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# Effects of palm stearin and seaweed powder (*Kappaphycus alvarezii*) on the quality of reduced-fat chicken sausages

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## Abstract

Consumption of meat products is associated with various health problems due to the high animal fat content in their formulation. The incorporation of additives is one of the strategies being studied to reduce saturated fat levels while maintaining the quality of meat products. This study examined the effects of palm stearin (PS) and *Kappaphycus alvarezii* powder (KAP) on the nutrient composition, physicochemical properties, sensory evaluation, and lipid oxidation of chicken sausage. Five chicken sausage formulations, namely control sausage containing 12% chicken fat (CF), F1 (6% chicken fat), F2 (3% chicken fat), F3 (6% palm stearin), and F4 (3% palm stearin), were produced. The control sausages had no seaweed, while F1 to F4 contained KAP. Adding KAP and palm stearin significantly increased the pH value, moisture, and ash content of the sausages ($p<0.05$), while there was no significant difference in the protein level ($p>0.05$). Furthermore, substituting CF with 2% KAP and 3% palm stearin resulted in the lowest fat content among the formulations ($p<0.05$). When compared to the control sample, the sausages with KAP and PS exhibited lower cooking loss and extracted water ($p<0.05$), which may be due to improved emulsion stability ($p<0.05$). At 3% and 6% PS concentrations, the sausages showed higher lightness, with reduced redness and yellowness values. The incorporation of both PS and KAP also significantly increased hardness, chewiness, and adhesiveness values but it reduced the cohesiveness value ($p<0.05$). Meanwhile, no significant difference was observed in springiness among the formulations ($p>0.05$). Among all formulations, F3 garnered the highest preference from sensory panellists, possibly attributed to its well-received texture and juiciness. Additionally, F3 demonstrated superior storage stability, indicated by a lower TBARS value. In conclusion, KAP and PS exhibit the potential for use as fat substitutes in producing reduced-fat sausages.

## 1. Introduction

Lean meat, animal fats, and additional non-meat substances are frequently found in emulsion-like meat products to enhance processed food formulation. Sausages and spreadable patties are two common processed meat products created by the secondary transformation of meat. The presence of fat in these products is essential for emulsions, reducing cooking loss, and enhancing juiciness and texture (Ren *et al.*, 2022). However, high-fat content in processed meat products has increased customer concern due to the cholesterol content and caloric value, which has led to the reformulation of emulsified meat products (Asyrul-Izhar *et al.*, 2023).

Palm oil (*Elaeis guineensis* Jacq.) has a high potential as an animal fat replacer (Sulaiman *et al.*, 2022). Processing of crude palm oil results in the

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crystallization of two parts: palm stearin (30–35%) and palm olein (65–70%) (Subroto and Nurannisa, 2020). Because it contains a significant amount of saturated fatty acids, palm stearin (PS) is solid at room temperature. PS is a promising animal fat substitute due to its yellowish-white appearance, neutral flavour, and more variable composition than palm olein (Akwetey *et al.*, 2019). Additionally, PS has a relatively lower price than animal fat and could positively address the concerns of health-conscious consumers, as low-density lipoproteins synthesised within animal tissues are not present in PS (Urugo *et al.*, 2021).

Functional ingredients such as seaweed are considered superfoods because they contain many bioactive compounds with both health-promoting potential and textural-enhancing attributes (Barros de Medeiros *et al.*, 2022). *Kappaphycus alvarezii* (KAP) is one of the largest tropical macroalgae and has the fastest growth rate in the genus *Kappaphycus*. It contains a high level of phenolic compounds, carbohydrates (27.4%) and fibre (29.4%) (Kanatt, 2023). These substances have various physiological effects, including anti-inflammatory, anti-allergenic, anti-atherogenic, anti-thrombotic, antibacterial, cardioprotective, and vasodilatory properties (Pindi, Qin, Sulaiman *et al.*, 2023). Furthermore, KAP is a source of kappa carrageenan, a phyllocoloid commonly used to thicken and stabilise foods like meat products (Kanatt, 2023).

