International Journal of Food Science + Technology



Original article

# Hybrid meat products: the physicochemical and microstructural properties of beef meat emulsion produced with jackfruit (*Artocarpus heterophyllus*) flesh and bamboo (*Bambusa polymorpha*) shoot as meat substitutes

**Ng Bee Chi,**[1] **Abu Bakar Asyrul-Izhar,**[1] **Muhamad Shirwan Abdullah Sani**[2] **& Mohammad Rashedi Ismail-Fitry**[1,3]*

1 Department of Food Technology, Faculty of Food Science and Technology, Universiti Putra Malaysia, UPM Serdang 43400, Selangor, Malaysia
2 International Institute for Halal Research and Training (INHART), Level 3, KICT Building, International Islamic University Malaysia (IIUM), Jalan Gombak, Kuala Lumpur 53100, Selangor, Malaysia
3 Halal Products Research Institute, Universiti Putra Malaysia, UPM Serdang 43400, Selangor, Malaysia

*(Received 30 July 2024; Accepted in revised form 26 August 2024)*

**Summary** Hybrid meat products are a beneficial approach to incorporating plant proteins into conventional meat formulations, taking into account current market trends that emphasise the partial decrease in animal protein content. This study aimed to evaluate the effects of using different percentages of beef meat (BM), jackfruit flesh (JF) and bamboo shoot (BS) as a meat substitute in beef meat emulsion. Emulsion with 100% BM (Control), (A) 50% JF + 50% BM, (B) 50% BS + 50% BM, (C) 50% BM + 25% JF + 25% BS, (D) 100% JF and (E) 100% BS were developed. Six formulations of meat emulsion samples were prepared and analysed in terms of physicochemical and microstructure properties. The substitution of JF and BS in meat emulsion resulted in more stable emulsion stability. The WHC and pH values showed no significant differences ($P > 0.05$) between samples. The samples with different percentages of JF and BS had significantly increased ($P < 0.05$) the moisture content and the crude fibre content, however, it significantly reduced ($P < 0.05$) the crude protein content. No significant difference ($P > 0.05$) in ash and fat content for the formulated meat emulsions from the control. One hundred per cent BS showed higher lightness ($L^*$), yellowness ($b^*$) and lower redness ($a^*$) values significantly ($P < 0.05$) compared to the control. One hundred per cent JF and 100% BS depicted significant differences ($P < 0.05$) for the textural properties and gel strength compared to the control. The scanning electron microscopy (SEM) provided evidence for the microstructure that the higher the percentages of plant-based ingredients, the smaller the cavities. Overall, the incorporation of 50% BM + 25% JF + 25% BS could produce the best-suited meat substitution product.

**Keywords** Bamboo shoot, fibre, jackfruit flesh, meat emulsion, meat substitute.

## Introduction

In the previous six decades, the global population grew by 250% rising from 2.6 billion to 7 billion people (Gabriel *et al.*, 2014; Hashempour-Baltork *et al.*, 2020). As the world population increases, the demand for meat consumption and food products is expected to rise in the future (Asyrul-Izhar *et al.*, 2023a). Food demand is expected to increase by 70% by 2050 as a result of the addition of another 2.3 billion people (Kumar *et al.*, 2017). However, there are issues with meat production and consumption that might pose a threat to people if the demand for meat continues to rise such as human health problems, animal welfare issues and environmental problems (Ming-Min & Ismail-Fitry, 2023).

There is a growing interest in creating flexitarian eating patterns that incorporate more plant-based options for reasons of sustainability, health and welfare. Given this, hybrid meat products which are made with a blend of plant and animal ingredients in different proportions are starting to gain popularity as an alternative to traditional meat products (Grasso & Goksen, 2023). They

*Correspondent: E-mail: ismailfitry@upm.edu.my

doi:10.1111/ijfs.17579

may have the added benefit of offering a familiar meaty taste and texture along with the nutritional advantages of plants (Asyrul-Izhar *et al.*, 2023b). As meat production is still growing, the shift from animal-based consumption to plant-based can make it more sustainable for the environment. Meat substitutes, according to Elzerman *et al.* (2021), are products created to be taken in place of meat. Furthermore, Alexy *et al.* (2017) reported that meat substitutes are intended to taste and feel like meat from animals with a lower saturated fat content. In addition, they claimed that since the basic ingredients of meat analogues are mostly plant sources of protein, thus, they are less hazardous in terms of food safety issues. Among reported plant-based meat substitutes are vegetables, legumes and tubers (Pintado & Delgado-Pando, 2020). Wheat flour, soyachunks (Sharma *et al.*, 2022); protein from wheat, fungi, peas and soy are among those used in the preparation of meat substitutes (Yuliarti *et al.*, 2021).

Jackfruit (*Artocarpus heterophyllus*) is a fruit that is usually consumed when it is completely ripe (Swami *et al.*, 2012). The fruit in the ripe stage has a high content of carbohydrates, mainly sugars which gets a sweet flavour to use as an ingredient in several dishes. Young jackfruit (unripe) is moderately rich in protein, while also being low in fat. The composition of young jackfruit per 100 g of edible portion generally varies, with its carbohydrate content ranging from approximately 9.4–11.5, protein content between 2 and 2.6 and dietary fibre around 2.6–3.6 on a fresh weight basis (Ranasinghe *et al.*, 2019). Moreover, jackfruit is high in various vitamins and minerals like vitamin C and potassium which makes it a healthy food (Ranasinghe *et al.*, 2019). Studies found that jackfruit flesh has the potential to be used as a meat substitute for meat products (Clayton *et al.*,2018). Abdullah (2017) found that substituting unripe jackfruit resulted in decreasing fat content while boosting fibre while Ismail-Fitry & Abas (2018) reported that the addition of jackfruit to chicken meat patties had increased the water-holding capacity, moisture content and protein values.

