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Effect of Agar and Konjac on Physicochemical Properties and Stability of *Coffea liberica*–Infused Marshmallows

Aisya Hazlee[1], Eng Keng Seow[1,2,3,4*]

[1]*Food Science and Technology Program, School of Industrial Technology, Faculty of Applied Sciences, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia.*
[2]*Food Science Research Group, Faculty of Applied Sciences, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia.*
[3]*Integrative Pharmacogenomics Institute (iPROMISE), Universiti Teknologi MARA, Selangor Branch, 42300 Bandar Puncak Alam, Selangor, Malaysia.*
[4]*Integrated Nutrition Science and Therapy Research Group (INSPiRE), Faculty of Health Sciences, Universiti Teknologi MARA, Selangor Branch, 42300 Bandar Puncak Alam, Selangor, Malaysia*

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ABSTRACT

This study investigated the physicochemical effects of incorporating agar and konjac powders into *Coffea liberica*–infused marshmallows as alternatives to gelatin. The usage of the plant-based gelling agents also addresses dietary preferences such as halal and vegan requirements. Various analyses, including total phenolic content (TPC), texture profile, color, moisture content, water activity, and scanning electron microscopy (SEM), were conducted during storage for 6 days. Results showed that marshmallows containing *Coffea liberica* had significantly higher TPC ($p<0.05$). In particular, the marshmallow containing 1.02% agar with Liberica coffee brew (MAC) exhibited consistent physicochemical properties, while the marshmallow containing 0.51% agar and 0.51% konjac with Liberica coffee brew (MKAC), exhibiting the highest value (0.8740 mg GAE/g) as compared to the control containing gelatin (0.2294 mg GAE/g). Texture profile parameters—including hardness, gumminess, chewiness, and resilience—increased consistently across all formulations over 6 days of storage. Color analysis showed a strong positive correlation ($r = 0.977$) between hydrocolloid b* values and marshmallow lightness (L*), indicating that greater yellowness was associated with lighter-colored marshmallows. It indicates that the yellowness of the hydrocolloid has a direct impact on marshmallow lightness, which is crucial for controlling product appearance. Significant differences ($p<0.05$) were observed in moisture content, whereas water activity showed no significant variation ($p>0.05$) throughout storage. This may be due to the changes in total water content that did not affect the amount of free water responsible for water activity. SEM analysis differentiated the hydrocolloid-based samples through variations in surface roughness, smoothness, and pore distribution. Overall, agar and konjac powders, together with *Coffea liberica*, significantly influenced the physicochemical properties of the marshmallows, demonstrating their potential as plant-based alternatives for use in the confectionery industry.

[1*] Corresponding author. *E-mail address*: ekseow@uitm.edu.my
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INTRODUCTION

The green coffee beans used for coffee production are seeds from trees and shrubs that thrive in tropical regions, including Africa and Asia. Among the coffee species, *Coffea Liberica* is notable for its large beans and unique jackfruit-like aroma. Introduced to Indonesia, replacing the more pest-prone Arabica, Liberica is valued for its distinct flavor and potential health benefits due to its antioxidant properties (Insanu *et al*., 2021). However, Malaysia has struggled to establish Liberica coffee in the export market, often needing to import it due to insufficient local production and market mismatches (Mojica *et al*., 2017; Lee *et al*., 2023). The chemical properties of Liberica include high levels of phenolic compounds and antioxidants, contributing to its health benefits (Seow et al., 2021).

Marshmallows, a popular confectionery, are made from gelatin, sugar, and corn syrup, creating a soft, spongy confection (Bender & Gowen, 2023). However, the usage of gelatin restricts the consumption of marshmallows within halal and vegan consumers due to its animal-derived source.

Agar and konjac are two potential substitutes for gelatin. Agar, originating in Japan in 1658, is a gelling agent derived from seaweed. It is composed of two polysaccharides: agarose, which forms gels, and agaropectin. Agarose, with high molecular weight, and agaropectin, with a lower molecular weight, give agar its gel-forming properties (Pandya *et al*., 2022). Agar is commonly used as a thickening and gelling agent. It can also be added to dietetic foods and improves satiety as well (Marcus *et al*., 2013; Menon, 2011). In addition, konjac is a starchy corm that produces glucomannan, a soluble dietary fiber. It has significant health benefits, including improvements in bowel movements and reductions in cholesterol and blood sugar levels due to its fiber content (Rosenzweig, 2023; McDermott, 2022).

Although agar and konjac are widely recognized as plant-based gelling agents, research on their application in *Coffea liberica*–infused marshmallows remain limited. Therefore, this study examines the physicochemical properties of *Coffea liberica*–infused marshmallows formulated with agar and konjac as halal- and vegan-friendly alternatives to gelatin.

EXPERIMENTAL

Materials

Cornstarch, konjac powder, gelatin powder, sugar, and aquafaba were purchased from the convenience store in Shah Alam, Malaysia. The Liberica coffee powder was purchased online.

Sample preparation

Firstly, 5 g of gelatin was soaked in cold water. Next, while the gelatin was set to bloom 200 g of sugar with 200 g of water was heated in the pan to make sugar syrup. The mixture was boiled until 115°C. While waiting for the sugar to boil, which took 30 minutes, 1 g of cream of tartar was added into the aquafaba in the stand-in mixture and whipped until a firm peak was formed. When the sugar syrup is almost done, the gelatin is transferred into the stand mixture and mixed at low speed before adding the sugar syrup. The mixing took about 7 to 8 minutes with gradual increase in speed. Finally, the whipped mixture was transferred into the corn starch covered mould. This would be the control formulation.

