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Effect of Red Palm Olein and Glutinous Rice Flour Mixture as Fat Replacers on the Physicochemical, Rheological, and Microstructural Properties of Buffalo Meat Emulsion

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ABSTRACT

The present study evaluated the physicochemical, rheological, and microstructural properties of buffalo meat emulsion incorporated with red palm olein (RPO) and glutinous rice flour (GRF) as fat replacers. A total of six different samples were prepared by using combinations of RPO and GRF replacing animal fat viz., control (with animal fat), R1 (100% fat replaced by RPO), R2 (50% fat replaced by RPO), RG (50% fat replaced by 25% RPO and 25% GRF), G1 (100% fat replaced by GRF), and G2 (50% fat replaced by GRF). The samples were analysed for physicochemical parameters, gel strength, rheological and microstructural properties. G1 and G2 samples were recorded with improved emulsion stability, cooking loss, hardness, and chewiness while lowering the fat content. Micrographs of G1 and G2 samples demonstrated a spongy/honeycomb-like structure with roughly spherical crystalline granules. The rheological properties of G1 indicated a more stable emulsion with a higher storage modulus (G'). Using RPO as a fat replacer seemed to produce a lower-quality emulsion. Therefore, replacing the fat with GRF, especially at 100%, is proposed for buffalo meat emulsion.

Keywords: Buffalo meat, fat replacer, glutinous rice flour, meat emulsion, red palm olein

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INTRODUCTION

Fat plays a crucial and fundamental role in sensory and technological attributes such as water-holding capacity (WHC), emulsion stability, shear force, gel strength, and juiciness of the reformulated products. Processed meat products have long been known to contain a high proportion of saturated fat. However, animal fat intake containing high levels of saturated fatty acids and cholesterol has been associated with adverse effects on consumers' health, such as obesity, cardiovascular disease, and coronary heart disease (Asyrul-Izhar et al., 2023). Consumers are becoming more concerned about the amount and composition of daily fat and prefer healthier meat products rich in mono- and polyunsaturated fatty acids. As an alternative, reducing the fat content of meat emulsion and replacing animal fat with plant oils and carbohydrates as fat replacers proved to be an ideal strategy for producing healthier meat products.

Palm olein is a liquid fraction of palm oil containing 39%–45% higher oleic acid and 10%–13% higher linoleic acid than palm oil (Lin, 2002). Read palm olein (RPO) has a balanced ratio of saturated and unsaturated fatty acids and is rich in vitamin E (tocopherol [30%] and tocotrienol [70%]) and β-carotene (Dauqan et al., 2011). Thus, its incorporation in meat during processing could improve the functional value of the developed meat products as well as stabilize the meat emulsion system. Further, carbohydrate-based fat replacers are increasingly applied in producing low-fat meat products. When added to water, these carbohydrate-based fat replacers form hydrogels having quality attributes similar to animal fat used in high-fat meat products in terms of gel-like matrix stability, lubricity, texture, and moisture or water release (Asyrul-Izhar et al., 2023). Glutinuous rice flour (GRF) (*Oryza sativa* L.) has the potential to be used as carbohydrate gels in meat products. The kernels of the glutinous rice will become stickier, softer, and easier to adhere together during cooking/heat treatment (Keeratipibul et al., 2008). GRF has low amylose content but is high in amylopectin content; later, it could be explored to improve the texture of food products. GRF has good binding properties, thereby imparting higher water-retaining properties of foods with GRF. It could improve the stability and technological attributes of the emulsified meat product (Pereira et al., 2016).

Properly selecting fat replacers or a combination of fat replacers is crucial for developing low-fat meat products owing to the wide variation in meat types and formulations (Syan et al., 2022). The excellent water-binding properties of GRF could favour the stability of the emulsified meat product. In contrast, the desirable fatty acid profile in RPO could be used to develop healthier meat products. Thus, a combination of RPO and GRF could be used as fat replacers in a meat emulsion matrix to enhance the functionality of the fat replacer and improve the physicochemical/technological properties of meat emulsion properties, leading to the development of reformulated emulsified meat products.

Therefore, the present study was envisaged to evaluate various physicochemical, microstructural, and rheological properties of buffalo meat emulsion added with RPO and GRF as animal fat replacers. The outcome of this research is expected to be beneficial in producing reformulated, healthier, low-fat, emulsified buffalo meat-based products.

MATERIALS AND METHODS

Raw Meat

Frozen boneless lean buffalo meat and fat were purchased from the Seri Kembangan wet market in Selangor, Malaysia. The meat and fat were packed in polyethene bags and stored in a freezer at -18°C prior to further processing. Frozen meat was used instead of fresh meat to imitate the current market practice adopted by the manufacturers of buffalo meat-based products.