Bamboo shoots (*Bambusa polymorpha*) have been acknowledged as a traditional Chinese medicinal ingredient for more than 2000 years and have been stated to be beneficial to human health (Li *et al.*, 2020). Bamboo shoots possess a nutritional composition that is particularly beneficial for individuals who follow a vegetarian or vegan diet, or those who aim to decrease their meat intake, due to their elevated levels of protein and fibre (Chauhan *et al.*, 2016). The composition of bamboo shoots per 100 grams of edible portion exhibits variability, with carbohydrate content at 5.44, protein content at 3.64 and dietary fibre at 3.81 (Nongdam & Tikendra, 2014). Besides, the dietary fibre, the bamboo shoots have the potential to improve the gelling properties, rheological and water distribution of beef batter while lowering the proportion of free water (Li *et al.*, 2020).

A meat emulsion is made up of two physically distinct phases: a disperse phase of fat globules and a continuous phase of a gel-like medium made up of a matrix of water, soluble myofibrillar proteins, salts, phosphates and other non-meat components (Ismail *et al.*, 2021b). Fat and water-holding capacity, protein content of meat, water, salt, fat, non-meat ingredient additions and mechanical and thermal treatments are among the factors that affect meat batter stability (Youssef & Barbut, 2010). To date, there has been limited research on the application of two types of meat substitutes namely jackfruit and bamboo shoot at the same time. Therefore, this work aimed to evaluate the effect of different percentages of jackfruit flesh and bamboo shoots as meat substitutes on the physicochemical and microstructural properties of beef meat emulsion.

## Materials and methods

### Samples preparation

Unripe jackfruit (*Artocarpus heterophyllus*), typically characterised by its firm texture and pale green to yellowish colour, bamboo shoot (*Bambusa polymorpha*) and lean sirloin meat were bought from Pasar Borong Seri Kembangan, Selangor. The beef was frozen at −18 °C in polyethylene bags for 2 weeks before usage. Suitable meat was tempered at 4 °C for 24 h before making meat batter. Unripe jackfruits and bamboo shoots were peeled, washed and cut. Unripe jackfruits were blanched for 2 min to avoid oxidation, while bamboo shoots were boiled for 20 min and soaked in plain water to eliminate toxic and bitter components. Six meat emulsions were prepared based on Table 1.

The beef meat was minced using a mincer machine (H.L TJ12-A, China) after being divided into smaller

**Table 1** Formulations of meat emulsions with different percentages of meat, jackfruit flesh and bamboo shoot

| Ingredient (%) | Control | A | B | C | D | E |
|---|---|---|---|---|---|---|
| Meat | 70 | 35 | 35 | 35 | 0 | 0 |
| Jackfruit | 0 | 35 | 0 | 17.5 | 70 | 0 |
| Bamboo shoot | 0 | 0 | 35 | 17.5 | 0 | 70 |
| Fat | 15 | 15 | 15 | 15 | 15 | 15 |
| Ice water | 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 |
| STPP | 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 |
| Starch | 4 | 4 | 4 | 4 | 4 | 4 |
| Total | 100 | 100 | 100 | 100 | 100 | 100 |

pieces. The YM-102 food processor (Gourmet Cuisine, Malaysia) was used to mince the jackfruit flesh and bamboo shoot into a paste. Triplicates of six beef, jackfruit and bamboo stalk ratios were prepared (see Table 1). Except for salt, STPP and ice water, all ingredients were mixed in the food processor for 1 min. Then, salt and STPP were added and mixed for 30 s. The mixture was further mixed for an additional 30 s after the addition of cold water. The emulsion that developed was transferred to 50 mL centrifuge cylinders. To eliminate any remaining bubbles, the emulsion is centrifuged at 2500 rpm for 1 min at 3 °C using a Kubota 3740 (Japan). The uncooked samples were subsequently kept in the freezer at −18 °C until they were subjected to additional analyses. The samples were heated in a water bath at 90 °C for 15 min to prepare the cooked sample for further analysis.

## Physicochemical properties analysis

*Emulsion stability*

The stability of the meat mixture emulsion was determined based on Cofrades *et al.* (2008) and Ismail *et al.* (2021b). Fifteen grams of meat emulsion was placed in the centrifuge tube and centrifuged at 3000 rpm at 4 °C for 15 min using a Kubota 3740 (Japan). For 30 min, the tubes were cooked in a water bath at 75 °C. The tubes were heated and then turned upside down and left for an hour to let the exudates drain onto a crucible that had already been weighed. The pellet that was still in the tube was measured in weight. The total fluid released was calculated as the percentage loss after heating. The fluid released in the crucible was oven-dried at 105 °C for 16 h. The remaining fluid in the crucible was determined. The total fluid released and the fat released was calculated by the following formula:

$$\text{Total fluid released}(\%) = \frac{(\text{initial weight of sample} - \text{weight of pellet})}{\text{the initial weight of the sample}} \times 100 \quad (1)$$

$$\text{Fat released}(\%) = \frac{(\text{weight of crucible} + \text{dried supernatant}) - \text{the weight of emptycrucible}}{\text{total fluid release}} \times 100 \quad (2)$$

*Water-holding capacity (WHC)*

The water-holding capacity was determined using the methodology outlined by Köhn *et al.* (2015). For 1 min, the unprocessed samples, weighing 5 g, are combined with 32 mL of distilled water in a centrifuge tube. The mixture was centrifuged at 2900 g for 25 min after being left for 10 min. The centrifuge carrying the supernatant was weighed. The supernatant was discarded. The pellet-containing centrifuge tube was upside-down and dried in an oven at 50 °C for 20 min. The WHC of the samples was determined by weighing the dried pellet and applying the following formula:

$$\text{WHC} = \frac{(b-a)-(c-a)}{(b-a)} \times 100\% \quad (3)$$

where, $a$, weight of empty centrifuge; $b$, weight of centrifuge with supernatant; $c$, weight of dried centrifuge.

