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Valorization of cocoa (*Theobroma cacao* L.) pod husks as a fruit pulp substitute in mango jam formulations: effects on jam qualities during storage and sensory discrimination†

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In this study, fruit pulp obtained from cocoa pod husks (CPHs) was utilized as a substitute in mango jam formulations at two different ratios of 25% and 50% with and without the addition of commercial pectin, in comparison with normal jam made from 100% mango pulp as the control. The results showed that the addition of CPH pulp significantly increased the phenolic content by 3.0–3.9 times and DPPH antioxidant activity by 1.5 times compared to the control sample. Moreover, the retention of phenolics in CPH-pulp-substituted jam was significantly enhanced during 4-week storage while DPPH activity declined remarkably by 60.3–72.7% after four weeks. In terms of appearance, all CPH-mango jams exhibited a characteristic yellow color similar to the control, although darker. CPH pulp reduced hardness and increased adhesiveness and springiness of mango jam without commercial pectin and CPH-mango jam showed slight differences in consumer sensory discrimination.

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Sustainability spotlight

Fruit waste valorization is a critical component in achieving the UN SDGs, particularly those related to sustainable consumption and production, climate action, and economic growth. The global food waste problem, with fruits and vegetables contributing significantly due to their perishable nature, presents both a challenge and an opportunity for sustainable development. Valorization strategies have been explored to transform these wastes into stable, value-added products, thereby reducing food wastage and aligning with the SDG target of halving food waste by 2030. In this study, the circular economy framework offers a promising approach for the valorization of cocoa pod husks, where waste is converted into pectin-rich pulp, showing potential as a substitute for commercial pectin and fruit pulp in the formulation of mango jam.

Introduction

Mango (*Mangifera indica* L.), a member of the Anacardiaceae family, is cultivated in over ninety tropical and subtropical nations, where hundreds of varieties exist.^{1,2} Mango, which contains an abundance of bioactive chemicals, carbohydrates, lipids and fatty acids, proteins, organic acids, vitamins, and minerals, is the most widely consumed tropical fruit. The biological features of phenolic compounds (phenolic alcohols, phenolic acids, and flavonoids) and carotenoids (α - and β -carotene) are characteristic of mango flesh.^{1,3} The Food and Agriculture Organization estimates that the annual global production of mangoes was approximately 52 million tons in 2018, with a consistent upward trend in output. India is the

leading mango producer globally, with an impressive annual output of 15 million tons.^{4,5} Green mangoes can be processed into powder, pickles, preserves, desserts, or chili sauce. On the other hand, ripe mangoes can be processed into concentrated mango products, dried mangoes, mango wine, mango juice, jams, jellies, syrups, and canned mangoes.⁶ However, fresh mango has a maximum shelf life of 30 days when stored at 4–5 °C, and it can be much shorter under less than ideal conditions. Decomposition and oxidation of vitamins and polyphenol components are two ways in which this impacts the nutritional content of raw materials. Efforts have been made in the past to diversify mango products, including mango jam, canned mango juice, dried mangoes,⁷ and mango leather sheets,⁸ in order to cater to a wider range of consumers' demands, increase the value of mangoes and boost regional and national economies.⁹ Among these products, jam, classified as a medium-moisture food item, is produced through the process of boiling fruit pulp, pectin, acids, sugar (sucrose), and other additives until a specific consistency is achieved.^{10,11} Jam is an excellent source of vital amino acids, vitamins, minerals, sugar,

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and fiber with negligible fat or cholesterol, leading to a low possibility of developing cardiovascular diseases upon jam consumption.¹² As per the guidelines set forth by the Bureau of Indian Standards and the Prevention of Food Adulteration, jam must have a minimum fruit content of 45% and a total soluble solid (TSS) content of 68.5% or higher.¹³ Similarly, as mandated by the Codex Alimentarius Commission, it is necessary for finished jam to comprise a minimum TSS of 65%. For consistent gel strength in industrial jam production, commercial pectin (0–10 g per kg of jam) may be necessary.¹² Pectins, which are natural polymers commonly extracted from a variety of plant sources such as passion fruit, grapes, mangoes, citrus fruits, pumpkins, apples, and carrots,^{14,15} have extensive utility in diverse applications such as fat or sugar substitutes, thickeners, stabilizers, and emulsifiers.¹⁶ Pectin is marketed in the form of dry powder and is used as a stabilizer in several culinary products, including fruit drinks, fruit powders, and tomatoes. Additionally, pectin can be utilized in the formulation of marmalades, jams, and jellies due to its gelling properties.¹⁷

Cocoa (*Theobroma cacao* L.) holds significant economic value in developing nations, with global cocoa bean production reaching approximately 5 252 377 tons in 2018 and a harvested area of 11 834 970 hectares.^{18,19} In parallel, it was estimated that 16 million tons of waste were produced during the collection of cocoa seeds, accounting for 80% of the fruit mass.¹⁸ The cocoa pod husk (CPH) is the rough, oval and relatively thick outer part of the cocoa fruit (exocarp), consisting of cellulose (35.0%), lignin (14.6%), hemicellulose (11.0%), pectin (6.1%) and protein (5.9%), in addition to minerals and water.^{20,21} CPH is obtained after removing the seeds and accounts for 70–80% of the dry weight of the fruit.²² Furthermore, the fiber content in CPH ranges from 61.05% to 83.39%, with dietary fiber accounting for 46.98% to 51.11%.²³ This high fiber content highlights its potential as a functional ingredient in food products and enhances its application in sustainable packaging solutions.^{24,25} In addition to its fiber content, CPH extract has been identified as a rich source of bioactive phenolic compounds. Previous studies have identified the phenolic components in CPH, such as quercetin, epicatechin, gallic acid, coumaric acid, and protocatechuic acid.^{26,27} These studies showed that the phenolic compounds in cocoa pod shells have significant potential in reducing the risk of developing chronic diseases, including cardiovascular disorders, cancer, and other chronic inflammatory diseases, confirming this raw material's nutritional and medicinal value.