Preparation of Meat Emulsion

Frozen boneless buffalo lean meat and fat were thawed under refrigeration and minced using a 5-mm plate meat mincer (H.L TJ12-A, Henglian, China). All ingredients (viz., 70% minced meat, 1.0% sugar (Central Sugars Refinery Sdn. Bhd., Malaysia), 1.0% garlic powder (Hexa Food Sdn. Bhd., Malaysia), 4.0% corn flour (THC® Sdn. Bhd., Malaysia), 0%–15% animal fat, 0%–15% red palm olein (CAROTINO, Malaysia), and 0%–15% glutinous rice flour (Erawan, Thailand) and mixed by using a food processor (YM-102, Gourmet Cuisine, China) except salt (1.2%) (Adabi Consumer Industries Sdn. Bhd., Malaysia), ice water (5%, temperature of 5°C), and sodium tripolyphosphate (STPP, 0.3%) (DChemie, Malaysia) and homogenized for 1 min at 220 ×*g*. Then, salt and STPP were added and homogenized for 30 s followed by ice water, and the mixture was homogenized for 30 s at 220 ×*g*. A total of six different formulations were prepared (Table 1) by using combinations of RPO and GRF viz., C (without fat replacers), R1 (100% animal

Table 1
The buffalo meat emulsion formulations with red palm olein (RPO) and glutinous rice flour (GRF) as fat replacers

Ingredients	Formulations (%)					
	C (Control)	R1 (100% RPO)	R2 (50% RPO)	RG (25% RPO and GRF)	G1 (100% GRF)	G2 (50% GRF)
Meat	70	70	70	70	70	70
Fat	15	0	7.5	7.5	0	7.5
RPO	0	15	7.5	3.75	0	0
GRF	0	0	0	3.75	15	7.5
Ice water (5°C)	7.5	7.5	7.5	7.5	7.5	7.5
Salt	1.2	1.2	1.2	1.2	1.2	1.2
Sodium tripolyphosphate	0.3	0.3	0.3	0.3	0.3	0.3
Sugar	1	1	1	1	1	1
Garlic powder	1	1	1	1	1	1
Corn starch	4	4	4	4	4	4
Total	100	100	100	100	100	100

fat replaced by RPO), R2 (50% animal fat replaced by RPO), RG (50% animal fat replaced by 25% RPO and 25% GRF), G1 (100% animal fat replaced by GRF), and G2 (50% animal fat replaced by GRF). The emulsion samples were transferred to the centrifuge tube and centrifuged (KUBOTA 3740, Japan) for 1 min at a speed of 610 ×*g* to eliminate the air bubbles. The samples were then stored at 4°C until subsequent analysis.

Physiochemical and Proximate Parameters

The pH values of the meat emulsion with different concentrations of GRF and RPO are determined according to the method described by M. A. Ismail et al. (2021). A 5 g homogenised buffalo meat emulsion sample was mixed with 45 ml of distilled water using a blender (MX-898M Panasonic, Malaysia), and pH value was recorded by using a pre-calibrated (at pH 4.0, 7.0, and 9.0) pH meter (3505 pH Meter Jenway, United Kingdom).

The percentage of cooking loss was calculated based on recording the emulsion weight before and after cooking. The following formula was used for cooking loss measurement:

$$\text{Cooking loss (\%)} = [(\text{Raw sample weight} - \text{Cooked sample weight}) / (\text{Raw sample weight})] \times 100\% \qquad [1]$$

Water holding capacity was determined using a centrifuge as described by Köhn et al. (2015). The empty centrifuge tube was weighed, and 5 g of raw sample with 32 ml distilled water was added and mixed manually for 10 min before being centrifuged (KUBOTA 3740, Japan) at 2,900 × *g* for 25 min. Then, the supernatant in the centrifuge tubes was weighed and discarded. The pellet was dried in the hot air oven for 20 min at a temperature of 50°C. Then, the dried pellet was weighed, and WHC (%) was calculated according to the following equation:

$$\text{WHC (\%)} = \frac{(b-a)-(c-a)}{(b-a)} \times 100\% \qquad [2]$$

where a represents the weight of the empty centrifuge, b is the weight of the centrifuge with supernatant, and c is the weight of the dried centrifuge (all weighed in g).

Emulsion stability was evaluated based on the procedure described by N. A. Ismail et al. (2021) with slight modifications to obtain the total fluid released and total fat released. The percentages of total fluid release and the total fat released were calculated as shown in the formulation below:

$$\text{Total fluid release} = \text{Initial weight of the sample} - \text{The weight of the pellet} \qquad [3]$$

$$\text{Total fluid release (\%)} = (\text{Total fluid release}/\text{Initial weight of sample}) \times 100\% \qquad [4]$$

$$\text{Total fat release (\%)} = (\text{Weight of dried supernatant} - \text{Total fluid release}) \times 100\% \qquad [5]$$

The proximate analysis was performed according to the Association of Official

Analytical Chemists (AOAC) standard methods (Association of Official Analytical Chemists [AOAC], 2019). Moisture content was determined using a hot air oven (BINDER, Germany) and total protein (Crude protein, N × 6.25) was determined using the micro-Kjeldahl method.