*pH*

The pH of raw and cooked samples was assessed using Kim *et al.* (2010)'s method, with minimal modifications. The MX-898M blender (Panasonic, Japan) was used to homogenise 5 g of fresh and cooked sample with 45 mL of distilled water for 1 min.

*Proximate analysis*

The analysis followed the AOAC standard methodology (AOAC, 2012). A universal oven (Binder, Germany) was used to measure the moisture content and the Kjeldahl method was used to measure the total protein (Crude protein, N = 6.25) content. The Soxhlet-Henkel method was used to measure the fat content and mineralisation at 550 °C was used to measure the ash content. Crude fibre was determined by the Weende method.

*Colour measurement*

The colour of the raw and cooked samples was measured using a Chromameter CR-410 (Konica Minolta Inc., Japan). The rates of lightness ($L^*$), redness ($a^*$) and yellowness ($b^*$) samples were assessed (Choi *et al.*, 2010).

*Texture profile analysis (TPA)*

Texture profile analysis (TPA) was evaluated following the methodology employed by Ismail *et al.* (2021b), with minor modifications. Texture analysers TA-XT2i 562 (Stable Micro Systems, Surrey, UK) examine the texture of the cooked products. The samples were twice examined under a pushing height of 75% using a probe with a 75 mm diameter and 30 kg force. The samples are measured in 1 cm diameter by 2 cm length. Hardness, springiness, cohesion, gumminess, chewiness and resilience will be the texture criteria' determinations. Texture analyser parameters included pre-test speed at 1.00 mm/s, test speed at 1.50 mm/s, post-test speed at 1.50 mm/s and strain at 70%.

*Gel strength (GS)*

The method outlined by Ismail *et al*. (2021a) was used to determine the gel strength of the cooked samples. The Texture Analyser TA-XT2i (Stable Micro Systems, UK) was used to test the gel's strength with a 25 kg load to find the maximum shear force (N) and work of shearing (N.sec). The sample, which was 2.5 cm long and 1.5 cm wide, was cut with a Warner-Bratzler shear blade that was 1 mm thick and moving at 1.5 mm/s with a cutting rate of 100%.

*Scanning electronic microscopy (SEM)*

The microstructure of the meat emulsion was cut into small fragments and applied to an aluminium mounting stub using double-sided adhesive. Thin layers of sausages were studied with a scanning electron microscope (LEO 1455 VPSEM, Cambridge, UK) at 100× magnification and photographed (Asyrul-Izhar *et al*., 2021).

*Statistical analysis*

Statistical analysis was performed using Minitab ver. 19.0 (Minitab Inc., State College, PA, USA). Significant differences between the data obtained were determined statistically using one-way analysis of variance (ANOVA) with Tukey's multiple comparison tests at a 95% confidence level. The values were expressed as a mean ± standard deviation.

## Result and discussion

### Emulsion stability, water-holding capacity and pH value of meat emulsion

Table 2 shows the result of the emulsion stability (ES), water-holding capacity (WHC) and pH value of meat emulsion using different ratios of beef meat (BM), jackfruit flesh (JF) and bamboo shoot (BS). A stable emulsion has less total fluid released (% TFR) and fat release (% FR) (Serdaroğlu *et al*., 2016). The results showed the % TFR were not significantly different from the control ($P > 0.05$). Despite this, the TFR and FR values of samples D and E were lower compared to the rest of the formulation. The lower values of TFR and FR of samples D and E were probably because of the higher value of total dietary fibre content in the plant-based ingredients which improved the water retention and oil absorption of meat emulsion (Han & Bertram, 2017).

The WHC showed no significant differences ($P > 0.05$) between samples. The highest WHC was determined with the formulation of 100% BM while the WHC decreased when the plant-based ingredient was added and this was consistent with the findings from Li *et al*. (2020) which stated that the water-holding capacity of meat batter decreased as the addition of bamboo shoot dietary fibre increased. However, it was in contrast to the result stated by Ismail-Fitry & Abas (2018) that the WHC value increased while the concentration of jackfruit increased. It may be due to the different types of meat, which the meat used by Ismail-Fitry & Abas (2018) was chicken meat. The data was projected to be directly related to moisture content, with higher WHC indicating more protein–protein interaction and the capacity of meat products to retain water in their systems.

There was no significant difference ($P > 0.05$) between the pH values in Table 2 on meat emulsions formulated with different types of plant-based ingredients either on the raw or cooked emulsion. The pH of raw emulsions was measured in the range of 5.10 to 5.76, whereas the pH of cooked emulsions was measured in the range of 5.41 to 6.11. The pH value of the cooked emulsion was somewhat higher than the raw emulsion,

**Table 2** Emulsion stability, water-holding capacity (WHC) and pH value of the meat emulsions

| Samples | Emulsion stability | | Water-holding capacity (%) | pH | |
|---|---|---|---|---|---|
| | Total fluid release (%) | Fat release (%) | | Before cooking | After cooking |
| Control | $12.67 \pm 1.76^{abc}$ | $18.17 \pm 7.90^{ab}$ | $90.02 \pm 1.22^{a}$ | $5.49 \pm 0.23^{a}$ | $5.61 \pm 0.22^{a}$ |
| A | $13.56 \pm 1.54^{ab}$ | $19.48 \pm 11.20^{ab}$ | $88.16 \pm 2.47^{a}$ | $5.58 \pm 0.43^{a}$ | $5.62 \pm 0.59^{a}$ |
| B | $15.78 \pm 3.67^{a}$ | $20.70 \pm 13.45^{ab}$ | $89.23 \pm 0.83^{a}$ | $5.37 \pm 0.23^{a}$ | $5.41 \pm 0.37^{a}$ |
| C | $16.22 \pm 2.69^{a}$ | $24.62 \pm 6.24^{a}$ | $89.36 \pm 0.65^{a}$ | $5.44 \pm 0.34^{a}$ | $5.51 \pm 0.67^{a}$ |
| D | $3.33 \pm 4.05^{c}$ | $0.00 \pm 0.00^{b}$ | $86.80 \pm 1.23^{a}$ | $5.76 \pm 0.47^{a}$ | $6.11 \pm 0.24^{a}$ |
| E | $4.45 \pm 5.43^{bc}$ | $1.11 \pm 1.92^{b}$ | $86.69 \pm 1.79^{a}$ | $5.10 \pm 0.44^{a}$ | $5.25 \pm 0.55^{a}$ |

