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# Palm-based oils as milk fat alternatives in Mozzarella cheese analogue

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**SUMMARY:** This research featured the noteworthy properties of a Mozzarella cheese analogue composed of palm oil (PO) and palm olein (POo) as milk fat alternatives. The objective of this study was to examine the properties of a palm-based Mozzarella cheese analogue (P-MCA) in comparison to a fat-free Mozzarella cheese analogue (FF-MCA) and a commercial Mozzarella cheese sample (C-MC) containing 68% palm-based Mozzarella cheese analogue. Mozzarella cheese samples were analyzed for compositional properties, color, functional properties (stretchability and meltability) and sensory evaluation. The stretchability and meltability of both P-MCA and FF-MCA were desirably and significantly ($p < 0.05$) higher than the C-MC. Moreover, the P-MCA had the significantly highest ($p < 0.05$) acceptance score for all sensory attributes in both raw form and as a pizza topping. In conclusion, the P-MCA showed superior performance in terms of functionality and sensory acceptance.

***KEYWORDS***: *Meltability; Palm oil; Sensory; Stretchability.*

**RESUMEN:** ***Aceites de palma como alternativa a la grasa láctea en sucedáneos de queso mozzarella***. Esta investigación destacó las propiedades notables de un sucedaneo de queso Mozzarella compuesto de aceite de palma (PO) y oleína de palma (POo) como alternativas a la grasa láctea. El objetivo fue estudiar las propiedades del sucedáneo de queso Mozzarella a base de palma (P-MCA) en comparación con un sucedaneo de queso Mozzarella sin grasa (FF-MCA) y una muestra comercial de sucedáneo de queso Mozzarella (C-MC) que contiene un 68% a base de palma. Se analizaron muestras de queso Mozzarella, sus propiedades composicionales, color, propiedades funcionales (elasticidad y capacidad de fundido) y evaluación sensorial. La plasticidad y capacidad de fundido tanto del P-MCA como del FF-MCA fueron deseables y significativamente ($p<0.05$) más altas que las del C-MC. Además, el P-MCA obtuvo la puntuación de aceptación significativamente más alta ($p<0.05$) para todos los atributos sensoriales tanto en su forma cruda como en cobertura de pizza. En conclusión, el P-MCA mostró un rendimiento superior en términos de funcionalidad y aceptación sensorial.

***PALABRAS CLAVE***: *Aceite de palma; Elasticidad; Fusibilidad; Sensorial.*

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## 1. INTRODUCTION

Cheese analogues are produced by combining water, oils/fats, proteins, emulsifying salts, hydrocolloids, acidifying agents, preservatives and food additives (cheese flavoring and salt) into a uniform cheese-like matrix (Masotti *et al*., 2018). Due to the tremendous increase in pizza pie consumption and the fact that cheese is one of the most expensive pizza pie ingredients, cheese manufacturers have been focusing on developing cheese substitutes (Bachmann, 2001). Furthermore, the substitution of milk fat with vegetable oils is gaining popularity in the production of cheese-like products because it can improve the fatty acid profile of the final cheese, thereby contributing to a healthier ratio of saturated to unsaturated fats (Achachlouei *et al*., 2013).

The vegetable oils of interest in this study for milk fat substitutes in cheese analogues are palm-based oils, specifically, a blend of palm oil (PO) and palm olein (POo). The equal proportion of unsaturated (primarily oleic, C18:1) and saturated (primarily palmitic, C16:0) fatty acid profiles of PO contribute to their stability and resistance to oxidation which can extend the shelf life of food products (Sulaiman *et al*., 2022). Both PO and POo are mostly utilized as cooking oils. Palm oil contains an extensive level of natural carotenes, including β-carotene. Additionally, these palm-based oils naturally exhibit the highest concentration of γ-tocotrienol, a compound renowned for its exceptional antioxidant capacity, in comparison to other vegetable oils (Ganesan *et al*., 2018). Therefore, palm-based oils are high in demand in the food industry and are widely incorporated into food products for both their functional and nutritional values (Absalome *et al*., 2020). Palm-based oil could be one of the best candidates for replacing milk fat in cheese analogue making due to its functional and nutritional properties.