Colour Determination

The colour of the raw and cooked buffalo meat emulsion samples was determined using a calorimeter (Chroma Meter CR-410, Japan) calibrated with the white tile supplied with the instrument. The samples were recorded for L^* (+lightness/-darkness), a^* (+redness/-greenness), and b^* (+yellowness/-blueness) colour coordinates (Ramle et al., 2021).

Texture Profile Analysis (TPA)

TPA was conducted on the cooked meat emulsion samples using a texture analyzer (TA-XT2i, Stable Micro System, United Kingdom). The hardness, cohesiveness, springiness, chewiness, gumminess, and resilience were determined. The cooked meat emulsion samples were cut into 10 mm length × 20 mm diameter for the analysis. A 75 mm compression platen (P75) was used with the test-speed setting of pre-test: 1.0 mm/s; test: 1.5 mm/s; post-test: 1.5 mm/s, where the sample was compressed twice with a 30-kg load from 75% of the original height (Ming-Min & Ismail-Fitry, 2023).

Gel Strength

The gel strength of the samples was evaluated using a method by Asyrul-Izhar et al. (2021) with slight modifications. The buffalo cooked meat emulsion samples were cut at 15 mm length × 20 mm diameter, and a test speed of 1.5 mm/s by using a Warner-Bratzler (WB) shear blade and connecting with a texture analyser (Stable Micro System, TA-XT2i, United Kingdom) was used to determine the maximum shear force (N).

Rheological Analysis

The dynamic rheological properties of the meat emulsions were continuously monitored and replicated according to Verma et al. (2019) with slide modifications using a rheometer (Rheostress RS600, USA) fitted with a 25 mm diameter stainless steel plate with a 1 mm size gap from the rotating cone. The samples were gently placed onto the plate using a plastic spoon and allowed to set the temperature at 25°C for 5 min. The frequency sweep test was run with a 0.1–10 Hz range at 1 Pa. The changes in storage modulus (G') and loss modulus (G'') were recorded during the processing.

Scanning Electron Microscope (SEM)

The microstructures of six cooked meat emulsions with different RPO and GRF formulations were analysed using SEM. The preparation of samples was conducted for 24 hr by fixing in 2.5% glutaraldehyde (Chemiz, Malaysia) at 4°C and then in 2% aqueous osmium tetroxide (Systerm Chemicals, Malaysia) for 4 hr. After that, samples were dehydrated in increasing concentrations of ethanol (Chemiz, Malaysia) and dried in tert-butyl alcohol. The sample was applied with a gold coat using a sputter coater and viewed at 1,000× magnification under the SEM (Model: JOEL-JSM 5600, Japan).

Statistical Analysis

All the data were analysed statistically using MINITAB Statistical Software version 19 (MiniTab Inc., USA). The whole experiment was repeated in triplicate. One-way analysis of variance (ANOVA) with Tukey's tests was performed at the 95% confidence level ($p<0.05$) to assess significant differences between the data collected. The results obtained in the study were expressed as the mean values ± standard deviation.

RESULTS AND DISCUSSION

pH

The pH value of the raw control emulsion was to be comparable ($p>0.05$) to all other treatments. The pH value was recorded highest for R1, which was significantly ($p<0.05$) higher than G2 samples, later showing the lowest pH value (Table 2). It could be due to the higher pH value of vegetable oils (6.9 to 6.7). The processing of RPO caused a further reduction of pH to 6.07 due to the hydrolysis of oil triglyceride, leading to the production of free fatty acids (FFAs) and glycerol (Baig et al., 2022). The pH values for the cooked samples were not significantly different ($p>0.05$) between the treatments and the control, and all samples showed an increased pH compared to the raw samples. The increase in pH value upon cooking might be due to protein denaturation and the production of imidazolium compounds upon cooking (Verma et al., 2022). Similar results were reported by Khalid et al. (2021), where the

Table 2

The physicochemical attributes of buffalo meat emulsions with red palm olein (RPO) and glutinous rice flour (GRF) as fat replacers

Sample	pH		Emulsion stability (%)		Cooking loss (%)	WHC (%)	Gel strength (N)
	Raw	Cooked	Total fluid release	Total fat release			
C	5.74 ± 0.15^{AB}	6.14 ± 0.14^{A}	9.79 ± 1.64^{BC}	5.440 ± 0.612^{BC}	0.21 ± 0.03^{AB}	84.59 ± 0.43^{A}	2.06 ± 0.55^{A}
R1	6.07 ± 0.05^{A}	6.11 ± 0.29^{A}	18.79 ± 8.05^{AB}	19.51 ± 11.17^{A}	0.76 ± 0.42^{AB}	84.44 ± 0.56^{A}	1.78 ± 0.33^{A}
R2	5.90 ± 0.09^{AB}	6.02 ± 0.06^{A}	23.12 ± 2.73^{A}	15.48 ± 2.93^{AB}	1.27 ± 0.92^{A}	84.97 ± 0.31^{A}	1.45 ± 0.25^{A}
RG	5.97 ± 0.15^{AB}	6.19 ± 0.08^{A}	5.24 ± 0.58^{C}	3.690 ±0.669^{BC}	0.47 ± 0.05^{AB}	84.10 ± 0.72^{A}	1.93 ± 0.28^{A}
G1	5.90 ± 0.13^{AB}	6.11 ± 0.21^{A}	2.59 ± 0.65^{C}	0.800 ± 0.674^{C}	0.076 ± 0.008^{B}	83.49 ± 0.49^{A}	3.79 ± 0.40^{A}
G2	5.68 ± 0.17^{B}	5.89 ± 0.14^{A}	3.99 ± 0.44^{C}	2.347 ± 0.617^{C}	0.76 ± 0.22^{AB}	84.98 ± 0.71^{A}	3.01 ± 0.25^{A}