Data are expressed in mean ± SD of triplicate ($n = 3$). Different superscript letters in the same column represent a significant difference ($P < 0.05$).
Ctrl (100% BM); A (50% BM, 50% JF); B (50% BM, 50% BS); C (50% BM, 25% JF, 25% BS); D (100% JF); E (100% BS).

although there was no significant difference between the varied formulations for both. Choi *et al.* (2009) came up with similar conclusions that uncooked meat batter with vegetable oil and rice bran fibre had a lower pH than cooked meat batter. Choi *et al.* (2008) indicated that the basic R group of the amino acid histidine (imidazolium) was liberated when the meat batter was cooked, thus causing the pH value to increase.

### Proximate composition

Moisture content resulted in significant differences ($P < 0.05$) between samples, showing the plant-based ingredient emulsion samples were greater than the control sample. The high moisture content of the plant-based component (JS and BS) was most likely a factor. As the percentage of the plant-based ingredient used increased from 50% to 100%, the moisture content also increased. Ash content presented with no significant differences ($P > 0.05$) between samples. Significant differences ($P < 0.05$) were observed for fat content samples with the one with meat substitute slightly decreased compared to the control could be due to the decrease of beef meat. There was a similar study presented by Slima *et al.* (2019) mentioned that the decrease of beef meat in sausage decreased the fat content of formulated sausage (Table 3).

Substitution with the plant-based ingredients significantly ($P < 0.05$) lowered the protein content of meat emulsion. Data showed that the meat emulsion without any plant-based ingredient (control) had the highest protein content (13.22%) followed by 50% BS. The result was in agreement with previous studies from Abdullah (2017), reducing meat content directly lowers the protein content. A similar result was reported by Slima *et al.* (2019) which the protein content of fresh sausage formulated with the two fibres was significantly decreased. The highest value of fibre (2.58%) was contained in the sample with 100% JF. According to Azad *et al.* (2000), 2.6 g to 3.6 g of dietary fibre was found in 100 g of edible portion of unripe jackfruit.

### Colour measurement

Colour values of uncooked and cooked meat emulsion were significantly different ($P < 0.05$) (Table 4). The study found that the lightness and yellowness value of both uncooked and cooked emulsion increased as the plant-based ingredients were added, however, the redness value decreased. The observations in the colour were consistent with the findings of Zhuang *et al.* (2016) which revealed that the addition of sugarcane dietary fibre to emulsified sausages raised the $b^*$ value but lowered the $a^*$ value. Comparing the meat emulsion with the presence of JF and BS, BS resulted in higher values of lightness and yellowness with a lower value of redness. This is because the bamboo shoot has a lighter colour compared to the beef meat and jackfruit. Comparing the colour between uncooked and cooked emulsion, the cooked meat emulsion resulted in lower values of lightness ($L^*$), yellowness ($b^*$) and redness ($a^*$). This was probably due to the non-enzymatic browning effect of the high-temperature treatment for the cooked sample. The decrease of the yellowness may be due to the decomposition of the carotenoid pigment (Bal *et al.*, 2011).

### Texture profile analysis and gel strength

Meat emulsion substituted with 100% plant ingredients (Sample D and E) showed the two lowest values of hardness. This might be due to the higher moisture content of the JF and BS. These results corroborate the ideas of Ismail *et al.* (2021a), who mentioned that the increase of moisture retention, decreased the hardness of patties. The high fibre content in the plant-based ingredient might also affect the reduction of the hardness of the samples. The previous study by

**Table 3** Proximate composition of the meat emulsion

| Samples | Moisture Content (%) | Ash Content (%) | Crude Fat Content (%) | Protein Content (%) | Crude Fibre Content (%) |
|---|---|---|---|---|---|
| Control | $62.68 \pm 2.15^{c}$ | $2.25 \pm 0.23^{a}$ | $11.23 \pm 0.98^{ab}$ | $13.22 \pm 3.65^{a}$ | $0.00 \pm 0.00^{d}$ |
| A | $67.12 \pm 3.32^{bc}$ | $2.12 \pm 0.27^{a}$ | $11.61 \pm 2.36^{a}$ | $8.07 \pm 1.88^{ab}$ | $0.87 \pm 0.43^{bc}$ |
| B | $69.63 \pm 1.81^{b}$ | $2.65 \pm 0.84^{a}$ | $6.05 \pm 3.20^{b}$ | $10.11 \pm 1.61^{a}$ | $0.55 \pm 0.35^{cd}$ |
| C | $69.96 \pm 1.19^{b}$ | $2.71 \pm 1.12^{a}$ | $7.68 \pm 1.41^{ab}$ | $8.46 \pm 1.05^{ab}$ | $0.94 \pm 0.35^{bc}$ |
| D | $75.87 \pm 2.28^{a}$ | $2.08 \pm 0.71^{a}$ | $10.12 \pm 1.78^{ab}$ | $1.85 \pm 1.18^{c}$ | $2.58 \pm 0.36^{a}$ |
| E | $76.37 \pm 1.40^{a}$ | $1.94 \pm 0.05^{a}$ | $10.91 \pm 1.09^{ab}$ | $3.21 \pm 1.05^{bc}$ | $1.45 \pm 0.14^{b}$ |

Data are expressed in mean ± SD of triplicate ($n = 3$). Different uppercase superscripts in the same column represent a significant difference ($P < 0.05$).