Over the years, significant attempts have been made to develop imitation cheeses with desired properties demanded by consumers. Moreover, the cheese analogues made using a cheaper vegetable oil such as palm oil are reasonably priced as the cost of the raw materials is reduced (Masotti *et al*., 2018). Most of the cheese analogues in the market are blended with natural cheese that consists of milk fat to improve their stretchability, meltability, texture properties, flavor properties and sensory acceptance among consumers. The present study used the Mozzarella cheese analogue as a model based on its functional properties. Different from the commercial samples, this study aimed to develop a Mozzarella cheese analogue based on a blend of PO and POo at a 50:50 (w/w) ratio without the incorporation of natural cheese at all. This developed palm-based Mozzarella cheese analogue (P-MCA) was further compared to a fat-free Mozzarella cheese analogue (FF-MCA) and a commercial Mozzarella cheese sample (C-MC) composed of 68% palm-based Mozzarella cheese analogue and 30% natural Mozzarella cheese. The comparison was made regarding compositions, physicochemical properties, functional properties and consumer acceptance of the sensory properties.

## 2. MATERIALS AND METHODS

### 2.1. Materials

Both PO and POo were purchased from Mewah Oil Sdn. Bhd. (Selangor, Malaysia). Rennet casein and skim milk powder were obtained from Promac Enterprises Sdn. Bhd. (Kuala Lumpur, Malaysia). Trisodium citrate, nisin, potassium sorbate and citric acid were purchased from Dchemie Chemical Supplies (Johor, Malaysia). Salt was purchased from the local supermarket. The cheese flavor was obtained from Matrix Sdn. Bhd. (Selangor, Malaysia). The FF-MCA was developed as a control sample, while the C-MC was purchased from the local supermarket.

### 2.2. Methods

#### *2.2.1. Preparation of samples*

The P-MCA was prepared in which the fat portion was totally composed of vegetable oil, i.e., a blend of PO and POo at a 50:50 (% w/w) ratio. The PO and POo were weighed and melted in the oven at 60 °C before being blended prior to use. The process of making the P-MCA and FF-MCA was conducted according to the method reported by Shah *et al*. (2010) with some modifications by using a cheese cooker (Universal Machine UMC5, Stephen, Germany), with each treatment yielding 1 kg Mozzarella cheese. The cheese sample was prepared by adding water, rennet casein, skim milk powder, trisodium citrate, nisin and potassium sorbate to the cheese cooker. The mixture was heated to 80 °C with intermittent scrapping for 4 minutes. The pH of the mixture was adjusted to 5.8 using citric acid. Then, the fat blend was added and the mixture was heated again to 80 °C for 4 minutes. The cheese samples were transferred to the containers and kept at 4 °C until analysis. Sample FF-MCA was prepared using the same method without the inclusion of fat.

#### *2.2.2. Compositional properties*

The cheese samples were evaluated for fat (AOAC 989.05), protein (AOAC 981.10), moisture (AOAC 950.46), ash (AOAC 923.03) (AOAC, 2016) and carbohydrate content (calculated by difference) (Pomeranz and Meloan, 2000). The pH value was measured by using a pH meter (Testo 206-pH2, United States).

#### *2.2.3. Color*

The readings were measured by using an illuminant set to D65 and color space L*, a*, b*. The chroma *C** and hue angle *h** were determined according to Tao *et al*. (2012).

#### *2.2.4. Functional properties*

The stretchability of the cheese samples was analyzed according to Zedan *et al*. (2014). A 250-ml beaker was filled to 75% of its capacity with hot water at a temperature of 85 °C. Cheese samples (10 g) were placed into the beaker and left submerged for a duration of one minute. A glass rod was inserted into the centre of the molten cheese and used to lift the cheese. The length of the thread created was measured in centimetres. Greater thread length correlated with superior stretching properties. The meltability of the cheese samples was accessed according to Altan *et al*. (2005) with some modifications. The cheese disk (diameter = 40 mm; height = 2 mm) was heated on the Petri dish at 232 °C for 5 minutes. Then, the melted cheese was removed from the oven and allowed to cool at ambient temperature for a period of 30 minutes. The areas of the initial and final areas were measured using ImageJ 1.53t (National Institutes of Health, Bethesda, Maryland, USA). The meltability (%) was calculated as:

Meltability (%) = (Final area – Initial area)/Initial area × 100%

The experiments were carried out in triplicate, with the data presented as means ± standard deviation.