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For the remaining formulations, the same preparation steps were followed, using varying concentrations of gelatin, agar, and konjac powder (Boerner, 2021). The MGC formulation contained 1.02% gelatin (5 g), MAC contained 1.02% agar, and MKC contained 1.02% konjac. The MKAC formulation included both agar and konjac at 0.51% each. Additionally, 30 g of Coffea liberica was added during the final mixing step before the mixture was transferred into the mold. All marshmallows were stored in airtight containers at 7 °C for this study.

Table 1. Formulations of marshmallows (%)

Ingredients	MG	MGC	MAC	MKC	MKAC
Aquafaba	10.29	10.29	10.29	10.29	10.29
Cream tartar	0.21	0.21	0.21	0.21	0.21
Gelatin	1.02	1.02	-	-	-
Agar	-	-	1.02	-	0.51
Konjac	-	-	-	1.02	0.51
Water	47.33	41.52	41.52	41.52	41.52
Sugar	41.52	41.52	41.52	41.52	41.52
Coffee	-	6.17	6.17	6.17	6.17
Total	100	100	100	100	100

MG: Contain 1.02% gelatin
MGC: Contain 1.02% gelatin with Liberica coffee brew
MAC: Contain 1.02% agar with Liberica coffee brew
MKC: Contain 1.02% konjac with Liberica coffee brew
MKAC: Contain 0.51% agar and 0.51% konjac with Liberica coffee brew

Total phenolic content

The total phenolic content (TPC) was determined using the Folin- Ciocalteu method as described by Bouakline *et al*. (2024), with a slight modification. Gallic acid (GA) served as the standard, and TPC was expressed as mg/g gallic acid equivalents (GAE) based on a calibration curve. To prepare the stock solution, firstly a mixture 0.5 g gallic acid and 10 mL ethanol was dissolved in 100 mL of distilled water. Then, 1,2,5 and 10 mL from this solution was taken to make (50, 100, 200 and 500 mg/mL). Next, in 12 test tubes, 3.2 mL of distilled water was added followed by 0.2 mL Folin-Ciocalteu reagent as well as 0.6 mL of sodium carbonate. Lastly, 40 µL of the different gallic acid stock solution was added in the prepared test tubes where each concentration was triplicated. The mixture was then thoroughly shaken and left to react at room temperature for two hours. A UV- Vis spectrometer was used to measure the absorbance at 725 nm. For sample stock solution, gallic acid was replaced with 0.5 g of marshmallow sample and then was analyzed in triplicate following this procedure. TPC was measured only on day zero to determine the initial properties of the marshmallows.

Texture profile analysis

This analysis was done by using a well-calibrated TA.XT Plus texture analyser with the cylinder probe, P/75. The probe was then calibrated. A cylindrical probe was utilized for the measurements, and parallel subsamples measuring 3.0 × 3.0 × 3.0 cm were placed on a flat metal plate. Then, 30% strain was chosen and conducted twice in a row, with 15-second intervals. Hardness, gumminess, chewiness, cohesiveness, adhesiveness and resilience parameters were calculated using the resulting force-time curve (Roobab *et al*., 2024). The analyses were carried out three times for each formulation. Texture measurements such as

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hardness, gumminess, chewiness, and resilience were conducted at multiple storage timepoints for six days.

Color analysis

Color analysis of marshmallow samples was conducted using a Minolta CR 400 Chroma Meter. Calibration was performed using the white calibration plate, and measurements were taken in triplicate. The CIELAB color space was employed, with L* denoting lightness, a* is red and green values, while b* is yellow and blue components (Du Toit *et al*., 2020; Ly *et al*., 2020). This analysis was performed only once on day zero to determine the related properties of the marshmallows.

Moisture content

The moisture content of marshmallow was analysed by drying the petri dish in the hot air oven at 100°C cooled in a desiccator until it reached constant weight. Then, using the analytical balance, the petri dish was weighed (W1). Next, five grams of marshmallow samples were transferred into the petri dish. The weight of the sample was (W2). Then, in the hot air oven, the petri dish containing samples was dried at 60°C overnight. After that, the petri dish was put in the desiccator to cool down before taking the final weight (W3) (Jemziya *et al*., 2022). It was measured only on day zero to assess the moisture content using the equation stated below.

$$\% \, Moisture = \frac{W2 - (W3 - W1)}{W2} \times 100\%$$

Water Activity (a_w)

Three grams of marshmallow sample was placed in a water activity cup and filled to about half capacity. The sample was then placed in a closed water activity meter, and the water activity measurement was monitored and recorded. This process was repeated, and the average values were computed and presented (Simons, 2018). Water activity has been conducted at multiple storage timepoints from day one until day five.

Scanning electron microscope (SEM)

The method was followed closely according to Moazzezi *et al*. (2022), with slight modification. An electron microscope (SEM) with a 5.0 kV acceleration voltage was utilized. The aluminium stub was cleaned with acetone before sticking the conductive tape. The samples were attached on an aluminium stub using double-sided tape for mounting purposes. The sample was subsequently made conductive by applying a tiny layer of gold coating to the stub containing it. The sample was examined using a SEM at 300× magnification.

Statistical analysis

The data was statistically evaluated with SPSS IBM 29.0.0.0 (241) version. Data was analyzed using one-way ANOVA for TPC, color, and moisture content analysis. Moreover, two-way ANOVA has been utilized for texture profile and water activity analysis. Experimental data were presented in means ± standard deviations. To compare the means, Tukey's multiple range test was used. The assumptions for normality and homogeneity of variances were checked to ensure the validity of ANOVA. To compare the means, Tukey's multiple range test was used. Pearson correlation was also utilized to determine the relationship

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between variables. A p-value of < 0.05 indicated statistical significance.