On account of its high pectin content and characteristic color similar to mango, CPH pulp emerges as a highly viable substitute for mango pulp throughout the jam manufacturing procedure, resulting in a cost reduction without compromising product quality or consumer reception. In this way, the issue of managing agricultural residues is also alleviated, contributing to sustainable development. Currently, there is a scarcity of data pertaining to the potential impact of substituting CPH pulp for mango pulp on jam quality during storage. Therefore, this study was conducted to evaluate the feasibility of the substitution of mango pulp with CPH pulp with the focus on textural attributes and sensory differences compared with traditional mango jam.

Experimental

Materials and chemicals

Fresh Trinitario cocoa (*Theobroma cacao* L. cv. Trinitario) fruits were collected from Binh Phuoc (Vietnam). After harvesting, the samples were stored under refrigeration at 4 °C for further use. Mango (*Mangifera indica* L. cv. 'Cat Hoa Loc') fruits from Tien Giang (Vietnam) were chosen for their maturity, uniform size, and lack of bruises and damage. The mangoes were stored at room temperature and used the same day. Other chemicals used in this study were of analytical grade.

Preparation of CPH pulp-substituted mango jam

After washing, cocoa pod husks were cut into 2-cm thick pieces and steamed for 10 min. Then, CPH was ground with a CPH : water ratio of 1 : 1.5 (g mL⁻¹), followed by filtration through a 100-mesh sieve to obtain CPH pulp which was stored at –4 °C until further use. For mango jam production, the mango fruits were washed, peeled and cut into 2-cm thick slices. After steam blanching for 5 min, mango slices were pureed, sieved through a 100-mesh sieve and promptly analyzed for dry matter content (%). The mango jam formulation used in this study includes mango pulp 100 g, sucrose 120 g, water 100 g, citric acid 3 g, and commercial pectin 1.5 g. The mixture was concentrated at 100 °C under continuous stirring until the soluble solid content reached 65 °Brix, poured into a sterilized glass jar, cooled and stored at room temperature.

To investigate the substitution of CPH pulp for mango pulp and commercial pectin, mango pulp was replaced with 25% and 50% CPH pulp in the mango jam formulation, both with and without commercial pectin. Because CPH has no distinctive flavor, it is only partially substituted in the mango jam recipe. The investigated samples are presented in Table 1.

Analytical methods

Proximate analysis. Moisture, crude protein, fat, and ash content were determined using official methods, namely, oven drying to constant mass, the micro-Kjeldahl method, Soxhlet extraction and dry ashing.²⁸ Total carbohydrate content was calculated by difference. Titratable acidity (TA) was measured by NaOH titration using phenolphthalein as an indicator and expressed as g citric acid per 100 g sample on a dry weight basis (g/100 g DW).

Pectin content. The determination of pectin content was conducted based on the procedure described in the literature with some modifications.²⁹ Briefly, 10 g of CPH pulp (M) was extracted with 10 mL of 20% citric acid solution. The mixture was then heated at 80 °C for 2 h before being centrifuged at 5000 rpm for 10 min to collect the supernatant. Next, the pH was adjusted to 4.5 by using 0.1 N HCl and 40 mL of pure ethanol was added. The mixture was refrigerated and left overnight for pectin precipitation. Finally, the precipitate was recovered by centrifugation and then dried to a constant mass (m_1). The pectin content was calculated using the following formula:

Table 1 Formulation of CPH pulp-substituted mango jam^a

	Mango pulp (g)	Sucrose (g)	Water (g)	Citric acid (g)	Pectin (g)	CPH pulp (g)
M0_1.5 (control)	100	120	100	3	1.5	—
M25_1.5	75	120	100	3	1.5	26.5
M25_0	75	120	100	3	0	28
M50_1.5	50	120	100	3	1.5	51.5
M50_0	50	120	100	3	0	53

^a M_x-y, where x is the substitution ratio (%) of CPH pulp and y is the amount of commercial pectin in the formulation.

$$\text{Pectin (\%)} = m_1 \times 100/M$$

pH, total soluble solids, and color attributes. pH and total soluble solids (°Brix) were measured using a HI 2211-02 pH meter (Hanna Instruments, Romania) and a Master-53M handheld refractometer (Atago Ltd, Japan), respectively. Color attributes in the CIELAB color space, including lightness (*L*^{*}), redness (*a*^{*}), yellowness (*b*^{*}), chroma (*C*^{*}) and hue (*h*[°]), were measured using an NR110 precision colorimeter (3NH Technology Co. Ltd, China) at five random points on the surface.

Total phenolic content and DPPH free radical scavenging assay. To prepare sample aliquots for the determination of total phenolic content and DPPH activity, the jam was 10-fold diluted with distilled water, vortexed for 30 s at 2000 rpm using a ZX4 advanced IR vortex mixer (VELP Scientifica, Italy) and sonicated for 10 min at 240 W in a Pro 100 ultrasonic cleaner (Asonic, Slovenia). The supernatant was collected by centrifugation in a PLC-05 centrifuge (Gemmy Industrial Corp., Taiwan). The total phenolic content (mg gallic acid equivalent per 100 g, mg GAE/100 g) and antioxidant activity (mg Trolox equivalent per 100 g, mg TE/100 g) were estimated using the Folin-Ciocalteu method according to ISO 14502-1:2005,³⁰ and DPPH free radical scavenging assay.³¹

Reducing sugar content. For the determination of reducing sugar content, the above clear solution (5 mL) was neutralized using 0.1 M NaOH in the presence of phenolphthalein, followed by protein precipitation with 2 mL of 20% (w/v) lead acetate before filtration through Whatman No. 2 filter paper. The total reducing sugar content (g glucose per 100 g) was measured according to the spectrophotometric method using the 2,3-dinitrosalicylic acid (DNS) reagent.³²

Texture profile analysis (TPA). Texture measurements were performed after 1-week storage using a CT3 texture analyzer (AMETEK Brookfield Inc., Middleboro, USA) with a cylindrical measuring head (TA4/1000, diameter of 38.1 mm) with fixed settings as follows: distance between the probe and sample of 30 mm, a trigger load of 10 g, a probe speed of 1 mm s⁻¹ and a returning speed of 1 mm s⁻¹. Textural attributes (hardness, adhesiveness, and springiness) were recorded using Texture Proc CT V1.3 Build 15 software.