#### *2.2.5. Sensory evaluation*

A sensory evaluation was carried out according to Rahman *et al*. (2023) with some modifications. The evaluation was done in two sessions by 60 untrained panellists (aged between 23 and 55) at the Food Technology Laboratory, Malaysian Palm Oil Board. For the first session, each panellist evaluated grated raw cheese samples for their acceptance in terms of appearance, aroma, taste, texture and overall acceptability. In the second session, pizza slices were prepared with cheese samples as topping because cheese is not a common ingredient in Malaysian cuisine. These samples were further evaluated for acceptance in terms of appearance, color, aroma, taste, texture and overall acceptability. The panellists of both sessions rated on a 7-point hedonic rating scale to indicate the degree of liking (1=dislike very much, 7=like very much).

#### *2.2.6. Statistical analysis*

All data were analyzed by one-way analysis of variance (ANOVA) and Tukey's multiple comparison test with the significance level set at $p < 0.05$. All statistical analyses were performed using the Minitab Statistical Software, Version 20.

## 3. RESULTS AND DISCUSSION

### 3.1. Compositional properties

The composition of the cheese samples is shown in Table 1. In terms of fat content, the C-MC contained a significantly higher fat content ($p < 0.05$) at a value of 23.53 ± 0.12 g/100 g than P-MCA at 21.26 ± 0.39 g/100 g; while the FF-MCA contained the lowest fat content at 0.20 ± 0.01 g/100 g ($p < 0.05$) due to its fat-free formulation. The carbohydrate content was similar in trend with the fat content. Due to its fat-free nature, the FF-MCA also exhibited the significantly highest ($p < 0.05$) moisture content (67.14 ± 0.09 g/100 g), followed by C-MC (46.33 ± 0.17 g/100 g) and P-MCA (43.45 ± 0.14 g/100 g). For both protein and ash contents, the P-MCA, at 18.19 ± 0.01 g/100 g and 6.01 ± 0.01 g/100 g, respectively and FF-MCA, at 17.74 ± 0.37 and 5.75 ± 0.13 g/100 g, respectively, were insignificantly different ($p > 0.05$) from each other, which can be justified by their similar formulations except for the fat and moisture contents; while the C-MC had significantly lower ($p < 0.05$) values at 3.64 ± 0.18 g/100 g and 5.75 ± 0.13 g/100 g, respectively. These findings highlighted differences especially between the formulated Mozzarella cheese analogue samples and the commercial one due to the different main ingredient used, which was the fat portion. In this research, the fat content of P-MCA was similar to the Mozzarella cheese analogue reported by Jana *et al*. (2015), which was 21.79 g/100 g. In addition, the fat content in the Mozzarella cheese analogue reported by Dhanraj *et al*. (2017) was in the range of 21.97-22.13 g/100 g. However, the fat contents in FF-MCA and C-MC were lower and higher, respectively, than those reported by Dhanraj *et al*. (2017) and Jana *et* *al*. (2015). As for the protein content, Dharaiya *et al*. (2021) obtained higher results at 23.29 g/100 g than all the cheese samples in this study. The moisture contents in P-MCA and C-MC were lower than the 49.54-49.87 g/100 g reported by Ali *et al*. (2022). The ash content in P-MCA was higher than those reported by Ali *et al*. (2022), Dhanraj *et al*. (2017) and Jana *et al*. (2015), which were 3.95-4.03 g/100 g, 4.90-5.32 g/100 g and 5.54-5.89 g/100 g, respectively. The formulation of the Mozzarella cheese analogue can be tailor-made to meet the demands of consumers. The Mozzarella cheese analogue can also be altered according to the specifications of the food restaurants (Dhanraj *et al*., 2017).

Despite exhibiting different compositions, the pH values for the cheese samples were insignificantly different ($p > 0.05$), ranging from 5.80-5.89 (Table 1). This finding indicated that the different fat portions used in the cheese samples had no pronounced effect on the pH values of the cheese samples.