To date, there have been few studies on the addition of KAP to meat products. Munsu *et al.* (2021) reported that sensory panellists considered 2% and 4% KAP acceptable. Recently, Pindi, Siang, Munsu *et al.* (2023) utilised KAP as a salt substitute in chicken patties, and a promising outcome indicated better textural properties due to the formation of a more rigid protein network in the presence of seaweed in the formulation. To the best of our knowledge, there has not been any research on the interaction of KAP and PS in reduced-fat meat products to study the technological and sensory aspects simultaneously. Hence, the present study aimed to evaluate the effects of these ingredients on the proximate composition, physicochemical properties, and sensory attributes of reduced-fat sausage.

## 2. Materials and methods

### *2.1 Materials*

The boneless chicken breast and chicken fat (CF) were obtained from Desa Hatchery Sdn. Bhd., Lok Kawi, Sabah, Malaysia. The palm stearin (PS) was supplied by the Malaysian Palm Oil Board. The *Kappaphycus alvarezii* (KAP) and dry ingredients were obtained from the local market around Kota Kinabalu, Sabah, Malaysia. All chemicals and solvents used were of analytical grade and obtained from Rinitek Sdn. Bhd. (Malaysia).

### *2.2 Preparation of Kappaphycus alvarezii powder*

*Kappaphycus alvarezii* samples were washed with tap water to remove any epiphyte and contamination from the algae. The samples were then dried in an oven for 48 hrs at 40°C (SMO28-2, MRC Lab, UK). The dried samples were ground in a blender, sieved through a mesh size of 250 µm, and kept in an airtight container at -4°C for further usage (Munsu *et al.*, 2021).

### *2.3 Preparations of chicken sausage*

Four batches of sausage containing different levels of PS (0%, 3%, and 6%), CF (0%, 3%, 6%, and 12%) and 2% concentration of KAP were processed based on the procedures reported by Munsu *et al.* (2021) and Mohd Zaini *et al.* (2021) with certain modifications (Table 1). Firstly, the chicken breast was ground through a 3 mm plate using a grinder (VCB61, Hobart Mg. Co. Ltd., UK) and mixed with iced water and salt for 1 min to extract the salt-soluble protein. Other additives such as fat, soy protein isolate, and spices were added and mixed again for 1 min. Then, the batter was stuffed in collagen casing (25 mm diameter) and cooked in a water bath (WB-6, Daihan Scientific Co. Ltd., South Korea) at 75°C for 30 mins before they were cooled with iced water for 15 mins. The sausages were stored at 4°C until further analysis.

Table 1. Chicken sausage formulations.

| Ingredients (%) | Control | F1 | F2 | F3 | F4 |
|---|---|---|---|---|---|
| Chicken meat | 65.0 | 65.0 | 65.0 | 65.0 | 65.0 |
| Chicken fat | 12.0 | 6.0 | 3.0 | 0.0 | 0.0 |
| Palm stearin | 0.0 | 0.0 | 0.0 | 6.0 | 3.0 |
| *Kappaphycus alvarezii* | 0.0 | 2.0 | 2.0 | 2.0 | 2.0 |
| Ice water | 13.0 | 17.0 | 20.0 | 17.0 | 20.0 |
| Soy protein isolate | 5.0 | 5.0 | 5.0 | 5.0 | 5.0 |
| Potato starch | 3.0 | 3.0 | 3.0 | 3.0 | 3.0 |
| Salt | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 |
| Seasoning | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| Total | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |

### *2.4 Proximate analysis*

The Association of Official Analytical Collaboration (AOAC) International technique was used to determine the proximate content of chicken sausages. The moisture, protein, and fat contents were measured using oven drying technique (AOAC International 950.46B), Kjeldahl method (AOAC International 981.10), and Soxhlet method (AOAC International 991.36), respectively. A muffle furnace was used to measure the ash content (AOAC International 920.153) in accordance with (AOAC International, 2016).