RESULTS AND DISCUSSION

Total phenolic content

Table 2 shows that there is no significant difference ($p>0.05$) in total phenolic content (TPC) between marshmallows containing Liberica coffee brew likely due to the uniform amount of coffee added across all formulations. The difference in TPC values ranging from 0.8577 mg GAE/g to 0.8740 mg GAE/g. The lack of statistical difference shows that the incorporation of Liberica coffee contributes significantly as well as enhancing the antioxidant capacity of the marshmallows. This could provide additional health benefits by increasing the antioxidant potential of the marshmallows.

On the other hand, compared to the control marshmallows without coffee, the Liberica-containing samples exhibited a significant difference ($p<0.05$) in TPC, proving that the addition of Liberica coffee effectively increases phenolic content.

Table 2. TPC value for different samples of marshmallows

Formulation	TPC, (mg GAE/g)
MG	0.2294 ± 0.0542^{b}
MGC	0.8577 ± 0.0252^{a}
MAC	0.8617 ± 0.0015^{a}
MKC	0.8583 ± 0.0015^{a}
MKAC	0.8740 ± 0.0010^{a}

The values are expressed by the mean ± standard deviation (n=3).
Different lowercase letters indicate significant differences between marshmallows ($p<0.05$).
MG (control, 1.02% gelatin), MGC (control, 1.02% gelatin with Liberica brew), MAC (1.02% agar with Liberica brew), MKC (1.02% konjac with Liberica brew), MKAC (0.51% agar, 0.51% konjac with Liberica brew).

Texture profile

Table 3 presents the hardness measurements for various marshmallow formulations over six days. The MG formulation displayed no significant changes ($p>0.05$) in hardness over time. However, the hardness of MG on day 1 differed significantly ($p<0.05$) from that of MGC and MKC, indicating that the type of hydrocolloid used impacts marshmallow hardness on a given day. No other significant pairwise differences were observed among the formulations on day 1.

Tables 4 and 5 show that there were no significant differences in gumminess and chewiness among most formulations over the storage period ($p>0.05$). Gelatin enhances gumminess, contributing to the chewiness of marshmallows by regulating sucrose recrystallization and improving emulsion and foaming capabilities (Chandra & Shamsundar, 2014; Sebastian, 2014). Konjac's high water-binding capacity results in less chewy structures compared to agar as it allows to retain more moisture within a gel network, as observed in previous studies (Yang *et al*., 2022). This aligned with the result in Table 5 where both MKC and MKAC appeared to have lower chewiness compared to those containing agar, although differences

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were not statistically significant, likely due to the softening effect of water retention on the aerated marshmallow matrix. Therefore, agar and konjac contribute differently to the chewiness of marshmallows due to their gelling mechanisms. Agar forms a rigid, heat-set gel that increases chewiness, whereas konjac binds more water, softening the matrix and resulting in lower chewiness.

All marshmallow samples displayed relatively consistent trends with minor increments in textural qualities, which were not statistically significant ($p>0.05$). MKAC maintained relatively stable textural qualities across storage, without significant changes ($p>0.05$) in comparison to other formulations. This consistency is attributed to the controlled refrigeration conditions applied throughout storage, which minimized temperature fluctuations and prevented deterioration that could have occurred at room temperature. Storing the samples in a regulated environment helps preserving texture and ensuring more reliable and repeatable measurements. Moisture redistribution also contributes to these results. The effective diffusion coefficient of water in marshmallows is $9.49 \times 10^{-11} \pm 0.56 \times 10^{-11}$ m^2/s (Fanek *et al*., 2012), indicating that water diffuses slowly, leading to gradual moisture redistribution. Additionally, slow freezing or multiple freeze-thaw cycles can lead to crystal formation, which negatively impacts texture, flavor, and quality (Amit *et al*., 2017; Li *et al*., 2018).

Table 3. Hardness (g) measurements of different marshmallow formulations over six days

Formulation	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6
MG	266.73 ± 14.27^{aA}	271.99 ± 12.93^{aA}	274.47 ± 12.07^{aA}	276.91 ± 4.58^{aA}	281.66 ± 3.42^{aA}	284.28 ± 4.89^{aA}
MGC	232.12 ± 7.15^{bAB}	246.19 ± 10.13^{aAB}	249.00 ± 9.99^{aAB}	246.75 ± 11.03^{cAB}	253.76 ± 10.98^{bAB}	258.61 ± 6.62^{bcA}
MAC	249.88 ± 3.22^{abAB}	266.81 ± 12.41^{aAB}	269.00 ± 12.22^{aAB}	274.551 ± 10.90^{abAB}	275.11 ± 7.95^{abAB}	276.32 ± 7.77^{abA}
MKC	145.36 ± 10.49^{cA}	146.98 ± 11.57^{bA}	150.67 ± 10.32^{bA}	151.11 ± 10.81^{dA}	152.99 ± 10.45^{cA}	153.18 ± 11.42^{dA}
MKAC	239.66 ± 15.52^{abA}	246.71 ± 9.44^{aA}	249.50 ± 9.10^{aA}	250.25 ± 6.10^{bcA}	253.02 ± 6.57^{bA}	253.87 ± 6.79^{cA}

The values are expressed by the mean ± standard deviation (n=3).
Different lowercase letters indicate significant differences between marshmallows ($p<0.05$). Different capital letters indicate significant differences between days ($p<0.05$).
MG (control, 1.02% gelatin), MGC (control, 1.02% gelatin with Liberica brew), MAC (1.02% agar with Liberica brew), MKC (1.02% konjac with Liberica brew), MKAC (0.51% agar, 0.51% konjac with Liberica brew).