Microbiological qualities of CPH-mango jams during storage. Microbiological analysis was performed after 4-week storage according to ISO 4833-1:2013 for total aerobic bacteria count (incubation for 72 h at 30 °C), ISO 4832:2006 for coliform

count (incubation for 24 h at 37 °C), ISO 16649-2:2001 for *E. coli* (incubation for 24 h at 44 °C), ISO 21527-2:2008 for total yeasts and molds (incubation for 5 days at 25 °C). The microbial counts were expressed as the logarithmic number of colony forming units per gram of sample (log CFU g⁻¹) and calculated using the following formula:

$$\text{Microbial count (CFU g}^{-1}\text{)} = \Sigma C/[V \times (n_1 + 0.1 \times n_2) \times df]$$

where, ΣC is the sum of all colonies counted on the two dishes retained from two successive dilutions; n_1 and n_2 are the number of plates used in the first and second dilutions, respectively; df is the first dilution factor; and V is the volume of inoculum placed in each plate in mL.

Sensory evaluation – difference from control (DFC) test. Three mango jams, namely M0_1.5 (Control), M25_0 and M50_0 were evaluated for their sensory differences by 30 untrained panelists (20 females and 10 males) within the age range of 19–30 years. All participants in the DFC tests were consecutively provided with a control sample denoted as “C” and an array of three test samples spread on sandwich slices, consisting of a blind control, M25_0, and M_50 0, each of which was assigned a random three-digit code. The test participants

Table 2 Proximate analysis and physicochemical properties of cocoa pod husks (CPH) and mango pulp^a

	Mango pulp	CPH pulp
Moisture (%)	82.56 ± 0.34a	96.07 ± 0.08b
Protein (%)	1.01 ± 0.05a	0.34 ± 0.01b
Ash (%)	0.21 ± 0.01a	0.40 ± 0.01b
Lipid (%)	0.68 ± 0.02a	0.65 ± 0.01b
Carbohydrate (%)	12.41 ± 0.34a	1.21 ± 0.08b
Reducing sugar (%)	2.87 ± 0.07a	0.71 ± 0.02b
Pectin (%)	—	0.20 ± 0.02
Total soluble solids (°Brix)	16.65 ± 0.52a	2.07 ± 0.06b
Total acidity (g citric acid/100 g)	0.25 ± 0.01	—
Phenolic (mg GAE/100 g)	14.08 ± 0.09a	316.84 ± 2.19b
DPPH (mg TE/100 g)	89.09 ± 1.91a	96.76 ± 0.52b
<i>L</i> [*]	53.74 ± 0.51a	62.72 ± 0.42b
<i>a</i> [*]	12.72 ± 0.04a	1.20 ± 0.04b
<i>b</i> [*]	58.67 ± 0.23a	24.25 ± 0.49b
<i>C</i> [*]	60.03 ± 0.23a	24.28 ± 0.49b
<i>h</i> [°]	77.76 ± 0.05a	87.48 ± 0.53b

^a Data are presented as mean ± standard deviation of triplicates and values in the same rows with different letters represent significant differences (*p* < 0.05).



evaluated the difference between the test samples and the control sample using a 5-point difference scale (0 = "no difference", 1 = "very slight difference", 2 = "slight difference", 3 = "moderate difference", 4 = "large difference", and 5 = "very large difference").³³

Statistical analysis

All statistical techniques, including the normality test (Shapiro-Wilk's test), homoscedasticity of variances (Levene's test), Student's *t*-test for comparison of mango pulp and CPH pulp, and one-way ANOVA along with the *post-hoc* Tukey test for quality changes during jam storage, were performed at a 5% significance level using SPSS Statistics v22 (IBM Corp., USA). For the sensory difference test, the Dunnett test was used to distinguish the differences between two samples and the blind control at a 5% significance level.

Results and discussion

Physicochemical properties and proximate analysis of CPH and mango pulps

The physicochemical properties and approximate composition of CPH and mango pulp are presented in Table 2.

It can be seen that both CPH and mango pulps had a high moisture content (>80%), which is in accordance with some studies on cocoa pod husk³⁴ and mango fruits.³⁵ However,

mango pulp has a significantly higher carbohydrate content (12.41%) than CPH pulp (1.21%). Similar trends were also observed for total soluble solids (TSSs) and reducing sugar content. In terms of bioactive compounds, although the total phenolic content of CPH pulp (316.84 mg GAE/100 g) was 22 times higher than that of mango pulp (14.08 mg GAE/100 g), their DPPH antioxidant activity was quite comparable. A possible justification is that CPH pulp predominantly comprises hydrophilic phenolic compounds, particularly flavan-3-ol compounds including epicatechin, quercetin, catechin, gallic acid, coumaric acid, and protocatechuic acid.³⁶ In contrast, mango pulp primarily comprises high concentrations of carotenoids, in addition to other flavonoid compounds.³⁷ In addition, pectin also accounted for a significant amount in CPH pulp (0.20%, corresponding to 5.10% on a dry basis), showing the potential of CPH pulp in stabilizing the structure of jam in formulations where mango pulp is replaced and pectin content is reduced.

As visually shown in Table 2 and Fig. 1, the *L** value of CPH pulp (62.72) is greater than that of mango pulp (53.74), indicating that mango pulp is darker in color than CPH pulp. The *a** and *b** values (12.72 and 58.67, respectively) observed in mango pulp indicate its substantial content of carotenoids and other yellow-red compounds. Considering that the *h*^o values of CPH pulp and mango pulp range between 77.76 and 87.48, it is evident that both materials possess a distinctive yellow hue.

