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Effects Of Osmotic Dehydration And Storage Time On Physicochemical, Microbiological Properties And Sensory Characteristics Of Cocoa Pod Husk Jam

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Abstract:
***Background**: Cocoa pod husk is the outer layer of the pod (exocarp) being known as underexploited by-product and not used properly. It contains a low level of lipid and a rich source of nutrients, minerals, antioxidants such as phenolics, and tannin, dietary fibers as well as pectin – a main ingredient which can be applied to the jam industry. Unfortunately, cocoa pod husk is a rough and thick residue with bitter and acrid taste from high total phenolic content leading to affect consumer's consumption behavior. Moreover, using high heat to make jam can cause undesirable qualities such as color and aroma; therefore, osmotic dehydration can be used for quality maintenance, nutritional retention during storage, flavor enhancement as well as efficiency in terms of energy. This project focused on investigating the changes of physicochemical and microbiological characteristics of cocoa pod husk jam during osmotic dehydration and storage time (at 4^0C for 2 months), as well as assessing product acceptability.*
***Materials and Methods**: Cocoa pod husk was either osmotically or non-osmotically dehydrated at 40°C in 3 hours before making jam, and finished jam samples were stored in the incubator at 4°C for varying amounts of time (0, 1 and 2 months).*
***Results**: Osmotic dehydration had a considerable impact on the physical qualities of the cocoa pod husk samples, including the total soluble solid and water activity. Total soluble solid values were still greater in treated jam samples compared to untreated ones, but other factors, such as moisture content, ash content, and color attributes, had significant influences as well (higher ash content, color values and lower moisture content); however, pH, moisture and color values gradually decreased throughout storage duration in this study. In terms of chemical qualities, osmotic dehydration preserved more nutritional levels in protein and total phenolic content of cocoa pod husk jam but they were lost at different storage times. Nevertheless, crude fiber of jam samples was just lost after jam manufacture, it kept unchanged after storing. Both treated and untreated jam samples had appropriate levels of microorganisms for consumption during storage at 4^0C. Sensory qualities were influenced by osmotic dehydration.*
***Conclusion:** Osmotic dehydration was the most effective approach for reducing nutrient loss, extending the shelf life, and improving the sensory quality of cocoa pod husk jam. After 2 months of storage at 4^0C, although there were some alterations in the jam samples, its qualities were in adequate assessment for consumers.*
***Key Word:** Cocoa pod husk jam, osmotic dehydration, storage*

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I. Introduction

Cocoa (*Theobroma cacao* L.) is a highly profitable tropical crop cultivated primarily in developing countries. It exists in nearly 20 varieties, with **Criollo**, **Forastero**, and **Trinitario** being the most common (Figueroa et al., 2019). In the chocolate industry, cocoa beans are the primary raw material, known for their rich nutrient content. During processing, cocoa beans are extracted from the pod, fermented, ground, and ultimately transformed into various chocolate products. However, the beans constitute only about 21–23% of the total fruit weight (equivalent to 30–40 beans per pod). The remaining portion comprises by-products, most notably the cocoa pod husk (CPH), which accounts for approximately 67–76% of the fruit's weight (Campos-Vega et al., 2018). CPH is typically discarded immediately after bean extraction, where it decomposes and emits unpleasant odors, potentially leading to environmental concerns (Figueroa et al., 2019).

CPH, the fibrous outer shell of the cocoa fruit, is oval-shaped, coarse, and thick, with a bitter and acrid taste due to its high phenolic content (Campos-Vega et al., 2018; Donkoh et al., 1991; Vásquez et al., 2019). Its coloration varies depending on the cocoa variety and serves as a natural defense against environmental stress, pests, and physical damage (Vásquez et al., 2019). While CPH is predominantly used in agriculture—for compost, organic fertilizers, or animal feed—it contains valuable nutrients and bioactive compounds, including carbohydrates (29.04–32.3 g/100g dry matter), dietary fiber (36.6–56.10 g/100g dry matter), and pectin (6.1–9.2 g/100g dry matter). Moreover, it is rich in phenolic compounds and tannins, with concentrations of 4.6–6.9 g GAE/100g and 5.2 g/100g dry matter, respectively—levels that are generally higher than those found in cocoa bean shells. It also has a high mineral content, particularly potassium (2768.0 mg/100g dry matter), manganese (35.72 mg/100g), and zinc (39.74 mg/100g).

Due to its rich composition—especially its high pectin content, a key gelling agent—CPH has potential as a raw material in jam production. This not only offers a way to reduce waste and environmental impact but also adds nutritional value to food products. Jam is a preserved fruit product made by homogenizing fruit pulp with sugar, pectin, citric acid, and optional additives such as flavorings and colorants under heat. Given the seasonal nature and perishability of fruits, jam production enables extended shelf life by reducing the water activity in the fruit matrix. Jam is typically consumed with bread, pastries, or desserts, providing a combination of taste, texture, and nutritional benefits. A high-quality jam should exhibit a spreadable yet firm consistency that prevents it from flowing like a liquid (Garg et al., 2018).

Recent studies have shown that fruit peels are rich in nutrients and health-promoting compounds, including dietary fiber and antioxidants, which can enhance the nutritional profile of the final jam product (B. C. et al., 2017; Boyer & Liu, 2004). Jams enriched with phytochemicals may offer protective health effects, such as improved blood glucose regulation and reduced risk of stroke, hypertension, diabetes, and obesity. Furthermore, jams made with fruit peels may help consumers meet dietary fiber recommendations (Anderson et al., 2009). However, storage conditions significantly affect the quality of jam. Elevated storage temperatures tend to degrade nutritional components, sensory attributes, and overall product stability (Ouarda & Hayette, 2017).

