.

Similarly, Parvin et al. reported a L value range of 49.86–51.34 of emulsified beef meatballs prepared with nutmeg extract [1]. This is similar to the range that we report herein. The L values of the EPM (S-20, S-40, S-60, S-80, and S-100) were significantly higher than S-0 (54.29) ($p > 0.05$) (Table 5). The addition ratio of SDGs was positively correlated with the L value. This was likely because heating denatured the proteins in the meat, particularly natural pigments retained in the muscle, resulting in higher L value [21].

The a values were 4.26–5.67 (S-20, S-40, S-60, S-80, and S-100), and all values were significantly higher than S-0 (4.23) (Table 5). Parvin et al. reported an a value range of 8.77–9.74 for emulsified beef meatballs prepared with nutmeg extract [1]. Peetitungwong et al. reported an a value range of 6.67–7.94 of pork meatballs prepared with rice bran flour and pea protein [20]. Mir et al. reported an a value range of 4.09–6.50 for mutton meat balls during refrigeration [16]. Our results are similar to these previous studies. We further found the addition ratio of SDGs was positively correlated with the a value, with higher SDGs corresponding to higher a values. This may be because of the Maillard reaction.

The b value were 13.81–18.51 for the EPM (S-20, S-40, S-60, S-80, and S-100) and were significantly higher than S-0 (12.62) (Table 5). The addition ratio of SDGs was positively correlated with the b value, with a higher SDGs corresponding to a higher b value (Table 5). Parvin et al. reported a b value range of 12.87–13.01 for emulsified beef meatballs prepared with nutmeg extract [1]. Peetitungwong et al. reported a b value range of 16.75–21.06 for pork meatballs prepared with rice bran flour and pea protein [20]. Mad-Ali and Benjakul observed a b-value range of 17.75–17.98 for quail meatballs using different types of flour [21], which is similar to the range that we report herein.

4. Conclusions

We examined the effects of adding SDGs on the quality of EPM. Compared to the control group (S-0), higher SDGs exhibited higher levels of hardness, gumminess, and chewiness ($p < 0.05$), with these values increasing with larger addition ratios of SDGs; EPM with a 100% SDG addition ratio (S-100) showed the highest values. Higher SDGs corresponded to lower springiness and cohesiveness. However, springiness and cohesiveness did not differ significantly between the experimental and control groups ($p > 0.05$). The pH and WHC of EPM decreased significantly with increasing SDG addition ratios. However, cooking loss, water loss, fat loss, and color (L, a, and b values) of EPM increased significantly as the SDGs addition ratio increased.

These results demonstrate that addition of SDGs can improve the quality of EPM. SDGs can be used to replace starch in the manufacture of meat-derived products and enhance the favorable qualities. Moreover, our results highlight the diverse possibilities of using SDGs in the food industry and promote the added value of SDGs. Additionally, our results provide an effective solution for the wastage and environmental problems caused by leftover distiller grains generated during alcohol brewing.

Data Availability

The data that supports the finding of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

Conflicts of Interest

The authors report that there are no competing interests to declare.

Authors' Contributions

Conceptualization was done by C.F.C.. Data curation was done by Y.C.H.. Formal analysis was the responsibility of Y.C.H.. Project administration was in charge of C.F.C.. Supervision was focused on by C.F.C.. Validation was done by C.F.C.. Writing the original draft was done by C.F.C.. Writing the review and editing was done by C.F.C.

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