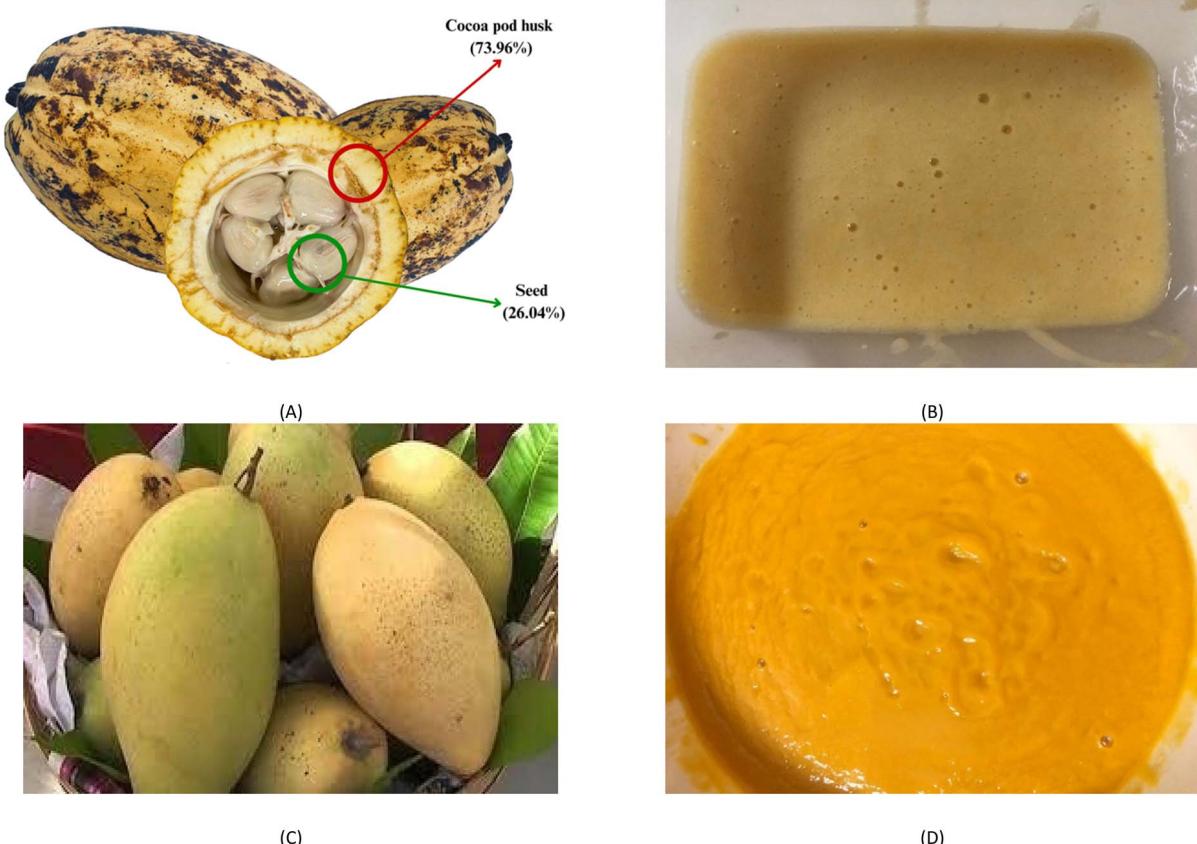


Fig. 1 (A) Cocoa fruits, (B) cocoa pod husk pulp, (C) mango fruits, and (D) mango pulp.



Hence, CPH pulp emerges as a highly viable substitute for mango pulp in the manufacturing of jam, serving the dual purpose of utilization of resources from the cocoa sector. By incorporating CPH pulp into the jam-making process, manufacturing costs are reduced and available raw materials are utilized in a more sustainable manner.

Changes in the qualities of CPH pulp-substituted mango jam during storage

Color and appearance. The color change of CPH pulp-substituted mango jam samples during storage is presented in Table 3 and Fig. 2. It is apparent that the control sample had

a higher lightness ($L^* = 63.76$) than the other samples; nevertheless, the M50_0 sample exhibited no significant difference on the initial day of storage. In addition, the L^* value of all samples tended to decrease significantly with increasing storage time, and the lightness of all mango jam samples ranged from 33.53–48.74 at the end of storage. This behavior could be attributed to the Maillard reaction, which generates a brown pigment,³⁸ or to elevated temperatures during jam storage, which darken the color of the jam.^{39,40}

In general, the increase in CPH pulp content decreased the b^* value (yellowness) of the mango jam samples throughout the storage, indicating that the addition of CPH pulp to the sample resulted in a less yellow product. In the meantime, the b^* values

Table 3 Changes in color attributes and total acidity of CPH pulp-substituted mango jam during storage^a