Ctrl (100% BM); A (50% BM, 50% JF); B (50% BM, 50% BS); C (50% BM, 25% JF, 25% BS); D (100% JF); E (100% BS).

**Table 4** The colour measurements ($L^*$, $a^*$, $b^*$) of the meat emulsions

| Samples | Before cooking | | | After cooking | | |
|---|---|---|---|---|---|---|
| | $L^*$ | $a^*$ | $b^*$ | $L^*$ | $a^*$ | $b^*$ |
| Control | $55.10 \pm 4.46^{c}$ | $13.17 \pm 3.62^{a}$ | $14.92 \pm 1.02^{b}$ | $53.31 \pm 4.33^{b}$ | $6.86 \pm 0.93^{a}$ | $12.69 \pm 0.50^{c}$ |
| A | $58.51 \pm 3.76^{bc}$ | $9.15 \pm 1.97^{ab}$ | $16.22 \pm 0.75^{b}$ | $57.43 \pm 0.53^{b}$ | $5.90 \pm 1.79^{a}$ | $14.23 \pm 0.39^{bc}$ |
| B | $59.02 \pm 0.22^{bc}$ | $8.75 \pm 1.25^{ab}$ | $19.60 \pm 1.47^{b}$ | $59.37 \pm 1.02^{b}$ | $3.26 \pm 1.49^{ab}$ | $19.06 \pm 2.37^{b}$ |
| C | $60.05 \pm 0.22^{abc}$ | $9.88 \pm 1.53^{a}$ | $18.60 \pm 0.64^{b}$ | $57.51 \pm 1.91^{b}$ | $4.53 \pm 2.10^{a}$ | $16.61 \pm 2.01^{bc}$ |
| D | $64.09 \pm 2.91^{ab}$ | $4.06 \pm 0.82^{bc}$ | $19.06 \pm 0.75^{b}$ | $58.34 \pm 2.31^{b}$ | $4.37 \pm 0.24^{a}$ | $16.38 \pm 0.87^{bc}$ |
| E | $67.46 \pm 2.50^{a}$ | $0.63 \pm 0.22^{c}$ | $28.96 \pm 4.20^{a}$ | $67.34 \pm 0.73^{a}$ | $-0.20 \pm 0.53^{b}$ | $28.95 \pm 3.85^{a}$ |

Data are expressed in mean ± SD of triplicate ($n = 3$). Different uppercase superscripts in the same column represent a significant difference ($P < 0.05$).

Ctrl (100% BM); A (50% BM, 50% JF); B (50% BM, 50% BS); C (50% BM, 25% JF, 25% BS); D (100% JF); E (100% BS).

Slima *et al.* (2019) stated that the reduction of hardness value is not only related to the reduction of beef meat and the water content, but it can be also due to the addition of fibre. Thus, the mixture of meat and plant ingredients would enhance the properties of the meat product. Significant decreases ($P < 0.05$) were observed for the cohesiveness, gumminess, chewiness and resilience as the percentages of plant-based ingredients added were increased except for sample C, which contained mixed plant ingredients (25% JF and 25% BS). Slima *et al.* (2019) reported that the combination of two types of fibre had no negative effect on texture behaviours compared to the control. Among the six formulations of meat emulsions, the control sample resulted in the highest value of hardness, springiness, cohesiveness, gumminess, chewiness and resilience. The result showed that the higher the percentages of the plant-based ingredients, the lower the value of the TPA parameters (Table 5).

The gel strength of the formulated meat emulsions was significantly lower ($P < 0.05$) than the control. The increase in the percentages of meat substitutes resulted in lower gel strength because when plant ingredients were used, the protein content would be lower. Thus, less protein network was able to hold the water to improve the gel strength (Ducept *et al.*, 2012).

## Microstructure

The microstructure of samples B and C showed more droplets of irregular shapes and sizes in comparison to the control, samples A, D and E (Fig. 1). The samples D and E showed less droplets and more empty space. Thus, the images of SEM revealed that the structure of the D and E were different. The control revealed a structure with spheres inserted in the protein network that is somewhat rough and porous. The spheres indicated the presence of fat globulus. The arrow showed that there may be interactions between protein, water and fat molecules, as well as the development of a thin film surrounding the oil droplet. Samples D and E showed fewer droplets and more empty spaces. This is due to the low amount of fat and the inclusion of fibre.

The microstructure showed that the emulsion without fibre had cavities as in the control sample. The higher the percentages of plant-based ingredients, the smaller the cavities. It supported the results of previous research by Zhao *et al.* (2019). The study was also supported by the research from Felisberto *et al.* (2015) that the formulation that contained fibres revealed formations that were less dense and compact than the control formulations, with similar porosity and the presence of empty spaces.