Table 4. Gumminess measurements of different marshmallow formulations over six days

Formulation	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6
MG	229.81 ± 5.53^{aA}	229.44 ± 10.40^{aA}	231.99 ± 10.31^{aA}	232.71 ± 5.28^{aA}	233.81 ± 5.53^{aA}	234.78 ± 5.48^{aA}
MGC	218.06 ± 4.02^{bA}	220.80 ± 1.39^{aA}	223.00 ± 1.32^{aA}	220.82 ± 4.38^{bA}	222.06 ± 4.02^{bA}	222.96 ± 3.92^{bA}
MAC	120.02 ± 4.02^{cA}	120.90 ± 2.33^{bA}	123.18 ± 2.19^{bA}	123.04 ± 3.78^{cA}	124.02 ± 4.02^{cA}	125.11 ± 3.89^{cA}
MKC	103.82 ± 4.15^{dA}	102.86 ± 1.30^{cA}	104.67 ± 1.04^{cA}	106.79 ± 3.96^{dA}	107.82 ± 4.15^{dA}	108.57 ± 4.04^{dA}
MKAC	111.86 ± 1.67^{cdB}	112.59 ± 1.49^{bcAB}	114.51 ± 1.31^{bcAB}	114.87 ± 1.90^{cdAB}	115.86 ± 1.66^{cdAB}	116.77 ± 1.40^{cdA}

The values are expressed by the mean ± standard deviation (n=3).
Different lowercase letters indicate significant differences between marshmallows ($p<0.05$). Different capital letters indicate significant differences between days ($p<0.05$).

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Table 5. Chewiness measurements of different marshmallow formulations over six days

Formulation	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6
MG	204.83 ± 2.15^{aABC}	201.33 ± 3.14^{aC}	202.93 ± 3.06^{aAB}	207.86 ± 2.21^{aABC}	$209.45 \pm 2.33a^{AB}$	210.81 ± 2.63^{aA}
MGC	177.05 ± 7.07^{bA}	160.14 ± 1.25^{bA}	182.29 ± 1.65^{bA}	179.67 ± 7.22^{bA}	181.05 ± 7.07^{bA}	182.05 ± 7.07^{bA}
MAC	135.03 ± 3.50^{cA}	135.69 ± 2.29^{cA}	137.67 ± 2.02^{cA}	137.96 ± 3.43^{cA}	139.03 ± 3.50^{cA}	140.03 ± 3.35^{cA}
MKC	97.49 ± 3.36^{eA}	96.79 ± 4.01^{eA}	99.36 ± 3.31^{eA}	100.28 ± 3.42^{eA}	101.49 ± 3.35^{eA}	102.49 ± 3.35^{eA}
MKAC	111.43 ± 1.23^{dC}	110.95 ± 0.73^{dC}	112.67 ± 1.04^{dBC}	114.57 ± 1.02^{dAB}	115.43 ± 1.23^{dAB}	116.43 ± 1.23^{dA}

The values are expressed by the mean ± standard deviation (n=3).
Different lowercase letters indicate significant differences between marshmallows ($p<0.05$). Different capital letters indicate significant differences between days ($p<0.05$).
MG (control, 1.02% gelatin), MGC (control, 1.02% gelatin with Liberica brew), MAC (1.02% agar with Liberica brew), MKC (1.02% konjac with Liberica brew), MKAC (0.51% agar, 0.51% konjac with Liberica brew)

Table 6. Resilience measurements of different marshmallow formulations over six days

Formulation	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6
MG	0.52 ± 0.05^{aA}	0.54 ± 0.03^{aA}	0.55 ± 0.02^{aA}	0.53 ± 0.05^{aA}	0.53 ± 0.05^{aA}	0.53 ± 0.05^{aA}
MGC	0.51 ± 0.30^{aA}	0.520 ± 0.04^{aA}	0.53 ± 0.01^{aA}	0.52 ± 0.03^{aA}	0.51 ± 0.30^{aA}	0.52 ± 0.30^{aA}
MAC	0.54 ± 0.02^{aA}	0.54 ± 0.01^{aA}	0.55 ± 0.01^{aA}	0.54 ± 0.02^{aA}	0.56 ± 0.02^{aA}	0.55 ± 0.02^{aA}
MKC	0.39 ± 0.01^{bA}	0.39 ± 0.01^{bA}	0.40 ± 0.01^{bA}	0.40 ± 0.01^{bA}	0.40 ± 0.01^{bA}	$0.40 \pm 0.01b^{A}$
MKAC	0.36 ± 0.03^{bA}	0.35 ± 0.03^{bA}	112.67 ± 1.04^{dA}	0.37 ± 0.03^{bA}	0.36 ± 0.03^{bA}	0.37 ± 0.03^{bA}

The values are expressed by the mean ± standard deviation (n=3).
Different lowercase letters indicate significant differences between marshmallows ($p<0.05$). Different capital letters indicate significant differences between days ($p<0.05$).
MG (control, 1.02% gelatin), MGC (control, 1.02% gelatin with Liberica brew), MAC (1.02% agar with Liberica brew), MKC (1.02% konjac with Liberica brew), MKAC (0.51% agar, 0.51% konjac with Liberica brew

Color analysis

Referring to Table 8, the L* values, which indicate brightness, show that the MGC formulation had the highest value (95.02 ± 1.14; $p < 0.05$), while MKC was the darkest, although not significantly different ($p > 0.05$) from MAC. MKC also exhibited the highest a* value (0.98 ± 0.09; $p < 0.05$), suggesting stronger retention of coffee's reddish pigments in the konjac-based matrix. These differences occurred despite uniform coffee addition and are likely attributed to the distinct interactions between coffee pigments and the different hydrocolloid networks. As shown in Table 7, konjac powder exhibited the highest L* value ($p < 0.05$), whereas agar and gelatin produced slightly darker base colours, which may explain why coffee pigments appear more pronounced in konjac-based marshmallows (Akesowan, 2014).