CPH pulp-substituted mango jam ^b (M _x _y)					
Week	M0_1.5	M25_1.5	M25_0	M50_1.5	M50_0
L^*					
0	63.76 ± 1.40aA	56.24 ± 1.25bA	55.71 ± 1.84bA	57.43 ± 1.64bA	62.65 ± 1.80aA
1	61.55 ± 2.52aA	55.50 ± 1.18bA	54.45 ± 1.09bA	53.24 ± 2.19cbB	51.32 ± 1.00cbB
2	51.59 ± 1.25aB	45.43 ± 1.16bB	43.59 ± 0.75cB	43.31 ± 0.58cC	46.10 ± 0.76bcC
4	44.16 ± 1.54aC	33.53 ± 1.86bC	48.74 ± 0.61cC	34.74 ± 1.74bdD	41.93 ± 0.84adD
a^*					
0	7.06 ± 0.21aA	12.68 ± 0.35bA	13.07 ± 0.49bA	13.23 ± 0.54bA	11.44 ± 0.33cA
1	8.82 ± 0.69aB	12.88 ± 0.52bA	16.63 ± 0.58cB	15.78 ± 0.21cB	15.37 ± 0.62cB
2	10.82 ± 0.43aC	10.58 ± 0.38aB	14.53 ± 0.35bA	14.96 ± 0.17cB	14.12 ± 0.73bcC
4	9.87 ± 0.30aD	13.52 ± 0.27bcC	31.83 ± 1.39cC	17.64 ± 0.81dC	16.77 ± 0.66dD
b^*					
0	74.43 ± 2.75aA	65.27 ± 1.88bA	69.11 ± 2.17cA	55.02 ± 1.67dA	54.13 ± 2.28dA
1	76.36 ± 0.34aB	62.34 ± 3.03bB	77.71 ± 3.13aAB	63.61 ± 1.88bcB	67.44 ± 2.05cB
2	55.19 ± 1.36aC	43.30 ± 1.18bcC	44.01 ± 1.44cC	41.68 ± 0.83bcC	43.34 ± 1.81bcC
4	78.26 ± 3.11aB	48.82 ± 0.55bD	73.98 ± 3.34cB	57.05 ± 1.31dA	59.79 ± 2.64dD
C^*					
0	69.44 ± 2.60baA	66.53 ± 1.96aA	76.02 ± 2.6bA	56.59 ± 1.72cA	55.45 ± 2.44cC
1	78.08 ± 1.08aB	62.68 ± 1.19bB	78.20 ± 3.17aA	65.78 ± 2.24bB	69.91 ± 1.90cB
2	56.17 ± 1.55aC	44.63 ± 1.05bcC	46.36 ± 1.42cB	44.28 ± 0.81bC	45.67 ± 1.53bcC
4	74.66 ± 3.11aB	50.62 ± 0.58bB	84.82 ± 3.74cC	59.63 ± 1.17dD	61.89 ± 2.33dD
h^o					
0	84.02 ± 1.20aA	78.90 ± 0.56bA	78.40 ± 1.63bA	76.48 ± 0.40cA	77.54 ± 0.87bcA
1	82.84 ± 1.82aA	78.14 ± 0.37bA	77.86 ± 1.33bA	75.42 ± 0.65bcA	73.01 ± 3.36cBC
2	79.34 ± 1.33aB	76.10 ± 1.22bB	71.74 ± 0.56cB	70.25 ± 0.32dB	71.66 ± 1.55cdB
4	82.39 ± 0.38aC	75.40 ± 1.13bB	68.65 ± 2.16cC	71.71 ± 2.23dB	75.12 ± 1.69bAC
Total acidity (g citric acid/100 g)					
0	1.43 ± 0.07aA	1.54 ± 0.06abA	1.70 ± 0.09bA	1.50 ± 0.03aAB	1.52 ± 0.06aA
1	1.37 ± 0.02aA	1.53 ± 0.02bA	1.61 ± 0.02cAB	1.54 ± 0.02bA	1.52 ± 0.02bA
2	1.40 ± 0.01aA	1.49 ± 0.01bAB	1.54 ± 0.01cB	1.48 ± 0.01bB	1.57 ± <0.01dA
4	1.17 ± 0.01aB	1.43 ± <0.01dB	1.37 ± 0.01cC	1.25 ± 0.01bC	1.31 ± 0.01cB
TSS (°Brix)					
0	60.75 ± 4.68aA	70.20 ± 3.12bA	75.60 ± 2.20cA	75.15 ± 1.56cA	70.88 ± 2.59bA
1	58.73 ± 0.45aAB	67.73 ± 1.13bAB	74.93 ± 2.97cA	57.35 ± 7.05aB	68.85 ± 4.73bA
2	62.33 ± 1.13aA	72.00 ± 0.10bA	73.13 ± 2.97bA	64.80 ± 3.20aC	68.85 ± 1.56cA
4	61.88 ± 2.59aA	71.33 ± 1.35bA	72.00 ± 0.73bA	63.90 ± 5.30aC	72.45 ± 0.90bAB

^a Data are presented as mean ± standard deviation of triplicates. For each quality attribute, values within the same rows with different lowercase letters and values within the same column with different uppercase letters represent significant differences ($p < 0.05$). ^b M_x_y, where x is the substitution ratio (%) of CPH pulp and y is the amount of commercial pectin in the formulation.