### 3.2. Color

Mozzarella cheese is a premium dairy product and color is an important factor in determining its quality (Minz and Saini, 2021). The color of the cheese samples showed variations ($p < 0.05$) in L* (lightness), a* (redness) and b* (yellowness), *C** (chroma) and *h** (hue angle) values (Table 1). P-MCA was the lightest in comparison to the other samples. The chroma *C** is mostly influenced by the b* value, representing yellowness (Półtorak *et al*., 2014). It was observed that FF-MCA exhibited significantly lower *C** and b* values ($p < 0.05$) than the other samples. C-MC had the highest b* and *C** values. This is because the C-MC contained 30% traditional cheese, which has milk pigments that contribute to the yellow color of the cheese. A higher *h** value was most likely related to the lower greenness value (-a*) (Półtorak *et al*., 2014). It was noted that FF-MCA showed significantly lower ($p < 0.05$) *h** and b* than the cheese samples containing fat. Minz and Saini (2021) stated that Mozzarella cheese is distinguished by its shiny, pale, off-white color. According to Jana and Mandal (2011), the white color of Mozzarella cheese is crucial in determining its quality characteristics. In this study, the L* value of P-MCA was higher than 78.12 to 80.75, as reported by Minz and Saini (2021). Nevertheless, the L* value of P-MCA

**Table 1**. The composition, pH and functional properties of cheese samples.

| Parameters | Cheese samples | | |
|---|---|---|---|
| | FF-MCA | P-MCA | C-MC |
| **Compositions** | | | |
| Fat (g/100 g) | 0.20 ± 0.01$^{c}$ | 21.26 ± 0.39$^{b}$ | 23.53 ± 0.12$^{a}$ |
| Protein (g/100 g) | 17.74 ± 0.37$^{a}$ | 18.19 ± 0.01$^{a}$ | 5.75 ± 0.13$^{b}$ |
| Moisture (g/100 g) | 67.14 ± 0.09$^{a}$ | 43.45 ± 0.14$^{c}$ | 46.33 ± 0.17$^{b}$ |
| Ash (g/100 g) | 5.98 ± 0.04$^{a}$ | 6.01 ± 0.01$^{a}$ | 3.64 ± 0.18$^{b}$ |
| Carbohydrate (g/100 g) | 8.94 ± 0.21$^{c}$ | 11.13 ± 0.30$^{b}$ | 20.76 ± 0.09$^{a}$ |
| pH | 5.80 ± 0.06$^{a}$ | 5.88 ± 0.05$^{a}$ | 5.89 ± 0.03$^{a}$ |
| Color | | | |
| L* | 79.39 ± 1.44$^{b}$ | 89.21 ± 0.68$^{a}$ | 79.49 ± 1.62$^{b}$ |
| a* | -6.91 ± 0.25$^{a}$ | -7.41 ± 0.29$^{b}$ | -8.05 ± 0.45$^{b}$ |
| b* | 13.25 ± 0.69$^{c}$ | 16.02 ± 0.43$^{b}$ | 25.39 ± 0.59$^{a}$ |
| *C** | 15.09 ± 0.32$^{c}$ | 18.06 ± 0.14$^{b}$ | 26.52 ± 0.32$^{a}$ |
| *h** | 60.79 ± 0.72$^{b}$ | 64.85 ± 0.06$^{ab}$ | 76.89 ± 8.33$^{a}$ |
| **Functional properties** | | | |
| Stretchability (cm) | 14.33 ± 1.15$^{b}$ | 30.00 ± 10.44$^{a}$ | 5.67 ± 1.16$^{b}$ |
| Meltability (%) | 165.8 ± 17.5$^{a}$ | 156.29 ± 10.81$^{a}$ | 47.07 ± 12.64$^{b}$ |

Values are mean ± SD (n=3). Parameters with different superscript letters in a row are significantly different according to Tukey's test ($p < 0.05$). FF-MCA, fat-free Mozzarella cheese analogue; P-MCA, palm-based Mozzarella cheese analogue; C-MC, commercial Mozzarella cheese sample.

was similar to those reported by Silvana *et al*. (2013) which ranged from 86.77 to 89.53.