The a* values, representing the red–green axis, further support this trend. MKC showed a significantly higher a* value (0.98 ± 0.09; $p < 0.05$), while MAC (0.35 ± 0.11) and MGC (0.13 ± 0.09) exhibited lower redness, indicating less intense incorporation of reddish pigments in agar- and gelatin-based formulations. Referring to Table 9, a strong negative correlation was observed between bh and bm (–0.966**), indicating that hydrocolloids with higher b* values tended to produce marshmallows with lower b* values. This is consistent with the colour data: gelatin, which had the highest hydrocolloid b* value (9.80), produced marshmallows with the lowest yellowness (b* = 4.99), whereas konjac, with the

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lowest hydrocolloid b* value (1.63), produced marshmallows with significantly higher b* values (13.88; $p < 0.05$) than MG and MGC. Conversely, the positive correlation between bh and Lm (0.977**) indicates that hydrocolloids with higher b values produced marshmallows that appeared brighter and more yellowish, which aligns with the L* trends in Table 8. Additionally, the strong positive correlation between am and bm (0.754**) shows that red and yellow intensities tend to increase simultaneously, consistent with the warm brown colour characteristic of coffee-infused marshmallows.

Table 7. Color analysis of hydrocolloids used.

Hydrocolloid	L*	a*	b*
Gelatin	42.74 ± 1.06^{b}	-0.79 ± 0.04^{c}	9.80 ± 0.61^{a}
Agar	44.81 ± 1.77^{b}	-0.16 ± 0.03^{a}	7.16 ± 0.12^{b}
Konjac	66.92 ± 2.90^{a}	-0.54 ± 0.30^{b}	1.63 ± 0.47^{c}

The values are expressed by the mean ± standard deviation (n=3).
Different lowercase letters indicate significant differences between marshmallows (p<0.05).

Table 8. Color analysis of different marshmallow formulations

Formulation	L*	a*	b*
MG	95.02 ± 1.14^{a}	-0.55 ± 0.08^{c}	4.99 ± 0.30^{c}
MGC	91.22 ± 0.46^{b}	0.13 ± 0.09^{b}	9.95 ± 1.70^{b}
MAC	86.93 ± 0.28^{cd}	0.35 ± 0.11^{b}	15.64 ± 0.46^{a}
MKC	85.04 ± 0.74^{d}	0.98 ± 0.09^{a}	13.88 ± 0.86^{a}
MKAC	89.04 ± 1.05^{c}	0.27 ± 0.04^{b}	15.09 ± 0.33^{a}

The values are expressed by the mean ± standard deviation (n=3).
Different lowercase letters indicate significant differences between marshmallows (p<0.05).
MG (control, 1.02% gelatin), MGC (control, 1.02% gelatin with Liberica brew), MAC (1.02% agar with Liberica brew), MKC (1.02% konjac with Liberica brew), MKAC (0.51% agar, 0.51% konjac with Liberica brew.

Table 9. Pearson correlation of marshmallow and hydrocolloid colors

	L*m	a*m	b*m	L*h	a*h	b*h
L*m	1	-0.929**	-0.875**	-0.888**	-0.135	0.977**
a*m		1	0.754**	0.716*	0.409	-0.863**
b*m			1	0.904**	0.141	-0.966**
L*h				1	-0.222	-0.950**
a*h					1	0.028
b*h						1

**. Correlation is significant at the 0.001 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed). Lowercase m represents marshmallow.
Lowercase h represents hydrocolloid.

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Moisture content

Table 10 shows significant differences in moisture content across formulations. Marshmallows typically have a high moisture content (17% to 21%) due to their fluffy, porous structure (Kirtil *et al*., 2017). MKC had the significantly highest moisture content (27.81%), likely due to the high-water absorption capacity of konjac glucomannan, which can absorb up to 100 g of water per gram of sample (Tatirat & Charoenrein, 2011). MAC had a moisture content of 22.34%, reflecting agar powder's lower water absorption capacity compared to konjac, as agar can absorb up to 15 times its weight in water (Mortensen *et al*., 2016). MKAC's moisture content fell between those of MAC and MKC. Both gelatin-based marshmallows, MG and MGC, exhibited significantly lower moisture content, as gelatin absorbs relatively little water—approximately 5.8 g of water per gram of gelatin. MG showed the lowest moisture content overall, likely due to the absence of brewed coffee, since the incorporation of liquid ingredients generally increases moisture in food matrices (Lewicki, 2004).

Table 10. Moisture content analysis of different marshmallow formulations

Formulation	Moisture (%)
MG	11.59 ± 1.36^{e}
MGC	16.21 ± 0.26^{d}
MAC	22.34 ± 0.69^{c}
MKC	27.81 ± 0.27^{a}
MKAC	24.75 ± 0.25^{b}

The values are expressed by the mean ± standard deviation (n=3).
Different lowercase letters indicate significant differences between marshmallows ($p<0.05$).
MG (control, 1.02% gelatin), MGC (control, 1.02% gelatin with Liberica brew), MAC (1.02% agar with Liberica brew), MKC (1.02% konjac with Liberica brew), MKAC (0.51% agar, 0.51% konjac with Liberica brew).

Water activity

Across all storage days, MKC consistently exhibited the highest water activity ($p < 0.05$), as indicated by the lowercase letters in Table 11. According to Schmidt and Fontana (2020), commercial marshmallows typically have water activity values between 0.629 and 0.635, while homemade marshmallows range from 0.8 to 0.9. The values obtained in this study fall within these reported ranges.

Water activity remained statistically unchanged throughout the storage period for all formulations, including MAC, showing no significant differences ($p > 0.05$) from day 1 to day 5. Lower temperatures are known to reduce water activity (El-Messiry et al., 2021), which may explain the relatively stable values observed in marshmallows stored at 7 °C. In contrast, increases in moisture content and water activity have been reported in marshmallows stored at 35 °C and 63% relative humidity over one month (Kirtil et al., 2017), supporting the gradual decrease in water activity seen in this study's samples.