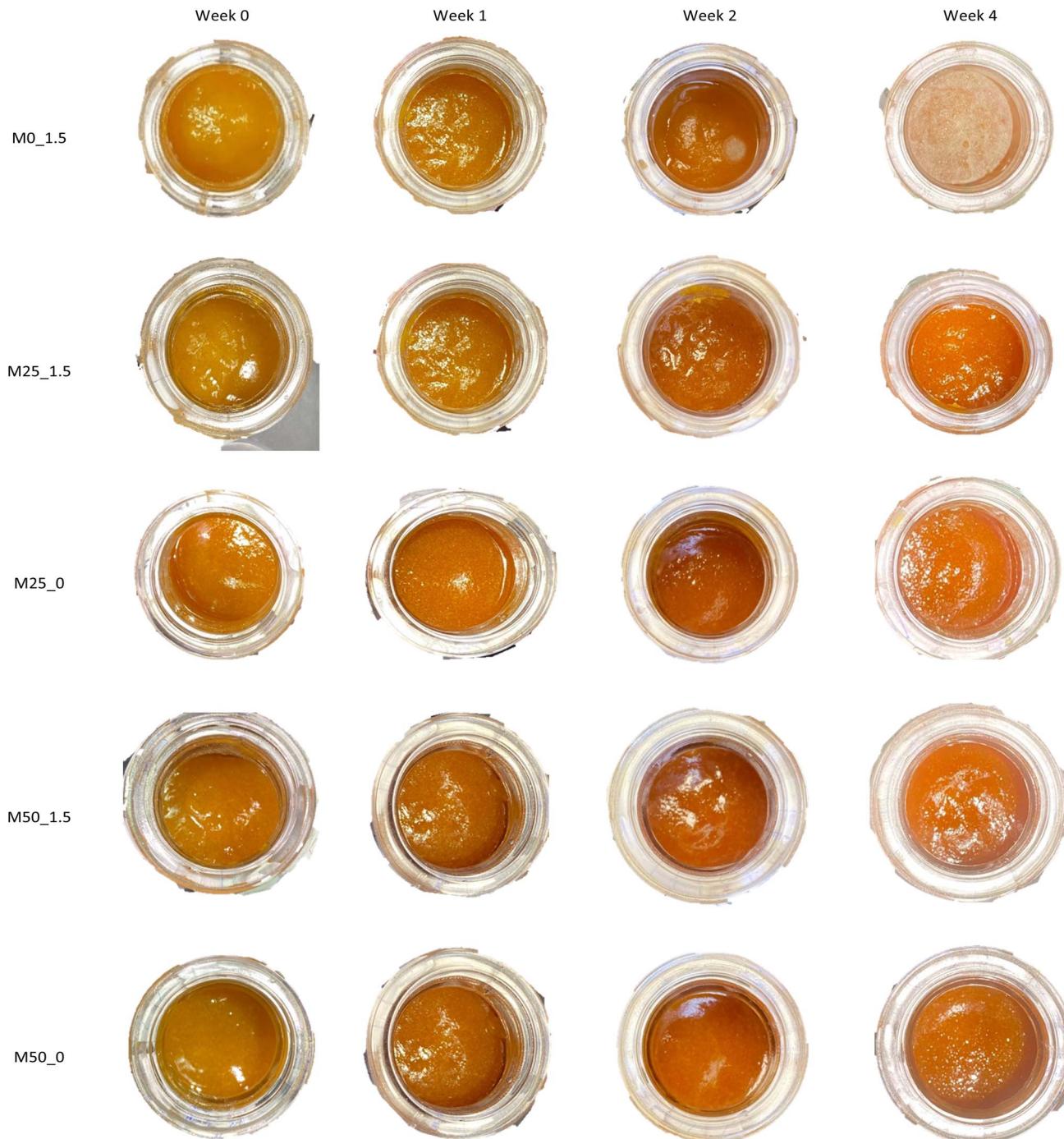


Fig. 2 Appearance of CPH pulp-substituted mango jam during storage. Notes: Mx_y, where x is the substitution ratio (%) of CPH pulp and y is the amount of commercial pectin in the formulation.⁴¹

of the mango jam samples at the end of storage decreased slightly compared to the first day of storage. The change in the b^* value (yellowness) during storage may be due to the decomposition of carotenoids and chlorophyll pigments.⁴¹ During storage, the control sample (M0_1.5) exhibited a range of h° values between 79° and 84°, as illustrated by its yellow to green hue. In contrast, the h° values of all samples substituted with CPH pulp fall within the range of 68–79°, indicating that

these samples do not differ in color from the control sample. According to Kumar *et al.* (2021),⁴² the high carotenoid content of CPH pulp (64.35 mg g⁻¹) exhibited colors comparable to the control sample.

Reducing sugar, TSS and total acidity. Changes in reducing sugar content of CPH pulp-substituted mango jam samples during storage are presented in Fig. 3. The data indicate that the reducing sugar content of mango jam samples varied between



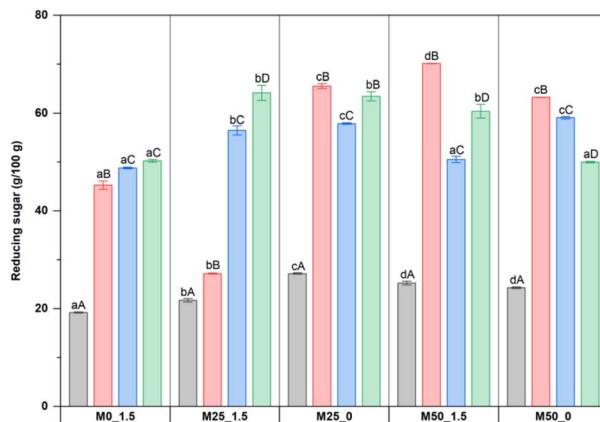


Fig. 3 Change in reducing sugar content (g/100 g) of CPH pulp-substituted mango jam during storage. Notes: Mx_y , where x is the substitution ratio (%) of CPH pulp and y is the amount of commercial pectin in the formulation; different lowercase letters and uppercase letters indicate the significant differences at the 95% confidence level ($p < 0.05$) among samples at the same storage time and among different storage times for the same samples, respectively.

19.20 and 25.25 g/100 g on the initial day of storage. Notably, this value exhibited a substantial increase ($p < 0.05$) as the storage period progressed. Similar findings were documented in studies pertaining to the storage of apple jam,⁴³ grape jam and apricot jam.⁴⁴ During storage, temperature and acidic conditions catalyze the conversion of sucrose to reducing sugars, which results in an increase in reducing sugars.⁴⁵

Regarding the total soluble solid content, the results showed that increasing the ratio of pectin replacement with CPH pulp significantly increased ($p < 0.05$) the TSS value and tended to increase gradually with the increasing storage time of mango jam (Table 3). Compared with the control sample (M0_1.5), the TSS of M50_0 was significantly higher than that of the control sample throughout the storage period. The increase in TSS of the mango jam samples may be due to the degradation of polysaccharides into monosaccharides, oligosaccharides, and sugar fermentation.^{46,47}

Total acidity is one of the most important physicochemical parameters that affect product quality, especially the sensory value and, to a certain extent, is effective against the growth of microorganisms.^{38,48} Table 3 reveals that the variation in titratable acidity across the five jam samples was negligible. Furthermore, this parameter exhibited a slight decline as the jam samples were subjected to storage, averaging 1.17–1.43 g of citric acid/100 g. The decrease in titratable acidity of mango jam during storage may be due to the degradation of ascorbic acid (vitamin C) present in mango, which is influenced by storage time and temperature.^{49,50}

Total phenolic content and DPPH antioxidant activity. Phenolic content plays a significant role in foods as the major antioxidant components.⁵¹ The change in phenolic content of mango jams over storage time is presented in Fig. 4.