Note. All values are mean ± standard deviation of three replicates. Means that do not share the same letter but are significantly different ($p<0.05$) in the same column. WHC = Water holding capacity; C = Without fat replacer; R1 = 100% animal fat replaced by RPO; R2 = 50% animal fat replaced by RPO; RG = 50% animal fat replaced by 25% RPO and 25% GRF; G1 = 100% animal fat replaced by GRF; G2 = 50% animal fat replaced by GRF pH values from uncooked to cooked beef patties samples have a significant increase in mixtures of wheat bran fibre and wheat germ oil as fat replacers.

Emulsion Stability

The incorporation of RPO and GRF as fat replacers had a significant impact on total fluid release and total fat release (Table 2). Lower (p<0.05) total fluid release and total fat release values were recorded in G1 and G2 emulsions compared to control and R1 and R2 samples. The RG samples had marginal (p>0.05) lower total fluid release and total fat release values as compared to control samples. It could be due to the formation of a fully gelled matrix of the protein-starch gel (Verma et al., 2015) in the GRF-incorporated buffalo meat emulsion, thereby enhancing water-binding and forming a stable emulsion. Upon heating, further expansion of starch granules increases pressure on the protein matrix, leading to higher emulsion stability. A similar significantly lower total fluid release and total fat release were also reported by Pereira et al. (2019) in low-fat sausage with increasing rice flour levels.

Cooking Loss

The G1 samples (100 % animal fat replaced by GRF) were recorded with the lowest cooking loss as compared to other treatments and significantly (p<0.05) lower than R2 (Table 2). The cooking loss of all remaining samples (C, R1, G2, and RG) was recorded as comparable (p>0.05). Its lower cooking loss in G1 samples could be due to the high content of starch (83-91%) in GRF, leading to more binding with water and swelling/expansion as well as gelatinisation of starch granules in the embedded protein gel matrix during heating process (Wu et al., 2020). Yi et al. (2012) also noticed the lowest cooking loss in samples with GRF compared to other formulations with corn flour, rice flour, and soy protein isolates.

Water Holding Capacity

WHC is described as the capability of meat to bind internal and external water during the application of any method of operation (Cheng & Sun, 2008). No significant difference (p>0.05) was observed in the WHC of the emulsion prepared using different levels of RPO and GRF mixtures and the control samples (Table 2). Similar findings of a marginal change in WHC were reported in sausage added with a variety of vegetable oil ratios of canola, sunflower, and olive oils by Shin et al. (2020). The fats and oil help improve the water-holding capacity of meat products by acting as binders, holding water molecules in the product, and preventing them from being lost during processing. Similarly, the GRF starch may absorb the excess moisture and maintain the water-holding capacity. Besides, as all buffalo meat emulsion formulations in the present study use the same quantity of salt and STPP, the WHC of the meat emulsion was stabilised.

Gel Strength

Similar to water-holding capacity results, no statistically significant difference (p>0.05) was observed in the gel strength of the buffalo meat emulsion prepared using different concentrations of RPO and GRF mixtures and the gel strength of the control samples (Table 2). It might be due to the myofibrillar network forming to its maximum extent when cooked treatment is applied, affecting the meat emulsion's gel strength. According to Tang et al. (2019), myofibrillar protein had an impact on the meat product's gel strength. Since all formulations in this study had the same amount of meat protein, no discernible changes in the gel strength of the meat emulsion properties were observed as a result.

Proximate Analysis

The incorporation of RPO and GRF as fat replacers did not affect (p>0.05) proximate parameters viz., moisture, ash content, crude protein, and crude fibre content except fat and carbohydrate (Table 3). It could be attributed to the incorporation of the RPO and GRF having similar content as well as the presence of a similar amount of meat in all samples prepared. A non-significant difference in the protein content was also observed between the control and different formulations, which could be attributed to the similar meat protein level of the formulation in terms of buffalo meat. For fat content, a significantly higher (p<0.05) amount of fat was observed in R1 and R2 samples, which might be attributed to the incorporation of red palm olein having higher fat content. The carbohydrate content in G1 samples was significantly higher compared to other formulations due to 100% replacing animal fat with GRF rich in carbohydrates (83%–91%). Nevertheless, the fat content in G1 reduced significantly (p<0.05) compared to others. In terms of good fat, R1 and R2 might be suitable as fat replacers. However, G1 can be used to produce meat products with a low-fat label because the fat content is below 3%.