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Table 11. Water activity analysis of different marshmallow formulations over a five-day period

Formulation	Day 1	Day 2	Day 3	Day 4	Day 5
MG	0.8448 ± 0.0033^{dA}	0.8432 ± 0.0026^{dA}	0.8441 ± 0.0031^{eA}	0.8417 ± 0.0018^{dA}	0.8413 ± 0.0024^{eA}
MGC	0.8764 ± 0.0031^{cA}	0.8754 ± 0.0032^{cA}	0.8754 ± 0.0185^{cA}	0.8749 ± 0.0019^{bcA}	0.8738 ± 0.0022^{cA}
MAC	0.8841 ± 0.0003^{bA}	0.8838 ± 0.0004^{bA}	0.8841 ± 0.0032^{bA}	0.8835 ± 0.0009^{bA}	0.8843 ± 0.0004^{bA}
MKC	0.8987 ± 0.0028^{aA}	0.8982 ± 0.0028^{aA}	0.8982 ± 0.0023^{aA}	0.8970 ± 0.0022^{aA}	0.8962 ± 0.0019^{aA}
MKAC	0.8728 ± 0.0016^{cA}	0.8708 ± 0.0018^{cA}	0.8689 ± 0.0021^{dA}	0.8698 ± 0.0075^{cA}	0.8657 ± 0.0020^{dA}

The values are expressed by the mean ± standard deviation (n=3).
Different lowercase letters indicate significant differences between marshmallows ($p<0.05$). Different capital letters indicate significant differences between days ($p<0.05$).
MG (control, 1.02% gelatin), MGC (control, 1.02% gelatin with Liberica brew), MAC (1.02% agar with Liberica brew), MKC (1.02% konjac with Liberica brew), MKAC (0.51% agar, 0.51% konjac with Liberica brew).

Scanning electron microscopy

Figure 3 shows that MG and MGC exhibit smooth surface structures. This smoothness is attributed to the behavior of gelatin: when mixed with warm water, its helical molecules partially unravel, and upon cooling, some re-form into helices while others remain flexible. This creates a matrix capable of trapping air bubbles, resulting in a soft and airy texture (Wesołowska-Trojanowska et al., 2019). In contrast, MAC displays a rougher, more irregular surface. Agar forms gels with tightly packed helical structures that differ from those of gelatin, producing a more brittle texture (Somboon et al., 2014). MKC shows clearly defined pores, likely due to the high fiber content of konjac glucomannan, which contributes to a porous structure (Li et al., 2018). MKAC presents a combination of roughness and porosity, reflecting the combined structural effects of agar and konjac.

These microstructural characteristics align with the textural measurements shown previously in Table 3 under texture profile analysis. MG exhibited the highest hardness, consistent with its denser and more cohesive matrix. Conversely, the porous structure of MKC corresponds with its significantly higher moisture content ($p < 0.05$) reported in Table 10, as the open matrix facilitates water retention. Together, these findings illustrate how different hydrocolloids influence microstructure, shaping the physical and chemical properties of *Coffea liberica*–infused marshmallows.

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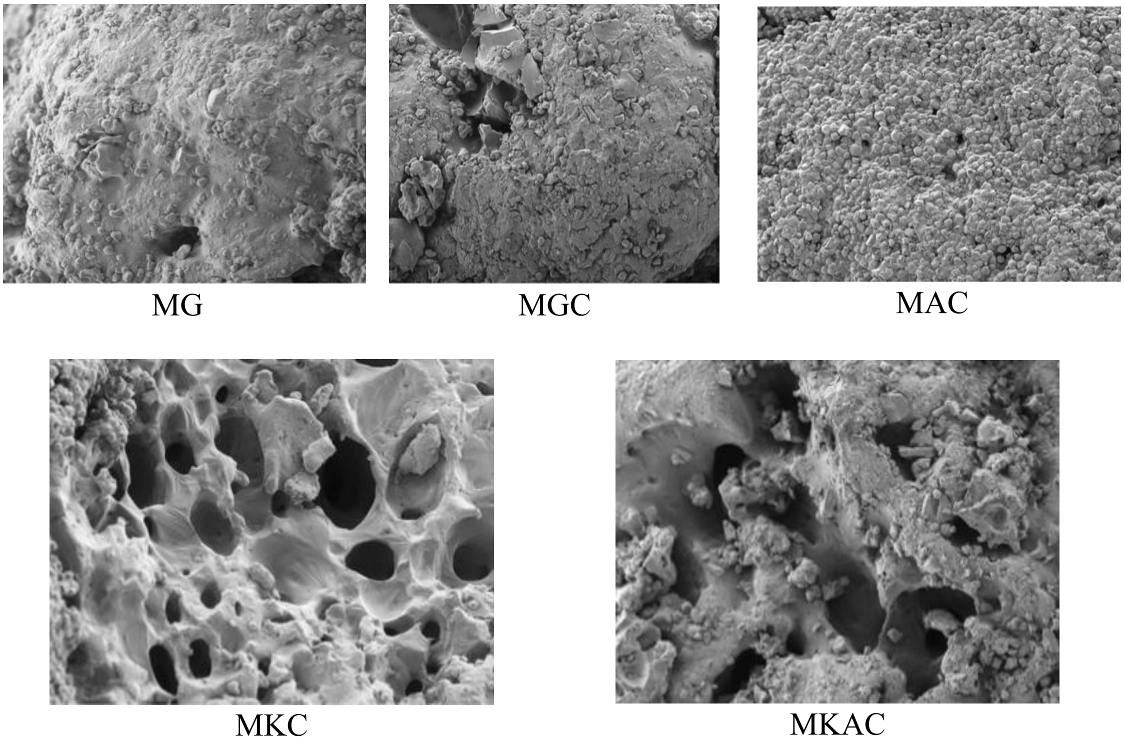