### 3.3. Functional properties

The stretchability of P-MCA was significantly higher ($p < 0.05$) than the other cheese samples (Table 1). The C-MC showed the lowest stretchability. Stretchability refers to the capacity of cheese to produce fibrous strings that exhibit stretching without rupture (Jana and Tagalpallewar, 2017). Fat contributes to this functionality (stretchability) through a lubricating effect when melted in Mozzarella cheese. Fat also affects the protein matrix in cheese; without it, the protein structure becomes more rigid, resulting in a diminished ability to be extended (Zisu and Shah, 2005). Although C-MC contained higher fat content than P-MCA, the stretchability of the sample was the lowest. The functional properties of Mozzarella cheese such as stretchability can be influenced by the ingredients and processing methods (Gonçalves and Cardarelli, 2021). It can be seen that the protein content of P-MCA is much higher than that of C-MC. Typically, rennet casein is used in the cheese analogue as the protein source. Jana *et al*. (2015) explained that the hydration of the rennet casein occurs with the addition of emulsifying salts such as trisodium citrate during the production of the Mozzarella cheese analogue. This increases the water binding capacity of the protein due to the casein peptization. The hydration of the protein can also be influenced by the shear parameters employed. High shear conditions result in a more rapid and significant breakdown of the rennet casein particles, creating more chances for interactions between the protein and the solvent. The hydration level of rennet casein protein significantly affects the rheological properties of the final product, which influences the functionality of the cheese such as meltability and stretchability. Jana *et al*. (2015) reported that the Mozzarella cheese analogue containing higher levels of rennet casein had higher stretchability than those containing less. Moreover, the highest carbohydrate content in C-MC suggested that a high amount of starch was added to the formulation. Starch is added to a cheese analogue to reduce the cost and because of its availability and benefits (Considine *et al*., 2011). Starch is often added to the cheese analogue as a filler to achieve a similar consistency to real cheese. However, a high amount of starch produces cheese analogue with poor functional properties (Masotti *et al*., 2018).

The meltability of P-MCA was similar ($p > 0.05$) to FF-MCA and both samples were significantly higher ($p < 0.05$) than C-MC. The melting quality of cheese is affected by the network formed during manufacturing, the structural integrity of casein, calcium equilibrium and the distribution of water and casein network fillers in the matrix (Guo *et al*., 2023). Moreover, the decrease in the meltability of cheese may be attributed to the presence of a bicontinuous phase structure, consisting of both protein and starch phases, in samples with a high starch concentration (Sołowiej *et al*., 2016). This is due to the water being trapped by inflated starch granules, which can lead to the dehydration of the protein matrix (Sołowiej *et al*., 2016). The C-MC contains unknown concentrations of modified starch and low protein content which may have contributed to the low meltability of the cheese.

### 3.4. Sensory acceptance

The sensory evaluation scores from both sessions are shown in Table 2. The highest score in the overall acceptability showed that P-MCA is well preferred by the panellists. C-MC had the lowest aroma, texture and overall acceptability scores. Figure 1 shows the cheese samples received by the panellists in the first session of sensory evaluation. The appearance score of FF-MCA was the lowest compared to the other samples. This might be due to the FF-MCA being too soft and clumping together after being shredded. These results are consistent with those of Deshwal *et al*. (2020) and Chatli *et al*. (2019), who reported that the fat-free cheese received the lowest appearance score compared to those with added fat. Drake *et al*. (2008) claimed that lower-fat cheese had a sticky and nonappealing appearance compared to those full-fat cheeses. The aromas of P-MCA and FF-MCA were relatively higher than that of the C-MC. This could be attributed to the masking of rennet casein by the flavor used in the cheese; whereas the C-MC had a very strong pungent smell. Although the FF-MCA had the lowest appearance score due to the sample's clumping, the sample was soft and moist. P-MCA pizza received the highest scores for appearance, color, aroma, taste, texture and overall

**Table 2**. Sensory scores of raw cheese and pizza using the 7-hedonic score.

| Attributes | Samples | | |
|---|---|---|---|
| | FF-MCA | P-MCA | C-MC |
| **First session: Raw cheese samples** | | | |
| Appearance | 4.47 ± 1.50[b] | 5.53 ± 1.25[a] | 5.55 ± 1.01[a] |
| Aroma | 4.92 ± 1.52[b] | 5.62 ± 1.37[a] | 3.08 ± 1.61[c] |
| Taste | 4.80 ± 1.52[a] | 5.23 ± 1.41[a] | 3.55 ± 1.57[b] |
| Texture | 4.80 ± 1.60[b] | 5.62 ± 1.28[a] | 3.58 ± 1.67[c] |
| Overall acceptability | 4.92 ± 1.54[b] | 5.70 ± 1.24[a] | 3.53 ± 1.65[c] |
| **Second session: Cheese samples as pizza topping** | | | |
| Appearance | 4.98 ± 1.28[b] | 5.97 ± 1.15[a] | 4.22 ± 1.81[c] |
| Color | 4.60 ± 1.37[b] | 5.53 ± 1.28[a] | 4.77 ± 1.75[b] |
| Aroma | 5.27 ± 1.36[b] | 5.92 ± 0.91[a] | 3.71 ± 1.49[c] |
| Taste | 4.92 ± 1.44[b] | 5.93 ± 1.09[a] | 3.78 ± 1.72[c] |
| Texture | 4.56 ± 1.68[b] | 5.87 ± 1.11[a] | 3.78 ± 1.59[c] |
| Overall acceptability | 4.95 ± 1.42[b] | 6.08 ± 1.01[a] | 3.68 ± 1.72[c] |