Colour Profile

The raw meat emulsion showed significantly (p<0.05) higher lightness (L*) values in the

Table 3
Proximate analysis of buffalo meat emulsions with red palm olein (RPO) and glutinous rice flour (GRF) as fat replacers

Sample	Moisture (%)	Ash (%)	Protein (%)	Fat (%)	Fibre (%)	Carbohydrate (%)
C	61.47 ± 4.37^{A}	2.32 ± 0.12^{A}	14.19 ± 1.12^{A}	5.98 ± 1.07^{BC}	0.45 ± 0.28^{A}	15.59 ± 4.95^{AB}
R1	56.15 ± 1.07^{A}	2.32 ± 0.42^{A}	13.99 ± 0.91^{A}	12.67 ± 1.08^{A}	0.66 ± 0.16^{A}	14.21 ± 1.39^{B}
R2	54.81 ± 4.94^{A}	2.84 ±0.91^{A}	14.66 ± 0.77^{A}	11.27 ± 1.90^{A}	0.58 ± 0.32^{A}	15.84 ± 4.88^{AB}
RG	57.37 ± 5.99^{A}	2.33 ± 0.16^{A}	13.08 ± 2.02^{A}	9.09 ± 1.69^{AB}	0.82 ± 0.09^{A}	17.31 ± 9.24^{AB}
G1	53.89 ± 0.63^{A}	3.48 ± 0.16^{A}	13.22 ± 1.81^{A}	1.72 ± 1.56^{C}	0.56 ± 0.43^{A}	18.79 ± 1.97^{A}
G2	61.46 ± 2.16^{A}	2.44 ± 0.36^{A}	14.38 ± 1.35^{A}	4.82 ± 1.88^{BC}	0.37 ± 0.21^{A}	16.53 ± 1.38^{AB}

Note. All values are mean ± standard deviation of three replicates. Means that do not share the same letter but are significantly different (p<0.05) in the same column. C = Without fat replacer; R1 = 100% animal fat replaced by RPO; R2 = 50% animal fat replaced by RPO; RG = 50% animal fat replaced by 25% RPO and 25% GRF; G1 = 100% animal fat replaced by GRF; G2 = 50% animal fat replaced by GRF

G1 sample as compared to R1 (Table 4). It could be due to the higher flour content in G1 contributing to the white colour. The redness (*a** value) for both raw and cooked samples was observed to be comparable ($p>0.05$) for all samples. However, yellowness (*b** values) was noted significantly ($p<0.05$) higher in the raw and cooked R1 samples as compared to other samples ($p<0.05$). The higher carotene in RPO might be attributed to the higher yellow colour in R1 samples (Ayu et al., 2016). A higher *b** value of ice cream incorporated with higher red palm olein content was also reported by A. H. Ismail et al. (2020). The higher lightness of control samples could be attributed to the presence of animal fat, which had a diluting effect on myoglobin (Serdaroğlu et al., 2016).

Texture Profile Analysis

The higher amounts of GRF in cooked meat emulsion were observed to increase ($p<0.05$) the hardness, chewiness, and gumminess (Table 5). It could be attributed to the higher starch in GRF samples, which led to changes in textural attributes. The high level of amylopectin in GRF caused starch granules to swell and be embedded in the gel matrix, thus leading to a stronger and denser structure (Khalil, 2000). A similar finding was reported by Pereira et al. (2016, 2019); the additional high amount of rice flour in the sample resulted in a significantly increased hardness value of beef sausages compared to the control and with other formulations.

There was no significant ($p>0.05$) difference in springiness, cohesiveness, and resilience properties among all samples. All buffalo meat emulsions were prepared using the same salt, water, and sodium tripolyphosphate, explaining their comparable cohesiveness, springiness, and resilience properties. Similar findings have shown comparable springiness and

Table 4
Colour profile of buffalo meat emulsions with red palm olein (RPO) and glutinous rice flour (GRF) as fat replacers

Sample	Colour profile					
	Raw emulsion			Cooked product		
	*L**	*a**	*b**	*L**	*a**	*b**
C	50.89 ± 0.69^{CD}	14.77 ± 4.67^{A}	17.86 ±1.00^{C}	50.91 ± 0.73^{A}	9.55 ± 0.20^{A}	17.20 ±0.97^{BC}
R1	48.48 ± 0.33^{D}	21.07 ± 2.44^{A}	32.89 ±0.85^{A}	48.05 ± 1.84^{B}	10.66 ±0.88^{A}	26.14 ± 2.96^{A}
R2	50.05 ± 1.58^{CD}	16.22 ± 4.57^{A}	29.46 ±0.49^{B}	48.65 ±0.89^{AB}	10.41 ±0.53^{A}	25.24 ± 0.89^{A}
RG	52.71 ± 1.25^{BC}	15.44 ± 3.63^{A}	28.05 ±1.02^{B}	47.04 ± 0.43^{B}	9.44 ± 0.28^{A}	20.69 ± 0.63^{B}
G1	56.97 ± 1.81^{A}	14.63 ± 1.63^{A}	19.98 ±0.95^{C}	47.40 ± 0.67^{B}	10.34 ±0.80^{A}	15.06 ± 1.00^{C}
G2	55.90 ± 0.72^{AB}	14.86 ± 1.01^{A}	19.33 ±0.07^{C}	48.47 ±0.61^{AB}	9.32 ± 0.59^{A}	15.24 ± 0.94^{C}