Fig. 3. Microstructure of marshmallows at 300x magnification

CONCLUSIONS

This study demonstrated that agar (1.02%) in combination with brewed *Coffea liberica* (6.17%) produced marshmallows with stable and consistent physicochemical properties, while konjac also showed promise as a viable gelatin substitute. The choice of hydrocolloid significantly affected textural attributes, water activity, and moisture content, with konjac-based formulations exhibiting the highest moisture retention and gelatin-based formulations the lowest, contributing to distinct differences in texture and storage stability. The incorporation of *Coffea liberica* enhanced phenolic content and colour intensity, while microstructural integrity was maintained throughout storage. These findings offer valuable insights for the development of gelatin-free marshmallows with improved functional properties within the confectionery sector. Nonetheless, this work did not include sensory evaluation or pilot-scale production. Future research should address consumer acceptability, shelf-life optimization, and the broader application of coffee–hydrocolloid systems in confectionery formulations

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AUTHOR'S CONTRIBUTION

Aisya Hazlee conducted the research, performed data analysis, and drafted as well as revised the manuscript. Eng Keng Seow conceptualized the central research idea, provided the theoretical framework, designed the research, supervised the research progress, anchored the review and revisions, and approved the article submission.

CONFLICT OF INTEREST STATEMENT

The authors agree that this research was conducted in the absence of any self-benefits, commercial or financial conflicts and declare absence of conflicting interests with the funders.

REFERENCES

Akesowan, A. (2014). Optimization of Textural Properties of Konjac Gels Formed with κ-Carrageenan or Xanthan and Xylitol as Ingredients in Jelly Drink Processing. Journal of Food Processing and Preservation, 39(6), 1735–1743. https://doi.org/10.1111/jfpp.12405

Amit, S. K., Uddin, Md. M., Rahman, R., Islam, S. M. R., & Khan, M. S. (2017). A Review on Mechanisms and Commercial Aspects of Food Preservation and Processing. Agriculture & Food Security, 6(1). https://doi.org/10.1186/s40066-017-0130-8

Bender, S., & Gowen, Z. (2023). Did You Know? The Mallow Plant Gave Marshmallow Its Name.

Boerner, L. K. (2021). What's in Marshmallows, and How Do the Ingredients Work together to Make Ooey-gooey Treats? Acs.org. https://cen.acs.org/food/food-science/s-marshmallows- ingredients-work-together/99/web/2021/04

Bouakline, H., Bouknana, S., Merzouki, M., Ziani, I., Challioui, A., Bnouham, M., Tahani, A., Bachiri, A. E. (2024). The Phenolic Content of Pistacia lentiscus Leaf Extract and Its Antioxidant and Antidiabetic Properties. The Scientific World Journal, 2024, 1–11. https://doi.org/10.1155/2024/1998870

Chandra, M. V., & Shamasundar, B. A. (2014). Texture Profile Analysis and Functional Properties of Gelatin from the Skin of Three Species of Fresh Water Fish. International Journal of Food Properties, 18(3), 572–584. https://doi.org/10.1080/10942912.2013.8457

Du Toit, L., Bothma, C., De Wilt, M., & Hugo, A. (2020). Replacement of Gelatin with Liquid Opuntia Ficus-Indica Mucilage in Marshmallows. Part 1: Physical Parameters. Journal of the Professional Association for Cactus Development, 18, 25–39. https://doi.org/10.56890/jpacd.v18i.51

El-Messiry, D., El Desoky, S., & Abd El-Razek, R. (2021). Characteristics of Children Marshmallow Candy Colored by Natural Anthocyanin Extract from Jamun (*Syzygium cumini*) During Cold Storage. Journal of Food and Dairy Sciences, 12(8), 189–194. https://doi.org/10.21608/jfds.2021.88671.1024

Fanek, H., Fava, C., & Huang, E. C. (2012). Determination of Effective Diffusion Coefficient of Water in Marshmallow from Drying Data Using Finite Difference Method Introduction. International Food Research Journal, 19(4), 1351–1354. http://www.ifrj.upm.edu.my/19%20%2804%29%202012/7%20IFRJ%2019%20%2804%29%202012%20Eric%20%2 8272%29.

https://doi.org/10.24191/scl.v20i1.8697

Insanu, M., Fidrianny, I., & Kusmardiyani, S. (2021). Liberica Coffee (*Coffea liberica* L.) from Three Different Regions: In Vitro Antioxidant Activities. Biointerface Research in Applied

Jemziya, M. B. F., & Mahendran, T. (2022). Quality Characteristics and Sensory Evaluation of Cookies Produced from Composite Blends of Sweet Potato (*Ipomoea Batatas* L.) and Wheat (*Triticum Aestivum* L.) Flour. Sri Lanka Journal of Food and Agriculture, 1(2), 23. https://doi.org/10.4038/sljfa.v1i2.16

Kirtil, E., Aydogdu, A., & Oztop, M. H. (2017). Investigation of Physical Properties and Moisture Sorption Behaviour of Different Marshmallow Formulations. Acta Horticulturae. https://doi.org/10.17660/actahortic.2017.1152.33

Lee, K. W. T. (2023). Liberica Coffee Development and Refinement Project in Sarawak Malaysia. Proceedings, 89(1), 15. https://doi.org/10.3390/ICC2023-14849

Lewicki, P. P. (2004). Water As the Determinant of Food Engineering Properties: A Review. Journal of Food Engineering, 61(4), 483–495. https://doi.org/10.1016/S0260-8774(03)00219-X