**Table 5** The texture profile analysis and gel strength of the meat emulsions

| Samples | Hardness (kg) | Springiness (mm) | Cohesiveness | Gumminess | Chewiness (kg.mm) | Resilience | Gel strength (*N*) |
|---|---|---|---|---|---|---|---|
| Control | $9.39 \pm 0.51^{a}$ | $0.76 \pm 0.03^{a}$ | $0.36 \pm 0.03^{a}$ | $3.40 \pm 0.45^{a}$ | $2.58 \pm 0.28^{a}$ | $0.10 \pm 0.01^{a}$ | $16.49 \pm 0.85^{a}$ |
| A | $4.47 \pm 0.68^{b}$ | $0.58 \pm 0.07^{b}$ | $0.29 \pm 0.02^{b}$ | $1.28 \pm 0.13^{bc}$ | $0.75 \pm 0.16^{b}$ | $0.07 \pm 0.01^{a}$ | $6.67 \pm 3.31^{bc}$ |
| B | $4.08 \pm 0.65^{b}$ | $0.57 \pm 0.08^{b}$ | $0.32 \pm 0.02^{ab}$ | $1.33 \pm 0.28^{b}$ | $0.77 \pm 0.25^{b}$ | $0.09 \pm 0.01^{a}$ | $12.20 \pm 0.27^{ab}$ |
| C | $4.33 \pm 0.57^{b}$ | $0.64 \pm 0.04^{ab}$ | $0.34 \pm 0.02^{ab}$ | $1.46 \pm 0.27^{b}$ | $0.93 \pm 0.12^{b}$ | $0.08 \pm 0.02^{a}$ | $8.95 \pm 3.76^{bc}$ |
| D | $1.54 \pm 0.44^{c}$ | $0.36 \pm 0.03^{c}$ | $0.21 \pm 0.03^{c}$ | $0.32 \pm 0.11^{c}$ | $0.11 \pm 0.04^{c}$ | $0.03 \pm 0.01^{b}$ | $3.74 \pm 0.71^{c}$ |
| E | $0.99 \pm 0.12^{c}$ | $0.30 \pm 0.04^{c}$ | $0.19 \pm 0.02^{c}$ | $0.19 \pm 0.02^{c}$ | $0.06 \pm 0.01^{c}$ | $0.02 \pm 0.00^{b}$ | $3.22 \pm 0.63^{c}$ |

Data are expressed in mean ± SD of triplicate ($n = 3$). Different uppercase superscripts in the same column represent a significant difference ($P < 0.05$).

Ctrl (100% BM); A (50% BM, 50% JF); B (50% BM, 50% BS); C (50% BM, 25% JF, 25% BS); D (100% JF); E (100% BS).

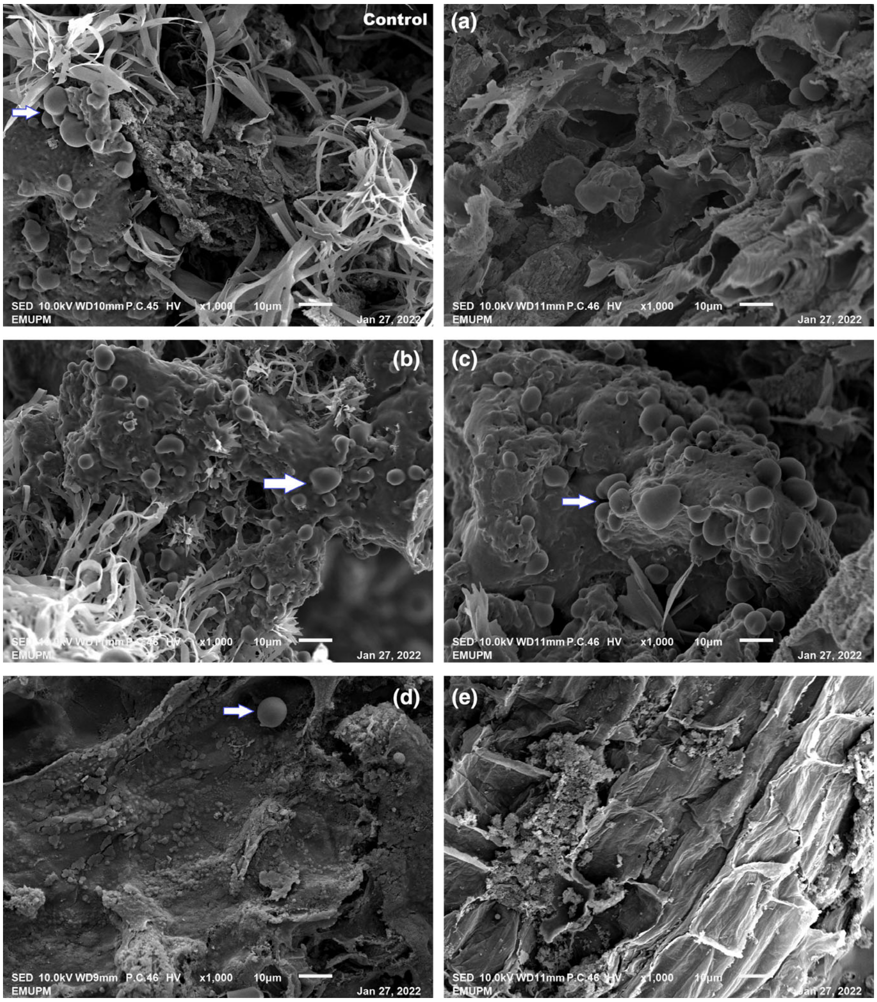


**Figure 1** The SEM image of the meat emulsion with different formulations. Ctrl (100% BM); a (50% BM, 50% JF); b (50% BM, 50% BS); c (50% BM, 25%JF, 25%BS); d (100%JF); e (100%BS).

## Conclusion

The meat emulsion samples with different percentages of jackfruit flesh and bamboo shoots as meat substitutes had influenced some physicochemical properties such as emulsion stability, moisture content and colour. The substitution of JF and BS in meat emulsion resulted in more stable emulsion stability. The samples with different percentages of JF and BS had significantly increased the moisture content and the crude fibre content; however, it significantly reduced the crude protein content. One hundred per cent BS showed higher lightness ($L$*), yellowness ($b$*) and lower redness ($a$*) values compared to the control. One hundred per cent JF and 100% BS depicted significant differences for the hardness, springiness, cohesiveness, gumminess, chewiness, resilience and gel strength compared to the control. Scanning electron microscopy (SEM) provided evidence for the microstructure that the higher the percentages of plant-based ingredients, the decreased the particle size of droplets. Overall, the more suitable formulation to produce the meat substitute product is the combination of 25% jackfruit flesh (*Artocarpus heterophyllus*), 25% bamboo shoot (*Bambusa polymorpha*) and 50% beef meat.

## Acknowledgments

The authors thank the Geran Inisiatif Putra Siswazah (GP-IPS/2023/9774300) for the financial support to conduct the research.