Values are mean ± SD (n=3). Parameters with different superscript letters in a row are significantly different according to Tukey's test ($p < 0.05$). FF-MCA, fat-free Mozzarella cheese analogue; P-MCA, palm-based Mozzarella cheese analogue; C-MC, commercial Mozzarella cheese sample.

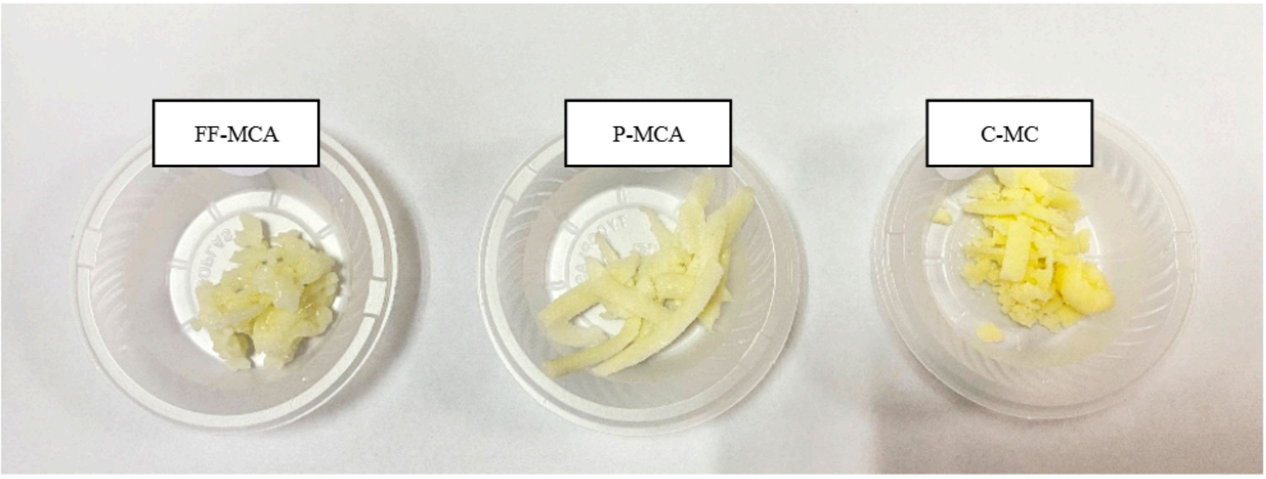


**Figure 1**. Raw cheese samples for the first session of sensory evaluation.

acceptability, whereas the C-MC received the lowest scores in appearance, aroma, taste, texture and overall acceptability. It can be seen that the panellists preferred the lightest color of P-MCA, which had the highest value of L*. Figure 2 shows the pizza samples received by the panellists. P-MCA melted evenly on the pizza compared to the other samples. The C-MC was not completely melted and had a dry surface. These could be the factors that contributed to the lowest scores in almost all attributes for the commercial sample.

## 4. CONCLUSION

Based on these findings, it is concluded that the P-MCA had superior functional and sensorial properties without the need to incorporate natural cheese in order to enhance these properties. Thus, the production of Mozzarella cheese analogue using a palm oil fraction could reduce the cost of the materials and production. A palm-based Mozzarella analogue could be a healthier choice of cheese as it contains vitamin E and β-carotene which are naturally available in palm oil.