Note. All values are mean ± standard deviation of three replicates. Means that do not share the same letter but are significantly different ($p<0.05$) in the same column. C = Without fat replacer; R1 = 100% animal fat replaced by RPO; R2 = 50% animal fat replaced by RPO; RG = 50% animal fat replaced by 25% RPO and 25% GRF; G1 = 100% animal fat replaced by GRF; G2 = 50% animal fat replaced by GRF

Table 5

Texture profile of buffalo meat emulsions with red palm olein (RPO) and glutinous rice flour (GRF) as fat replacers

Sample	Texture Profile Analysis					
	Hardness (g)	Springiness (mm)	Cohesiveness	Gumminess (g)	Chewiness (g)	Resilience
C	14979 ± 2446^{B}	0.75 ± 0.02^{A}	0.43 ± 0.06^{A}	6517 ± 1518^{ABC}	4899 ± 1248^{B}	0.15 ± 0.04^{A}
R1	14736 ± 2498^{B}	0.85 ± 0.01^{A}	0.42 ± 0.05^{A}	6282 ± 1482^{BC}	5380 ± 1345^{B}	0.13 ± 0.02^{A}
R2	11394 ± 1834^{B}	0.79 ± 0.03^{A}	0.43 ± 0.03^{A}	4995 ± 1161^{C}	3969 ± 821^{B}	0.13 ± 0.01^{A}
RG	14878 ± 1809^{B}	0.76 ± 0.04^{A}	0.39 ± 0.02^{A}	5958 ± 952^{BC}	4577 ± 935^{B}	0.13 ± 0.01^{A}
G1	25737 ± 5282^{A}	0.78 ± 0.09^{A}	0.52 ± 0.08^{A}	13572 ± 4036^{AB}	10467 ± 2126^{A}	0.20 ± 0.04^{A}
G2	25413 ± 3057^{A}	0.79 ± 0.06^{A}	0.53 ± 0.13^{A}	13745 ± 4594^{A}	10777 ± 3095^{A}	0.20 ± 0.06^{A}

Note. All values are mean ± standard deviation of three replicates. Means that do not share the same letter but are significantly different ($p<0.05$) in the same column. C = Without fat replacer; R1 = 100% animal fat replaced by RPO; R2 = 50% animal fat replaced by RPO; RG = 50% animal fat replaced by 25% RPO and 25% GRF; G1 = 100% animal fat replaced by GRF; G2 = 50% animal fat replaced by GRF

cohesiveness values upon incorporating rice flour as a fat replacer in sausages (Pereira et al., 2019) and sunflower oil as a replacer to pork backfat in frankfurters (Panagiotopoulou et al., 2016). The gumminess value, a derivative of hardness and cohesiveness, of RPO-incorporated samples, was recorded significantly ($p<0.05$) lower values, with R2 recorded as the lowest value. It could be attributed to the liquid phase of RPO replacing solid animal fat, resulting in droplets acting as "fillers" in the voids of the protein gel matrix (Wu et al., 2009). It indicated that RPO-incorporated meat emulsion was softer and juicier on the palate, allowing it to deform more easily in the mouth. Lower gumminess values in pork grease formulation prepared by partially replacing palm olein and soybean isolate were also reported by Barragan et al. (2018). Therefore, 50 and 100% replacement of animal fat with GRF resulted in a higher value of textural properties of meat emulsion. However, 50% animal fat replacement by RPO could be a good choice in terms of consumers' health as well as the palatability to form a softer buffalo meat emulsion.

Rheological Properties

The rheology properties of the frequency sweep study with storage (G') and loss (G") modulus against the frequency (Hz) of buffalo meat emulsion are presented in Figure 1. All the formulations showed a similar trend: G' increased with higher frequency values and were higher than G". Kumar et al. (2017) reported that G' and G" refer to the ability of the emulsions and protein gel matrix's intermolecular interactions. The G′ represents a viscoelastic material's solid-like characteristics, whereas G″ indicates its liquid-like characteristics.