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### 2.5 Cooking loss

About 20 g of sausage samples were cooked at 75°C for 30 mins in a water bath (WB-6, Daihan Scientific Co. Ltd., South Korea). Then, the sausages were left to cool for another 30 mins. The percentage of cooking loss was calculated based on the difference in weight of raw and cooked samples using the formula (Pindi, Qin, Sulaiman *et al.*, 2023):

$$\text{Cooking loss (\%)} = \frac{\text{weight of raw batter (g)} - \text{weight of cooked sample (g)}}{\text{weight of cooked sample (g)}} \times 100$$

### 2.6 Water holding capacity

Approximately 5 g of meat was weighed and centrifuged (5430R, Eppendorf, Germany) at 15000×*g* for 15 mins at 4°C. Water holding capacity (WHC) was expressed as a percentage of extracted water and calculated using the formula (Pindi, Qin, Sulaiman *et al.*, 2023):

$$\text{Extracted water (\%)} = \frac{\text{Initial weight (g)} - \text{Sample weight after centrifugation (g)}}{\text{Sample weight after centrifugation (g)}} \times 100$$

### 2.7 Emulsion stability

The emulsion stability of sausages was determined following Munsu *et al.* (2021) with slight modifications. A total of 25 g of raw batter was centrifuged (5430R, Eppendorf, Germany) at 4000 rpm for 1 min. After that, the samples were heated at 70°C for 30 mins and centrifuged (5430R, Eppendorf, Germany) at 4000 rpm for 3 mins. The pellets were removed while the supernatants were weighed and put into crucibles before drying at 100°C overnight. The volumes of expressible fat (EFAT) and total expressible fluid (TEF) were calculated using the formula:

$$\text{TEF (\%)} = \frac{\text{Weight of sample (g)} - \text{Weight of pellet (g)}}{\text{Weight of sample(g)}} \times 100$$

$$\text{EFAT (\%)} = \frac{\text{Weight of dried supernatant (g)}}{\text{Weight of sample (g)} - \text{Weight of pellet (g)}} \times 100$$

### 2.8 Texture profile analysis

An instrumental examination of texture was conducted using a texture analyser (TA-XT plus, Stable Micro Systems Co. Ltd., United Kingdom) based on a method described by Caldas-Cueva *et al.* (2021) with certain modifications. Cooked sausage samples were cut into cylindrical slices (20 mm thickness) and were subjected to a two-cycle compression using a 25 kg load cell. The samples were compressed to 50% of their original height. The test condition was set at a pre-test speed of 2.0 mm/s, test speed of 2.0 mm/s, and post-test speed of 5.0 mm/s. The determined parameters, namely hardness (g), springiness (mm), chewiness (N × mm), adhesiveness (g), and cohesiveness (dimensionless), were recorded using Texture Exponent 32 v. 5.1.2.0 software (Stable Micro Systems Co. Ltd., UK).

### 2.9 pH and instrumental colour

About 10 g of sausage sample was homogenized with 100 mL of deionized water (Mantihal *et al.*, 2021). The pH of the resulting homogenate was measured at 25°C using a pH meter (PH2700, Eutech Instruments Pte Ltd., UK).

Colour measurement was conducted on the sliced cooked sausage using a colourimeter (CR-400, Konica Minolta Inc, Japan). The colourimeter was calibrated against a white tile immediately before readings were taken based on CIE L*, a*, and b* parameters (Mantihal *et al.*, 2021).