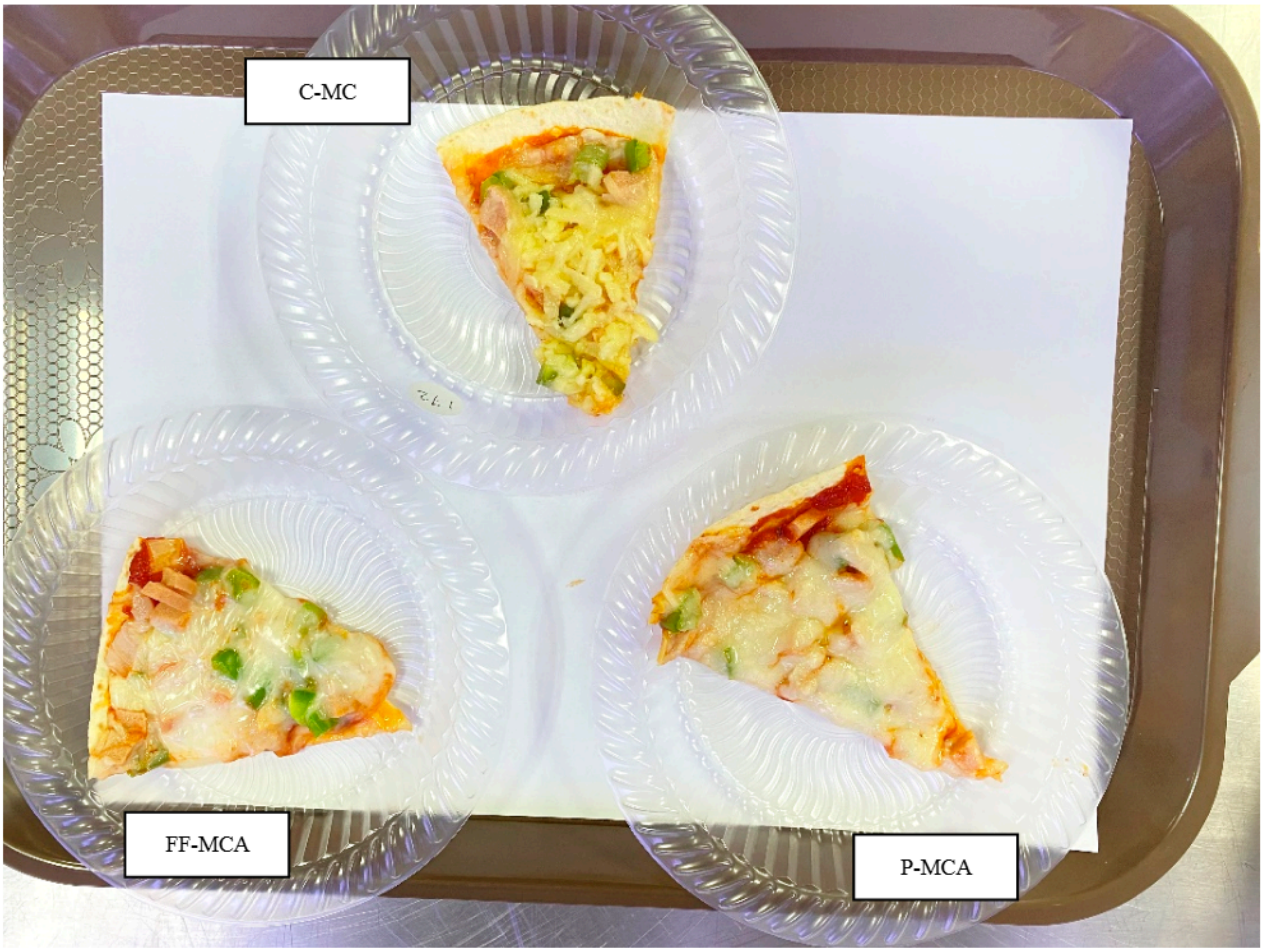


**Figure 2**. Pizza samples for the second session of sensory evaluation.

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## DECLARATION OF COMPETING INTEREST

The authors of this article declare that they have no financial, professional or personal conflicts of interest which could have inappropriately influenced this work.

## AUTHORSHIP CONTRIBUTION STATEMENT

N.H. Ismail: Conceptualization, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Writing – original draft. M. Mat Yusuff: Writing – review & editing. N. A. Mohd Hassim: Writing – review & editing. M. H. Saw: Writing – review & editing. H. Wazir: Writing – review & editing. T.K Tang: Writing – review & editing. S. Kanagaratnam: Funding acquisition, Writing – review & editing.

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