Li, D., Zhu, Z., & Sun, D.-W. (2018). Effects of Freezing on Cell Structure of Fresh Cellular Food Materials: A Review. Trends in Food Science & Technology, 75, 46–55. https://doi.org/10.1016/j.tifs.2018.02.019

Ly, B. C. K., Dyer, E. B., Feig, J. L., Chien, A. L., & Del Bino, S. (2020). Research Techniques Made Simple: Cutaneous Colorimetry: A Reliable Technique for Objective Skin Color Measurement. Journal of Investigative Dermatology, 140(1), 3-12. e1. https://doi.org/10.1016/j.jid.2019.11.003

Marcus, J. B. (2013). Chapter 2 - Food Science Basics: Healthy Cooking and Baking Demystified: The Science behind Healthy Foods, Cooking and Baking (J. B. Marcus, Ed.). ScienceDirect; Academic Press. https://www.sciencedirect.com/science/article/abs/pii/B978 0123918826000029

McDermott, A. (2022). What Is Konjac? Uses, Benefits, and Side Effects. Healthline. https://www.healthline.com/health/konjac

Menon, V. V. (2011). Seaweed Polysaccharides-Food Applications. Handbook of Marine Macroalgae, 541–555. https://doi.org/10.1002/9781119977087.ch36

Moazzezi, S., Elhamirad, A., Nateghi, L., Haddad Khodaparast, M., & Zarei, F. (2022). Studies on Physicochemical and Structural Properties of Marshmallow (*Althaea officinalis*) Seed Mucilage. Journal of Food Biosciences and Technology, 12(1), 29–38. https://doi.org/10.30495/JFBT.2022.18967

Mojica. (2017). Investing in Liberica. Philippine Coffee Board. https://philcoffeeboard.com/investing-in-liberica/

Mortensen, A., Aguilar, F., Crebelli, R., Di Domenico, A., Frutos, M. J., Galtier, P., Gott, D., Gundert-Remy, U., Lambré, C., Leblanc, J., Lindtner, O., Moldeus, P., Mosesso, P., Oskarsson, A., Parent-Massin, D., Stankovic, I., Waalkens-Berendsen, I., Woutersen, R. A., Wright, M., & Younes, M. (2016). Re-evaluation of Agar (E 406) As a Food Additive. EFSA Journal, 14(12). https://doi.org/10.2903/j.efsa.2016.4645

Pandya, Y. H., Bakshi, M. B., & Sharma, A. (2022). Agar- Agar Extraction, Structural Properties and Applications: A Review. ResearchGate. https://www.researchgate.net/publication/361254986_Agar agar_extraction_structural_properties and_applications_A_review

https://doi.org/10.24191/sl.v20i1.8697

Ralph, H. (2023). Researchers Reveal New Insights into The History of Liberica Coffee. Global Coffee Report. https://www.gcrmag.com/researchers-reveal-new-insights- into-the-history-of-liberica-coffee/

Roobab, U., Chen, B., Madni, G.M., Tong, Z. G., Zeng, X., Abdi, G., Hussain, S., Aadil, R. M. (2024). Evaluation of Ultrasound and Pulsed Electric Field Combinations on the Cooking Losses, Texture Profile, and Taste-Related Amino Acids of Chicken Breast Meat. Ultrasonics Sonochemistry, 107, 106919. https://doi.org/10.1016/j.ultsonch.2024.106919

Rosenzweig, M. (2023). The History and Cultural Significance of Konjac in Japanese Society. Pac Pac Snacks. https://pacpacsnacks.com/blogs/news/the-history- and-cultural-significance-of-konjac-in-japanese-society

Schmidt, S. J., & Fontana, A. J. (2020). E: Water Activity Values of Select Food Ingredients and Products. In Water Activity in Foods. 573–591. https://doi.org/10.1002/9781118765982.app5

Sebastian, M. (2014). Industrial Gelatin Manufacture - Theory and Practice. Academia. https://www.academia.edu/8410348/Industrial_Gelatin_Manufacture_Theory_and_Practice

Seow, L. J., Shamlan, S., & Seow, E. K. (2021). Influence of roasting degrees on the antioxidant and anti-angiogenic effects of Coffea liberica. Journal of Food Measurement and Characterization, 15(5), 4030-4036.

Simons, C. (2018). How to Measure Water Activity. Food Science Toolbox. https://foodsciencetoolbox.com/water- activity-testing-of-food/

Somboon, N., Karrila, T., Kaewmanee, T., & Karrila, S. (2014). Properties of Gels from Mixed Agar and Fish Gelatin. International Food Research Journal, 21(2), 485–492. http://www.ifrj.upm.edu.my/21%20(02)%202014/8%20IF RJ%2021%20(02)%202014%20Karrila%20457.pdf

Tatirat, O., & Charoenrein, S. (2011). Physicochemical Properties of Konjac Glucomannan Extracted from Konjac Flour by a Simple Centrifugation Process. LWT - Food Science and Technology, 44(10), 2059–2063. https://doi.org/10.1016/j.lwt.2011.07.019

Wesołowska-Trojanowska, M., Tomczyńska-Mleko, M., Terpiłowski, K., Muszyński, S., Nishinari, K., Nastaj, M., & Mleko, S. (2019). Co-gelation of Gluten and Gelatin as a Novel Functional Material Formation Method. Journal of Food Science and Technology, 57(1), 163–172. https://doi.org/10.1007/s13197-019-04042-8

Yang, J., Choi, Y. J., & Hahn, J. (2022). Development of Flaxseed Gum/Konjac Glucomannan with Agar as Gelling Agents with Enhanced Elastic Properties. Food Science and Biotechnology. https://doi.org/10.1007/s10068-022-01179- 9

https://doi.org/10.24191/scl.v20i1.8697