Thus, this study showed that incorporating RPO and GRF in the meat emulsion affected their network structure and caused a more elastic characteristic than

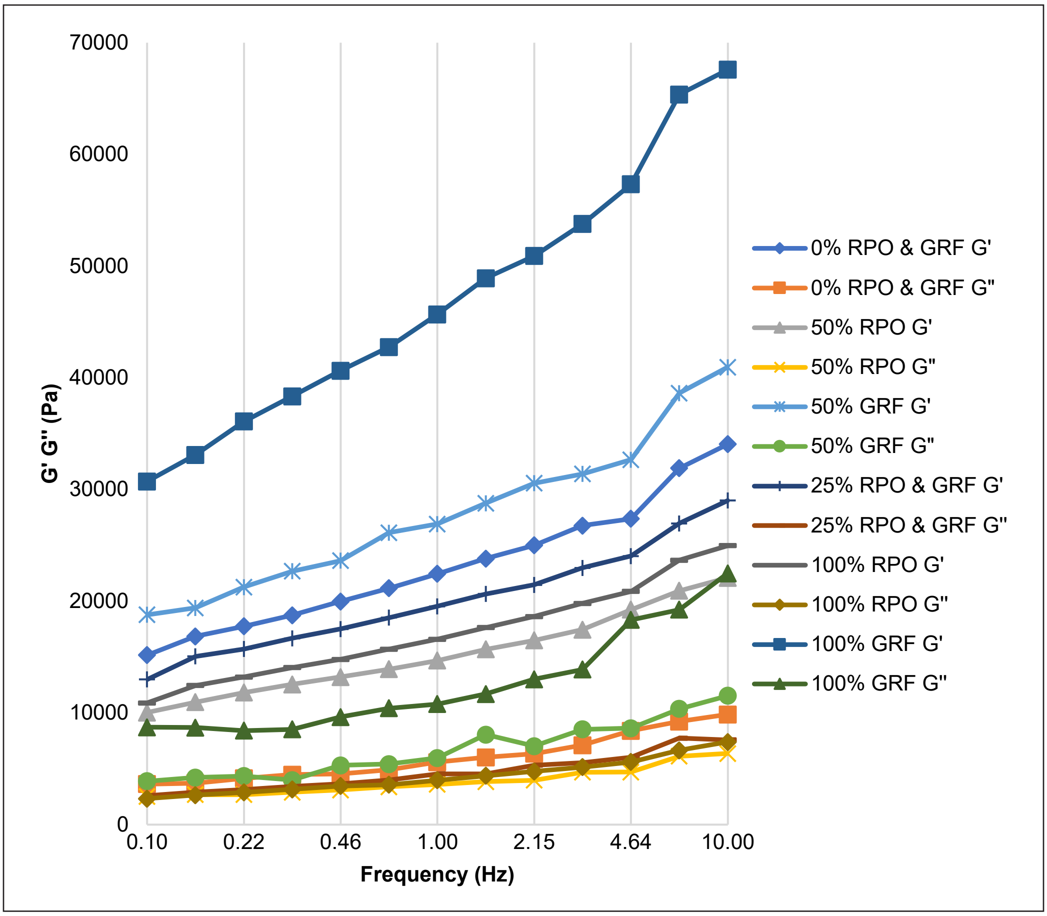

Figure 1. Storage modulus (G') and loss modulus (G") of the buffalo meat emulsion with different levels of red palm olein (RPO) and glutinous rice flour (GRF)

viscous. Apart from that, the value of G' for meat emulsion with 100% GRF (G1) was higher compared to the other formulations, which indicated that the intermolecular connections were stronger and the matrix was more stable. Similar research was stated by Verma et al. (2019), where formulations of 3% quinoa have high values of G′ for the meat emulsion due to the formation of solid-like characteristics. However, the RG sample had the most similarity to the control samples in terms of G' and G" on the rheological properties.

Emulsion Micrograph

The microstructure of buffalo meat emulsion formulated with animal fat is presented in (Figure 2C) and with fat replacers in (Figure 2: R1, R2, RG, G1, and G2). The micrographs demonstrated the microstructural properties of the cooked meat-emulsion systems with a gel-like compact structure of the meat batter. C (control) had the smoothest surface, was porous, and consisted of a coarse structure with numerous smallest cavities, representing very well-emulsified microstructural properties. The cavities influenced the capillary action, which is responsible for water being held inside while heating the meat emulsion (Liu et al., 2016). Apart from that, G2 and G1, which consist of 50 and 100% animal fat replaced by GRF, showed a spongy (honeycomb-like) structure with roughly spherical crystalline granules. It might be due to the presence of starch content in GRF. The higher starch presence in meat emulsion had a few