## Author contributions

**Ng Bee Chi:** Writing – original draft; investigation; formal analysis; methodology. **Abu Bakar Asyrul-Izhar:**

Writing – review and editing; visualization; supervision. **Muhamad Shirwan Abdullah Sani:** Supervision; writing – review and editing. **Mohammad Rashedi Ismail-Fitry:** Methodology; validation; supervision; funding acquisition; project administration; conceptualization; writing – review and editing.

## Peer review

The peer review history for this article is available at https://www.webofscience.com/api/gateway/wos/peer-review/10.1111/ijfs.17579.

## Data availability statements

The data that support the findings of this study are available from the corresponding author upon reasonable request.

## References

Abdullah, I. (2017). Effect of using unripe jackfruit as a meat substitute on nutrition composition and organoleptic characteristic of meat Patty. *Politeknik & Kolej Komuniti Journal of Engineering and Technology*, **2**, 96–106.

Alexy, U., Janz, N. & Kersting, M. (2017). Food and meals in vegetarian children and adolescents. In: *Vegetarian and Plant-Based Diets in Health and Disease Prevention*. Pp. 549–564. Cambridge, MA: Academic Press. https://doi.org/10.1016/B978-0-12-803968-7.00031-9

AOAC International., & In Latimer, G. W (2012). *Official Methods of Analysis of 702 AOAC International*. Gaithersburg, MD: AOAC International.

Asyrul-Izhar, A.B., Bakar, J., Sazili, A.Q., Goh, Y.M. & Ismail-Fitry, M.R. (2023a). Emulsion gels formed by electrostatic interaction of gelatine and modified corn starch via pH adjustments: potential fat replacers in meat products. *Gels*, **9**, 50.

Asyrul-Izhar, A.B., Bakar, J., Sazili, A.Q., Meng, G.Y. & Ismail-Fitry, M.R. (2023b). Incorporation of different physical forms of fat replacers in the production of low-fat/reduced-fat meat products: which is more practical? *Food Reviews International*, **39**, 6387–6419.

Asyrul-Izhar, A.B., Sarbon, N.M. & Ismail-Fitry, M.R. (2021). Effects of mixing duration and raw materials on the physicochemical, microstructural and sensorial properties of sausages prepared from red tilapia (*Oreochromis sp.*). *Asian Fisheries Science*, **34**, 355–364.

Azad, A.K. (2000). *Genetic Diversity of Jackfruit in Bangladesh and Development of Propagation Methods*, Thesis for Award of Doctor of Philosophy at University of Southampton, UK.

Bal, L.M., Kar, A., Satya, S. & Naik, S.N. (2011). Kinetics of colour change of bamboo shoot slices during microwave drying. *International Journal of Food Science & Technology*, **46**, 827–833.

Chauhan, O.P., Unni, L.E., Kallepalli, C., Pakalapati, S.R. & Batra, H.V. (2016). Bamboo shoots: composition, nutritional value, therapeutic role and product development for value addition. *International Journal of Food and Fermentation Technology*, **6**, 1–12.

Choi, Y.S., Choi, J.H., Han, D.J. *et al.* (2009). Characteristics of low-fat meat emulsion systems with pork fat replaced by vegetable oils and rice bran fiber. *Meat Science*, **82**, 266–271.

Choi, Y.S., Jeong, J.Y., Choi, J.H. *et al.* (2008). Effects of dietary fiber from rice bran on the quality characteristics of emulsion-type sausages. *Food Science of Animal Resources*, **28**, 14–20.

Choi, Y.S., Park, K.S., Choi, J.H. *et al.* (2010). Physico-chemical properties of chicken meat emulsion systems with dietary fiber extracted from makgeolli lees. *Food Science of Animal Resources*, **30**, 910–917.

Cofrades, S., López-López, I., Solas, M.T., Bravo, L. & Jiménez-Colmenero, F. (2008). Influence of different types and proportions of added edible seaweeds on characteristics of low-salt gel/emulsion meat systems. *Meat Science*, **79**, 767–776.

Ducept, F., de Broucker, T., Souliè, J.M., Trystram, G. & Cuvelier, G. (2012). Influence of the mixing process on surimi seafood paste properties and structure. *Journal of Food Engineering*, **108**, 557–562.

Elzerman, J.E., Keulemans, L., Sap, R. & Luning, P.A. (2021). Situational appropriateness of meat products, meat substitutes and meat alternatives as perceived by Dutch consumers. *Food Quality and Preference*, **88**, 104108.

Felisberto, M.H.F., Galvão, M.T.E.L., Picone, C.S.F., Cunha, R.L. & Pollonio, M.A.R. (2015). Effect of prebiotic ingredients on the rheological properties and microstructure of reduced-sodium and low-fat meat emulsions. *LWT- Food Science and Technology*, **60**, 148–155.

Gabriel, A., Victor, N. & du Preez James, C. (2014). Cactus pear biomass, a potential lignocellulose raw material for single cell protein production (SCP): a review. *International Journal of Current Microbiology and Applied Sciences*, **3**, 171–197.

Grasso, S. & Goksen, G. (2023). The best of both worlds? Challenges and opportunities in the development of hybrid meat products from the last 3 years. *LWT*, **173**, 114235.

This article examines current progress in the creation of hybrid meat products, which involve the combination of plant-based and animal-based components. The authors examine the technological, economic, and consumer acceptance obstacles and possibilities linked to these items throughout the last three years. In addition, they analyse advancements in the development of methods, manufacturing techniques, and market patterns, offering a thorough assessment of the present condition of hybrid meat products.

Han, M. & Bertram, H.C. (2017). Designing healthier comminuted meat products: effect of dietary fibers on water distribution and texture of a fat-reduced meat model system. *Meat Science*, **133**, 159–165.

Hashempour-Baltork, F., Khosravi-Darani, K., Hosseini, H., Farshi, P. & Reihani, S.F.S. (2020). Mycoproteins as safe meat substitutes. *Journal of Cleaner Production*, **253**, 119958.