### 2.10 Lipid oxidation

The lipid oxidation of sausage samples was assessed by measuring the aldehydes formed at Day 0, 7, and 14 of storage, following the method of Das *et al.* (2023). Briefly, 5 g of sample was mixed with 20 mL of 7.5% trichloroacetic acid (TCA) solution and homogenized for 2 mins. Then, the supernatant was filtered using a Whatman number 1 filter paper, and the pellet was discarded. 2 mL of the obtained supernatant was transferred into a test tube, and 2 mL of thiobarbituric acid (TBA) solution (0.02 M) was then added. After that, the tube was heated in a water bath (SSB-45 Wisebath, Sci Lab Sdn. Bhd., Malaysia) at 95°C for 35 mins. After that, the absorbance of samples was measured at 532 nm using a spectrophotometer (Lambda 25, PerkinElmer Inc, USA). The TBARS value was calculated from the malonaldehyde (MDA) standard curve and expressed as mg malondialdehyde/kg sample using the following formula:

$$TBARS\ (mg/kg) = \frac{C \times V \times (V_1 + V_2)}{M \times V_1}$$

Where C represents the MDA concentration (µM/L), V is the volume of TCA (mL), $V_1$ is the volume of supernatant (mL), $V_2$ is the volume of TBA (mL), and M is the sample weight (g).

### 2.11 Sensory evaluation

The sensory evaluation was performed using the 7-point hedonic scale (1-extremely disliked, 7-extremely liked). The analysis was conducted by 50 randomly picked untrained panellists. The sausage samples were labelled with three-digit numbers and randomly given to the panellists. The panellists were also given a glass of water to cleanse their palate. Appearance, aroma, hardness, juiciness, taste, and overall acceptance were evaluated (Munsu *et al.*, 2021).

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*2.12 Statistical analysis*

All analyses were performed in triplicates. Data analysis was conducted using SPSS 25.0 software (IBM Corporation, USA) with one-way Analysis of Variance (ANOVA), accompanied by Tukey's HSD test for multiple comparisons at $p<0.05$.

## 3. Results and discussion

*3.1 Proximate composition*

Incorporating *K. alvarezii* significantly increased the moisture content of sausage samples ($p<0.05$, Table 2), which may be attributed to dietary fibre in seaweed. Ferjančič *et al.* (2021) reported that adding dietary fibre increased the moisture level of meat batter by 2 – 4%. A similar trend was observed in the present study as adding KAP increased the moisture content by 4 – 7% compared to the control sample. However, reducing the fat level to 3% in F2 and F4 samples resulted in significantly lower ($p<0.05$) moisture content compared to F1 (6% CF) and F3 (6% PS). Additionally, the control sample had the highest protein content (28.88%), with no significant difference with the treatments ($p>0.05$). In agreement with Wang *et al.* (2018), the same amount of chicken meat added to each formulation resulted in similar protein content of sausages. Furthermore, Kılıç and Özer (2017) reported that substituting animal fat with palm oil did not affect the protein level of Turkish sausage.

The control sample (0% KAP + 12% CF + 0% PS) showed the highest fat content (19.79%), while the lowest fat level was observed in F4 (2% KAP + 0% CF + 3% PS) at 11.96%. There was no significant difference ($p>0.05$) when a similar amount of fat was added in the formulation, as shown by F1 (6% CF) and F3 (6% PS) as well as F2 (3% CF) and F4 (3% PS). Wang *et al.* (2018) also reported that the addition of a similar amount of palm oil Pickering emulsion with pork back fat had no effect on the fat level of emulsified sausage. The treatments had significantly higher ($p<0.05$) ash content than the control sample, ranging from 3.81 – 3.90%. The results may be attributed to the high ash content of *K. alvarezii*, which reached 46.19% (Kanatt, 2023). Similar findings were obtained from research incorporating brown and red Irish seaweed in pork sausages (Mohammed *et al.*, 2022).

*3.2 Cooking loss, water holding capacity, and emulsion stability*

Treatments containing *K. alvarezii* powder showed significantly lower ($p<0.05$) cooking loss than the control sample (Table 3). Based on previous studies, the addition of *K. alvarezii* reduced the cooking loss of sausages due to the ability of dietary fibre in the seaweed to hold water and fat (Munsu *et al.*, 2021). Furthermore, the substitution of chicken fat with palm stearin significantly reduced ($p<0.05$) the cooking loss, but there was no significant difference ($p>0.05$) between F3 and F4 when varying amounts of PS were used. Plant oils provide stronger emulsion stability in meat products as the fat globules are equally distributed in the protein matrix, resulting in lower cooking loss (Kim *et al.*, 2021).