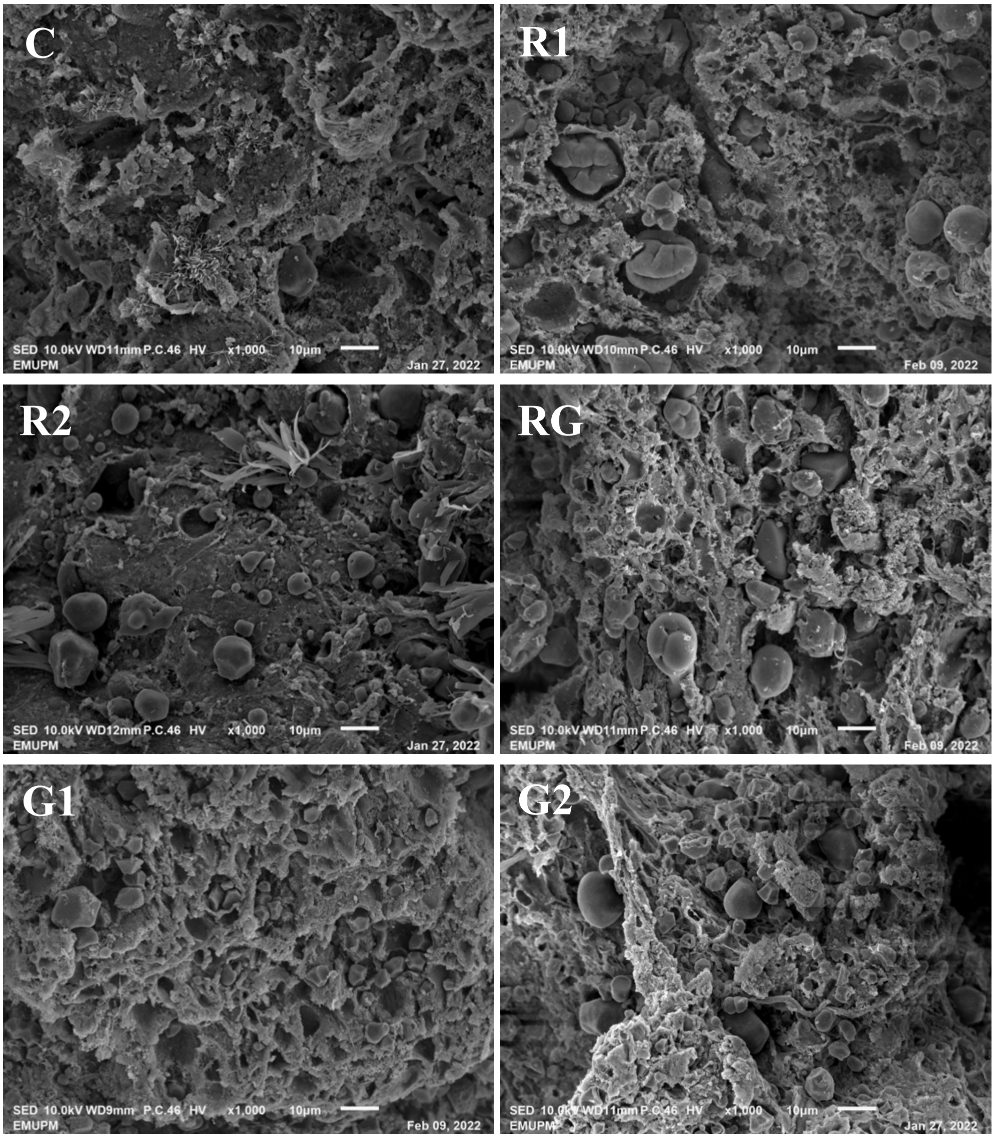

Figure 2. Scanning electron micrograph of buffalo meat emulsions (1,000× magnification). C = Without fat replacer; R1 = 100% animal fat replaced by *red palm olein (RPO)*; R2 = 50% animal fat replaced by RPO; RG = 50% animal fat replaced by 25% RPO and 25% glutinous rice flour (GRF); G1 = 100% animal fat replaced by GRF; G2 = 50% animal fat replaced by GRF

cavities that were smaller in size. As the amount of starch in the protein matrix is high, it becomes significantly more compact due to starch granule expansion and swelling during high-temperature processing.

CONCLUSION

Based on the study, it can be concluded that up to 100% animal fat replacement by GRF (G1) is the best formulation that can be replaced in buffalo meat emulsion, which significantly affected the emulsion stability, cooking loss, hardness, and chewiness of the texture emulsion, lowering the fat content, but produced the most stable meat emulsion, followed by 50% GRF (G2) as the second-best emulsion. However, less stable emulsions were found in the 50% RPO (R2) and 100% RPO (R1), but in terms of health preferences, these formulations could lower cholesterol and provide health benefits, as well as palatability with softer buffalo meat emulsion. The RG samples (mixture of 25% RPO and 25% GRF) had the most similarity to the control in terms of rheological properties. Meanwhile, WHC, gel strength, springiness, cohesiveness, moisture, ash, and fibre content were not significantly different between all the fat replacers and control formulations. Since G1 was the best formulation, it should be known as buffalo meat batter rather than meat emulsion due to the lack of fat. In addition, although meat batter without fat can still have good texture and flavour and can be used for certain applications such as meatballs or meatloaf, the sensory of other meat products with normally high amounts of fat, such as sausages, might be affected. Therefore, the sensory of buffalo meat products produced using the G1 formulation needs to be tested for future work.

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