Ismail, M.A., Chong, G.H. & Ismail-Fitry, M.R. (2021a). Comparison of the microstructural, physicochemical and sensorial properties of buffalo meat patties produced using bowl cutter, universal mixer and meat mixer. *Journal of Food Science and Technology*, **1-8**, 4703–4710.

Ismail, N.A., Bakar, J., Sazili, A.Q. & Ismail-Fitry, M.R. (2021b). Effect of different levels of fat, sodium chloride, and sodium tripolyphosphate on the physicochemical and microstructure properties of Jamnapari goat meat emulsion modelling system. *International Food Research Journal*, **28**, 916–925.

Ismail-Fitry, M.R. & Abas, N.F.A. (2018). Potential use of jackfruit (*Artocarpus heterophyllus*) and breadfruit (*Artocarpus altilis*) as fat replacer to produce low-fat chicken patties. *International journal of Engineering & Technology*, **7**(4.14), 292–296.

This article explores the possibility of utilising jackfruit as substitutes for fat in the manufacturing of low-fat chicken patties. The authors conducted empirical investigations to assess the influence of these fruit-derived fat substitutes on the consistency, taste, and overall excellence of the patties. The research offers a comprehensive examination of how various substitutions impact the sensory characteristics and nutritional composition of the end product.

Kim, H.Y., Lee, E.S., Jeong, J.Y. *et al.* (2010). Effect of bamboo salt on the physicochemical properties of meat emulsion systems. *Meat Science*, **86**, 960–965.

Köhn, C.R., Fontoura, A.M., Kempka, A.P., Demiate, I.M., Kubota, E.H. & Prestes, R.C. (2015). Assessment of different methods for determining the capacity of water absorption of ingredients and additives used in the meat industry. *International Food Research Journal*, **22**, 356–362.

Kumar, P., Chatli, M.K., Mehta, N., Singh, P., Malav, O.P. & Verma, A.K. (2017). Meat analogues: health promising sustainable meat substitutes. *Critical Reviews in Food Science and Nutrition*, **57**, 923–932.

Li, K., Liu, J.Y., Fu, L. *et al.* (2020). Effect of bamboo shoot dietary fiber on gel properties, microstructure and water distribution of pork meat batters. *Asian-Australasian Journal of Animal Sciences*, **33**, 1180–1190.

This study evaluates the effects of adding bamboo shoot nutritional fibre to pork batters. The authors examine the impact of including this fibre on the gel characteristics, microstructure, and water distribution of the batters. Various analytical approaches are employed to quantify changes in texture, stability, and moisture retention, so offering a comprehensive evaluation of the functional advantages of using bamboo shoot fibre in meat processing, 1190.

Ming-Min, W. & Ismail-Fitry, M.R. (2023). Physicochemical, rheological and microstructural properties of chicken meat emulsion with the addition of Chinese yam (*Dioscorea polystachya*) and arrowroot (*Maranta arundinacea*) as meat substitutes. *Future Foods*, **7**, 100221.

Nongdam, P. & Tikendra, L. (2014). The nutritional facts of bamboo shoots and their usage as important traditional foods of northeast India. *International scholarly research notices*, **2014**, 679073.

Pintado, T. & Delgado-Pando, G. (2020). Towards more sustainable meat products: Extenders as a way of reducing meat content. *Food*, **9**, 1044.

Ranasinghe, R.A.S.N., Maduwanthi, S.D.T. & Marapana, R.A.U.J. (2019). Nutritional and health benefits of jackfruit (*Artocarpus heterophyllus* lam.): a review. *International Journal of Food Science*, **2019**, 4327183.

Serdaroğlu, M., Öztürk, B. & Urgu, M. (2016). Emulsion characteristics, chemical and textural properties of meat systems produced with double emulsions as beef fat replacers. *Meat Science*, **117**, 187–195.

Sharma, A., Rawat, K., Jattan, P. *et al.* (2022). Formula refining through composite blend of soya, alfalfa, and wheat flour; a vegan meat approach. *Journal of Food Processing and Preservation*, **46**, e15235.

Slima, S.B., Ktari, N., Triki, M. *et al.* (2019). Effects of two fibers used separately and in combination on physico-chemical, textural, nutritional and sensory properties of beef fresh sausage. *British Food Journal*, **121**, 1428–1440.

Swami, S.B., Thakor, N.J., Haldankar, P.M. & Kalse, S.B. (2012). Jackfruit and its many functional components as related to human health: a review. *Comprehensive Reviews in Food Science and Food Safety*, **11**, 565–576.

Youssef, M.K. & Barbut, S. (2010). Physicochemical effects of the lipid phase and protein level on meat emulsion stability, texture, and microstructure. *Journal of Food Science*, **75**, S108–S114.

This article investigates the impact of changes in the lipid phase and protein levels on the stability, texture and microstructure of beef emulsions. Youssef and Barbut conducted studies to examine the impact of varying lipid levels and protein concentrations on the physicochemical features of meat emulsions. This included assessing their stability under different conditions, evaluating their textural attributes and analysing their structural characteristics.

Yuliarti, O., Kovis, T.J.K. & Yi, N.J. (2021). Structuring the meat analogue by using plant-based derived composites. *Journal of Food Engineering*, **288**, 110138.

Zhao, Y., Hou, Q., Cao, S., Wang, Y., Zhou, G. & Zhang, W. (2019). Effect of regenerated cellulose fiber on the properties and microstructure of emulsion model system from meat batters. *Food Hydrocolloids*, **87**, 83–89.

Zhuang, X., Han, M., Kang, Z. *et al.* (2016). Effects of the sugarcane dietary fiber and pre-emulsified sesame oil on low-fat meat batter physicochemical property, texture, and microstructure. *Meat Science*, **113**, 107–115.