The water holding capacity is expressed as a percentage of extracted water, inversely proportional to the cooking loss. Generally, lower extracted water

Table 2. Proximate composition of sausages.

| Treatments | Moisture (%) | Protein (%) | Fat (%) | Ash (%) |
|---|---|---|---|---|
| Control | 56.78±0.34$^{c}$ | 28.88±0.35$^{a}$ | 19.79±0.38$^{a}$ | 2.56±0.11$^{b}$ |
| F1 | 65.43±0.28$^{a}$ | 28.34±0.49$^{a}$ | 17.90±0.02$^{b}$ | 3.90±0.27$^{a}$ |
| F2 | 63.12±0.56$^{b}$ | 28.67±0.32$^{a}$ | 12.34±0.09$^{c}$ | 3.88±0.21$^{a}$ |
| F3 | 64.88±0.94$^{a}$ | 28.43±0.24$^{a}$ | 17.62±0.08$^{b}$ | 3.81±0.04$^{a}$ |
| F4 | 63.79±0.85$^{b}$ | 28.82±0.18$^{a}$ | 11.96±0.74$^{c}$ | 3.86±0.14$^{a}$ |

Values are presented as mean±SD. Values with different superscripts in the same column are statistically significantly different ($p<0.05$).

Table 3. Cooking loss, water holding capacity, and emulsion stability of sausages.

| Treatments | Cooking loss (%) | Extracted water (%) | Emulsion stability | |
|---|---|---|---|---|
| | | | Total expressible fluid (%) | Expressible fat (%) |
| Control | 5.84±0.29$^{a}$ | 9.17±0.06$^{a}$ | 5.05±0.81$^{a}$ | 15.21±0.09$^{a}$ |
| F1 | 5.30±0.07$^{b}$ | 2.06±0.06$^{b}$ | 3.32±0.40$^{b}$ | 10.30±0.47$^{b}$ |
| F2 | 4.31±0.13$^{c}$ | 2.10±0.08$^{b}$ | 3.42±0.40$^{b}$ | 11.38±0.51$^{b}$ |
| F3 | 2.30±0.16$^{d}$ | 2.05±0.08$^{b}$ | 4.03±0.61$^{ab}$ | 10.50±0.39$^{b}$ |
| F4 | 2.45±0.32$^{d}$ | 2.08±0.07$^{b}$ | 4.51±0.33$^{ab}$ | 10.92±0.87$^{b}$ |

Values are presented as mean±SD. Values with different superscripts in the same column are statistically significantly different ($p<0.05$).

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indicates a higher water holding capacity of meat products, resulting in better moisture retention (Carballo *et al.*, 2021). The control sample had the highest percentage of extracted water (9.17%), while F3 showed the lowest extracted water at 2.05%. However, there was no significant difference in the extracted water among treatments ($p>0.05$). Similar results were obtained by Pindi, Siang, Munsu *et al.* (2023), indicating that *K. alvarezii* could retain water in emulsified meat products.

The TEF and EFAT of the sausages were lower than the control ($p<0.05$, Table 3). The improved emulsion stability can be attributed to high water and fat binding capacity due to the presence of cellulose in seaweed. Qi *et al.* (2020) mentioned that cellulose could improve the water-binding capacities of sausages through physical entanglement, aggregation, and supramolecular interactions.

### *3.3 Textural properties*

The treatments showed significantly higher hardness, chewiness, and adhesiveness with lower cohesiveness than the control sample ($p<0.05$, Table 4). However, there was no significant difference in springiness among the samples ($p>0.05$). F3, formulated with 2% KAP and 6% PS) had the highest hardness value (46.79 N), followed by F1 (2% KAP + 6% CF) at 37.36 N. Wang *et al.* (2018) reported that sausage formulated with pre-emulsified palm oil showed higher hardness than pork fat, as palm oil caused the structure of the meat batter to become firmer.