It is noticeable that the addition of CPH pulp remarkably enhanced phenolic content of mango jams, from 31.91 mg GAE/

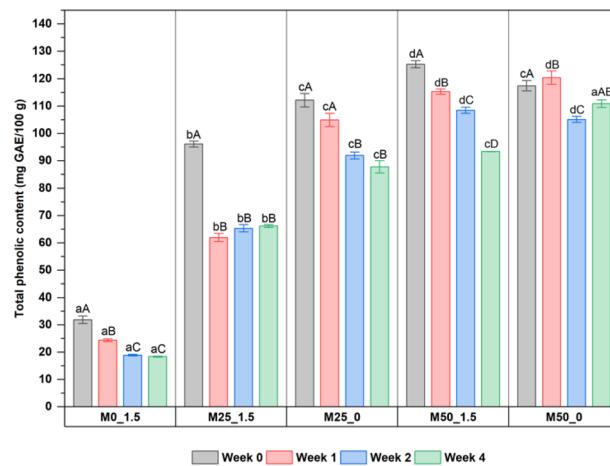


Fig. 4 Change in total phenolic content (mg GAE/100 g) of CPH pulp-substituted mango jam during storage. Notes: Mx_y , where x is the substitution ratio (%) of CPH pulp and y is the amount of commercial pectin in the formulation; different lowercase letters and uppercase letters indicate the significant differences at the 95% confidence level ($p < 0.05$) among samples at the same storage time and among different storage times for the same samples, respectively.

100 g for the control sample to 96.10–125.28 mg GAE/100 g for four CPH-mango jam samples. This result is due to the inherent high phenolic content of CPH pulp (Table 2), which contributes to the total content of CPH-mango jams and its retention. Considering the effect of storage time, the phenolic content tended to decrease throughout the storage and showed stability for the last two weeks. The gradual decrease in TPC with increasing storage time is attributed to the non-enzymatic oxidation caused by high temperature during storage.⁵²

A similar trend to phenolic content was also observed for DPPH antioxidant activity. Specifically, the addition of CPH

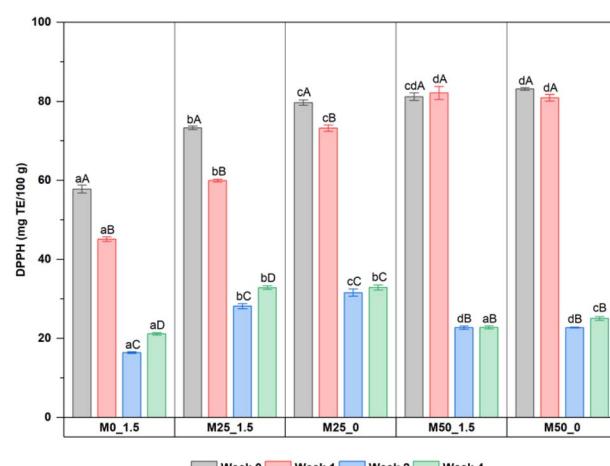


Fig. 5 Change in DPPH antioxidant activity (mg TE/100 g) of CPH pulp-substituted mango jam during storage. Notes: Mx_y , where x is the substitution ratio (%) of CPH pulp and y is the amount of commercial pectin in the formulation; different lowercase letters and uppercase letters indicate the significant differences at the 95% confidence level ($p < 0.05$) among samples at the same storage time and among different storage times for the same samples, respectively.

pulp increased antioxidant activity by 1.5 times, from 57.76 mg TE/100 g for the control sample to 73.30–83.08 mg TE/100 g for four CPH–mango jam samples (Fig. 5). It should be mentioned that unlike the phenolic content, DPPH activity did not increase substantially when CPH was added. However, after two weeks of room temperature storage, there was a notable decline (60.3–72.7%), followed by stability in the last two weeks with values ranging from 21.13–32.87 mg TE/100 g for all samples. A decrease in antioxidant activity during storage was also reported for blueberry jam,⁵³ and grape peel jam.⁵⁴ One explanation for the different trends between phenolic content and DPPH activity may be that during storage, highly biologically active components such as flavonoids, betalains and carotenoids are significantly decomposed.⁵²

Textural properties. Textural attributes including hardness, adhesiveness, and springiness of CPH pulp-substituted mango jam after 1-week storage are presented in Fig. 6. Hardness is defined as the amount of force required to achieve a specific level of deformation⁵⁵ and is a typical parameter for estimating the product's gel structure and consistency or homogeneity.⁵⁶ Obviously, the hardness of the jam was increased by roughly 15–25% compared to the control sample upon CPH substitution at a fixed content of commercial pectin (M25_1.5 and M50_1.5). Meanwhile, when commercial pectin was excluded from the formulation (M25_0 and M50_0), a reduction of up to 43.5% in

hardness was observed. In addition, Fig. 6 shows that adhesiveness and springiness tended to gradually increase with the increasing CPH pulp ratio, from 0.15 mJ and 3.12 mm for the control to 0.8–0.85 mJ and 2.60–3.48 mm for M25, and 0.90–1.12 mJ and 1.57–3.84 mm for M50, respectively.

One of the reasons leading to the increase in hardness of samples M25_1.5 and M50_1.5 is that CPH pulp contains a high level of dietary fibers and thickening agents, especially pectin,²⁰ which contributes to an increase in the number of interfacial zones.^{57,58} In addition, the high mineral content such as calcium in CPH pulp also contributes to increasing the hardness of CPH–mango jam. The high amounts of hemicellulose and gelling agents in cocoa fruits^{20,21} are responsible for the increased adhesiveness.⁵⁹ Meanwhile, insoluble fiber in CPH pulp increases water retention capacity, thereby improving the springiness of mango jam.⁶⁰ Belović *et al.* (2017)⁶¹ suggested that jams with added pectins often demonstrate greater adhesiveness and spreadability owing to enhanced integration of fruit solids within the pectin matrix.