The springiness values of sausages ranged from 0.89 mm to 0.94 mm. The findings coincide with those of Pindi, Siang, Munsu *et al.* (2023), who observed that adding *K. alvarezii* gel did not affect the springiness of chicken patties. In addition, F1, F3, and F4 showed similar chewiness values ($p>0.05$). According to Mohd Zaini *et al.* (2021), hardness primarily affects chewiness; the harder the food sample, the more energy is required to chew it.

As shown in Table 4, adding *K. alvarezii* significantly increased the adhesiveness of samples ($p>0.05$). Mohammed *et al.* (2022) mentioned that brown and red seaweed species contain dietary fibres such as galactans, agar, carrageenan, alginate, fucans, and laminarans, which provide gelling and thickening properties. In contrast, samples containing KAP and PS showed significantly lower cohesiveness values ($p<0.05$). Ferjančič *et al.* (2021) reported that lower cohesiveness values may be caused by the use of dietary fibre instead of fat, as a hydrocolloid to stabilize meat emulsion.

### *3.4 pH and instrumental colour*

Adding KAP resulted in a higher pH of sausages and substituting CF with PS further increased the pH ($p<0.05$, Table 5). The results were supported by Asamoah (2019), who observed increased pH value with an increasing amount of palm stearin in rabbit sausage due to the higher pH of palm oil. However, the results contrast with Choi *et al.* (2012), who reported that the presence of fucoidan and alginic acid in seaweed reduced the pH values of chicken sausages.

The addition of PS into sausages significantly increased the lightness (L*) values while it decreased the redness (a*) values ($p<0.05$). F1 had the highest yellowness (9.30), followed by F2 at 8.94 (Table 5). Kim

Table 4. Texture profile analysis of sausages.

| Treatments | Hardness (N) | Springiness (mm) | Chewiness (mJ) | Adhesiveness (g) | Cohesiveness |
|---|---|---|---|---|---|
| Control | 17.47±1.57$^{e}$ | 0.94±0.04$^{a}$ | 12.33±1.27$^{c}$ | 0.94±0.02$^{b}$ | 0.76±0.03$^{a}$ |
| F1 | 37.36±2.47$^{b}$ | 0.92±0.02$^{a}$ | 23.80±1.72$^{a}$ | 1.35±0.30$^{a}$ | 0.72±0.07$^{a}$ |
| F2 | 33.06±1.94$^{d}$ | 0.90±0.20$^{a}$ | 21.87±1.50$^{b}$ | 1.34±0.33$^{a}$ | 0.74±0.10$^{a}$ |
| F3 | 46.79±2.83$^{a}$ | 0.89±0.22$^{a}$ | 23.85±1.84$^{a}$ | 1.34±0.63$^{a}$ | 0.59±0.21$^{b}$ |
| F4 | 34.23±1.64$^{c}$ | 0.89±0.10$^{a}$ | 23.90±1.70$^{a}$ | 1.35±0.59$^{a}$ | 0.50±0.02$^{c}$ |

Values are presented as mean±SD. Values with different superscripts in the same column are statistically significantly different ($p<0.05$).

Table 5. pH and instrumental colours of sausages.

| Treatments | pH | L* | a* | b* |
|---|---|---|---|---|
| Control | 6.19±0.51$^{d}$ | 56.49±1.36$^{d}$ | 0.17±0.09$^{a}$ | 7.17±0.91$^{bc}$ |
| F1 | 6.24±0.45$^{c}$ | 64.52±1.19$^{b}$ | -0.09±0.02$^{b}$ | 9.30±0.82$^{a}$ |
| F2 | 6.24±0.63$^{c}$ | 59.41±0.06$^{c}$ | -0.06±0.03$^{b}$ | 8.94±0.93$^{ab}$ |
| F3 | 6.68±0.73$^{a}$ | 68.83±1.66$^{a}$ | -0.60±0.10$^{c}$ | 5.96±0.89$^{c}$ |
| F4 | 6.60±0.61$^{b}$ | 68.14±1.85$^{a}$ | -0.66±0.14$^{c}$ | 6.30±0.96$^{c}$ |

Values are presented as mean±SD. Values with different superscripts in the same column are statistically significantly different ($p<0.05$).