Microbiological qualities. Fruit jam is susceptible to microbial degradation due to its substantial moisture content, which can reach 40% on average.⁵¹ Microbiological qualities of CPH pulp-substituted mango jam after 4 weeks of storage are presented in Table 4. It can be seen that the total plate counts, molds and yeasts of all jam samples were of good quality and within the allowable limits. In addition, no *E. coli* and coliforms was detected in any of the mango jam samples, suggesting that processed jam, with a low water activity of approximately 0.86, inhibits the growth of the majority of bacteria.⁵¹ These results may be also attributed to the presence of β-carotene and acidic nature of jam.⁶²

Difference from the control test for CPH pulp-substituted mango jam. The sensory differences between the CPH pulp-substituted mango jam (M25_0 and M50_0) and the control sample (M0_1.5) are shown in Fig. 7. The sensory discrimination between the jam samples supplemented with CPH pulp (M25_0 and M50_0) and the control sample is perceptible to consumers, although there is no significant difference between the two samples with difference scores being 2.83 and 3.13, respectively. This distinction can be attributed to the characteristic sour flavor and aroma of mango pulp, which was lowered in these two samples. However, it is interesting that the inclusion of the blind control in the test samples also resulted in a difference score of 2.27, indicating a slight difference between the CPH–mango jam and normal mango jam. This may

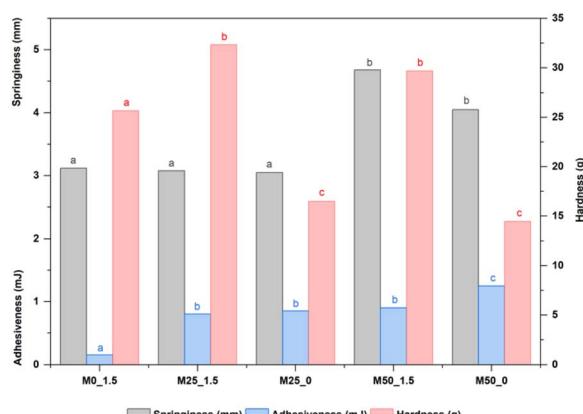


Fig. 6 Texture profiles of CPH pulp-substituted mango jam after 1-week storage. Notes: M_x-y, where x is the substitution ratio (%) of CPH pulp and y is the amount of commercial pectin in the formulation; different lowercase letters for each textural attributes indicate the significant differences at the 95% confidence level ($p < 0.05$).

Table 4 Microbiological quality of CPH pulp-substituted mango jam after 4-week storage^a

Microbiological attribute (CFU g ⁻¹)	CPH-substituted mango jam ^b (M _x -y)				
	M0_1.5	M25_1.5	M25_0	M50_1.5	M50_0
Total plate count	n.d.	n.d.	1×10^1	n.d.	1×10^1
<i>E. coli</i>	n.d.	n.d.	n.d.	n.d.	n.d.
Coliforms	n.d.	n.d.	n.d.	n.d.	n.d.
Total yeasts and molds	1×10^1	1×10^1	2×10^1	1×10^1	n.d.

^a n.d. – not detected. ^b M_x-y, where x is the substitution ratio (%) of CPH pulp and y is the amount of commercial pectin in the formulation.



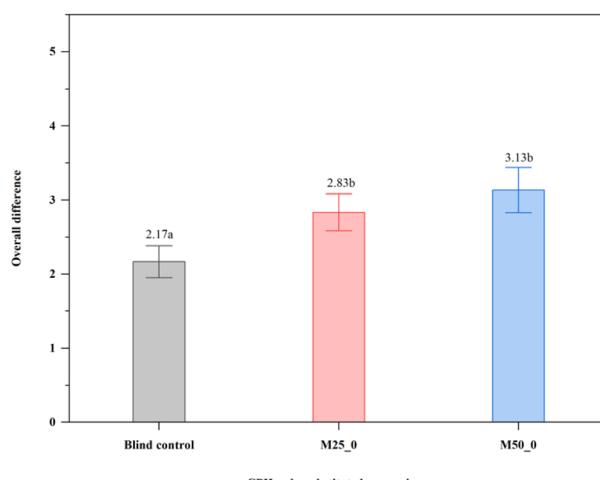


Fig. 7 Difference from the control test of CPH pulp-substituted mango jam, compared with the M0_1.5 sample as the blind control. Notes: M_x-y, where x is the substitution ratio (%) of CPH pulp and y is the amount of commercial pectin in the formulation.

be due to the discriminating power of the panelists, which is verified through the introduction of the blind control.

Conclusions

The feasibility of replacing mango pulp in jam formulation with pulp obtained from cocoa pod husks, an agricultural waste from cocoa cultivation and production, was investigated with the aim of utilization of agricultural resources. CPH pulp obtained from fresh cocoa fruits showed potential as a substitute for mango pulp owing to its high pectin content and characteristic yellow color similar to mango. Furthermore, the antioxidant content and activity of CPH-mango jam are enhanced by the substantial phenolic content present in CPH pulp. The characteristic flavor of mango jam was not altered by the plant taste of CPH pulp, leading to a minor sensory difference compared to traditional mango jam. The present study collectively highlighted the applicability of pectin-rich pulp from CPH for pulp substitution in fruit jams, offering unique benefits in lowering the production cost and addressing environmental challenges for sustainability.

Data availability

The data supporting this article have been included as part of the ESI.†

Author contributions

Vinh-Lam Nguyen: data curation; visualization; investigation; writing – original draft. Minh-Thoai Tran: data curation; investigation. Thuy-Diem Nguyen-Thi: data curation; investigation. Minh-Anh Nguyen: data curation; investigation. Minh-Tri Le: data curation; investigation. Tra-My Nguyen: data curation; investigation. Quoc-Duy Nguyen: conceptualization; data

curation; visualization; investigation; methodology; writing – original draft; writing – review & editing.

Conflicts of interest

There are no conflicts to declare.

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