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*et al.* (2020) stated that higher lightness was caused by the even distribution of oil in meat matrices. Moreover, smaller oil globules reflected more light due to the larger surface area, resulting in a higher L* value (Shao *et al.*, 2020).

The treatments showed significantly lower a* than the control sample ($p<0.05$). The findings agreed with Munsu *et al.* (2021), who reported that the green colour of *K. alvarezii* seaweed lowers the redness values of chicken sausage. Meanwhile, adding PS reduced the yellowness of sausages compared to when CF was used in the formulations. This was in accordance with Panpipat and Chaijan (2017), who reported decrease in b* values of tilapia sausage added with PS, which might be caused by the chemical degradation of β-carotene.

### *3.5 Lipid oxidation*

The control showed a significantly higher lipid oxidation rate during 14 days of storage ($p<0.05$, Table 6), as indicated by the larger amount of thiobarbituric acid reactive substances (TBARS). Munsu et al. (2021) mentioned that adding *K. alvarezii* to sausage reduced the TBARS values due to the high antioxidant content of seaweed. On Day 7, F3 (2% KAP + 6% PS) showed the lowest lipid oxidation, followed by F4 (2% KAP + 3% PS) at 1.52 and 1.55 mg malonaldehyde/kg, respectively. The lower lipid oxidation could be attributed to the presence of natural antioxidants such as carotenoids and tocopherols in PS, which slowed down the formation of TBARS (Panpipat and Chaijan, 2017).

Table 1. Chicken sausage formulations.

| Treatments | mg malonaldehyde (mg MDA/kg) | | |
|---|---|---|---|
| | Day 0 | Day 7 | Day 14 |
| Control | $0.55\pm0.10^{aC}$ | $2.12\pm0.21^{aB}$ | $3.63\pm0.68^{aA}$ |
| F1 | $0.48\pm0.15^{bC}$ | $1.76\pm0.14^{bB}$ | $2.84\pm0.40^{bA}$ |
| F2 | $0.46\pm0.21^{bC}$ | $1.65\pm0.30^{bcB}$ | $2.73\pm0.94^{bcA}$ |
| F3 | $0.45\pm0.12^{bC}$ | $1.52\pm0.17^{cB}$ | $2.61\pm0.79^{cA}$ |
| F4 | $0.45\pm0.30^{bC}$ | $1.55\pm0.41^{cB}$ | $2.69\pm0.70^{bcA}$ |

Values are presented as mean±SD. Values with different lowercase superscripts in the same column are statistically significantly different ($p<0.05$) while values with different uppercase superscripts in the same row are also statistically significantly different ($p<0.05$).

Generally, lipid oxidation of reduced-fat sausages increased throughout 14 days of storage ($p<0.05$). On Day 14, the control sample had the highest lipid oxidation (3.63 mg malonaldehyde/kg), followed by F1 (2.84 mg malonaldehyde/kg) and F2 (2.73 mg malonaldehyde/kg). According to Olagbegi *et al.* (2023), the minimum threshold required to detect adverse changes in the sensory qualities of meat products was 2.0 mg malonaldehye/kg. Hence, future studies should focus on the optimum concentration of KAP and PS that should be incorporated to slow down the lipid oxidation of sausages.

### *3.6 Sensory analysis*

There was no significant difference in colour scores between the control sample and treatments ($p>0.05$, Table 7). The colour of F2 was the most accepted by sensory panellists, followed by F4 at 5.08 and 5.04, respectively. According to Altmann *et al.* (2023), consumers preferred meat products with a bright colour. Hence, the sensory scores aligned with instrumental colour analysis (Table 5) as the treatments showed higher lightness values than the control sample.

Aroma and taste are hard to define objectively as these attributes determine flavour, which is a complex sensation. In terms of aroma, the control sample (5.34) showed significantly higher ($p<0.05$) scores than F3 (4.38) and F4 (4.08). The findings indicated that simply using water to substitute chicken fat was impracticable. Zhu *et al.* (2021) also observed sharp decrease in appearance, flavour, and texture by simply using water and vegetable oil to replace animal fat. Meanwhile, the taste scores showed no significant difference ($p>0.05$). Kılıç and Özer (2017) mentioned that fatty acid compositions of animal fat and palm oil were comparable. Hence, meat products formulated with palm oil had the same sensory attributes with those produced with animal fat.

F3 (2% KAP + 6% PS) received the highest texture and juiciness scores, but there was no significant difference among the samples ($p>0.05$). In contrast, F2 (2% KAP + 3% CF) and F4 (2% KAP + 3% PS) received the lowest scores for juiciness and texture,

Table 7. Sensory evaluation of sausages.

| Treatments | Colour | Aroma | Taste | Texture | Juiciness | Overall acceptance |
|---|---|---|---|---|---|---|
| Control | $4.52\pm1.50^{a}$ | $5.34\pm1.10^{a}$ | $5.20\pm1.65^{a}$ | $5.06\pm1.61^{a}$ | $4.30\pm1.57^{a}$ | $5.04\pm1.54^{a}$ |
| F1 | $5.02\pm1.42^{a}$ | $5.04\pm1.26^{ab}$ | $4.96\pm1.60^{a}$ | $4.78\pm1.47^{a}$ | $4.38\pm1.46^{a}$ | $5.10\pm1.40^{a}$ |
| F2 | $5.08\pm1.18^{a}$ | $5.00\pm1.09^{ab}$ | $4.72\pm1.64^{a}$ | $4.72\pm1.49^{a}$ | $4.32\pm1.54^{a}$ | $5.02\pm1.44^{a}$ |
| F3 | $4.84\pm1.33^{a}$ | $4.38\pm1.21^{bc}$ | $4.56\pm1.34^{a}$ | $5.12\pm1.53^{a}$ | $4.62\pm1.50^{a}$ | $5.18\pm1.38^{a}$ |
| F4 | $5.04\pm1.24^{a}$ | $4.08\pm1.70^{c}$ | $4.38\pm1.61^{a}$ | $4.66\pm1.62^{a}$ | $4.44\pm1.54^{a}$ | $4.86\pm1.40^{a}$ |

Values are presented as mean±SD. Values with different superscripts in the same column are statistically significantly different ($p<0.05$).

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respectively. The findings might be attributed to the low level of CF and PS used in the formulations, resulting in a less stable emulsion and lower juiciness of sausages. Additionally, F3 was the most preferred, followed by F1 and the control sample. F4 received the lowest overall acceptance score (4.86) due to the low aroma, taste, and texture scores. However, there was no significant difference in overall acceptance scores between the treatments and control, indicating that adding KAP powder at a reduced-fat level produced sausage that were acceptable to sensory panellists.

## 4. Conclusion

The addition of *K. alvarezii* powder while reducing the lipid content to 6% and 3% resulted in increased moisture and ash, with significantly lower fat content. The treatments also showed lower cooking loss due to better water holding capacity and emulsion stability. Additionally, the texture profile analysis showed that the hardness increased with increasing PS and CF percentages. However, the addition of PS reduced the springiness of sausages. The treatments also showed higher pH and lightness values than the control sample, but the addition of seaweed powder reduced the redness (a*) of the sausages. Samples containing PS showed lower lipid oxidation, which may be attributed to the natural antioxidants present in palm oil. Sausage formulated with 2% KAP and 6% PS was the most acceptable to sensory panellists due to its highly accepted texture and juiciness. Hence, PS may be used to formulate low-fat sausages that comply with food regulations and provide healthier options for consumers.

## Conflicts of interest

The authors declare no conflict of interest.

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