Osmotic dehydration is a promising technique to enhance the shelf life and stability of jam ingredients. This process involves the movement of water from a food product into a hypertonic solution (typically sugar syrup or brine), driven by osmotic pressure. Simultaneously, solutes such as sugars and minerals from the solution diffuse into the food matrix. This bidirectional mass transfer reduces moisture content and can influence the nutritional and sensory characteristics of the final product (Le Maguer & Biswal, 1988; Oyeyinka et al., 2011; Yadav & Singh, 2012).

II. Material And Methods

Raw material preparation

Raw cocoa pod husk and cocoa sweating were obtained from Cocoa Trong Duc Company (Dong Nai Province, Vietnam). The pod husks were washed thoroughly under tap water to remove dust and foreign matter. The cleaned husks were sliced into pieces approximately 3.8 mm thick (Araújo et al., 2014) to enhance osmotic solution absorption.

The osmotic solution was prepared by dissolving icing sugar in distilled water using a blender (Philips HR2118, Indonesia). The solution was adjusted to 40°Brix and maintained at 40 °C in a drying oven. Cocoa pod husk slices were soaked in the solution at a 1:10 (w/v) ratio for 3 hours.

Control samples (non-osmotically dehydrated) were dried in an oven at 40 °C for 3 hours without soaking in sugar solution.

Jam preparation

After soaking, both osmotically and non-osmotically dehydrated husk samples were blended separately (Philips HR2118, Indonesia) to form a uniform mixture (blending time: 8 minutes).

Each mixture was then combined with its corresponding sugar solution at a 1:1 (v/v) ratio:
Osmotically treated husk mixture was mixed with its osmotic solution.
Non-treated mixture was blended with a 40°Brix sugar solution.

Cocoa juice was added to both formulations and heated to approximately 80 °C to ensure complete dissolution. Lime juice (0.1%) was added as an acidifying agent. Manual stirring was continued until gel formation, with a final total soluble solids (TSS) content of 46.1°Brix, measured using a refractometer (Perumpuli et al., 2018). Prepared jam was stored in sterilized glass jars at 4 °C for 0, 1, and 2 months.

Jam Storage Conditions

Jam samples were coded based on treatment and storage duration (Table 1). Osmotically dehydrated samples were labeled “OD”, and non-osmotically treated samples as “NO”.

Table 1. Experimental design of cocoa pod husk jam

Storage time (month)	0	1	2
Osmotic dehydration	OD_0	OD_1	OD_2
No osmotic dehydration	NO_0	NO_1	NO_2

Physical and Chemical Analyses

Total Soluble Solids and pH

TSS was measured using a digital refractometer (Atago RX 5000 Alpha), and pH was determined with a calibrated pH meter (HANNA Instruments HI 2216).

Moisture Content

Moisture content was determined using a forced draft oven at 130 °C. Pre-dried aluminum pans (at 105 °C for 3 hours) were used to hold ~2 g samples. Weights were recorded at 30-minute intervals until constant. Moisture content was calculated as:

$$Moisture\ content\ (\%) = \frac{(wt\ of\ wet\ sample+pan)-(wt\ of\ dried\ sample+pan)}{(wt\ of\ wet\ sample+pan)-(wt\ of\ pan)}\ x100$$

Ash Content

Ash content was determined using the dry ashing method (AOAC, 2006). Dried jam samples were incinerated in a muffle furnace at 550 °C for 4 hours. The residue was weighed and used to calculate ash content.

Color Measurement

Color parameters (L*, a*, b*) were measured using a colorimeter (LUTRON RGB-1002, Coopersburg, Pennsylvania, USA).

Protein Conten

Protein was quantified using the Kjeldahl method (AOAC, 1995). A 1 g sample was digested with 0.09 g $CuSO_4$, 4.9 g K_2SO_4, and 20 mL concentrated H_2SO_4. After digestion, distillation was performed using 50 mL NaOH and 50 mL 4% H_3BO_3 with Tashiro's indicator. The distillate was titrated with 0.1 N H_2SO_4 until a light purple endpoint was reached.

$$\%\ N = Normality\ H2SO4 \times \frac{Corrected\ acid\ volume\ (l)}{g\ of\ sample}\ x\ \frac{14gN}{mol}\ x100$$

$$Protein\ content\ (\%) = \%N \times Protein\ factor$$

Crude Fiber Content

Crude fiber was measured by the standard method involving acid-base digestion using sulfuric acid and potassium hydroxide to eliminate soluble components. The insoluble residue was dried, weighed, and used to compute crude fiber content.

Total Phenolic Content (TPC)

TPC was determined using the Folin–Ciocalteu method (Lamuela-Raventós, 2017). Two milliliters of sample were extracted with 8 mL of 1.2 M HCl in 50% methanol at 60 °C for 2 hours in darkness. The extract was centrifuged at 4500 rpm for 15 minutes at 4 °C. One milliliter of supernatant was mixed with 1 mL of 10% Folin–Ciocalteu reagent, 8.4 mL of distilled water, and 5 mL of 10% sodium carbonate. After 2 hours of incubation at room temperature, absorbance was measured at 760 nm. Gallic acid was used as the standard. Results were expressed as mg GAE/100 mL.

Microbiological Analysis

Microbial quality was assessed following Choo et al. (2018) with slight modifications. Samples were serially diluted to 10^{-3} using buffered peptone water.

Aerobic mesophilic bacteria were plated on Plate Count Agar (PCA) and incubated at 37 °C for 24 hours.
Yeast and mold counts were assessed on Dichloran Rose Bengal Chloramphenicol (DRBC) agar at 25 °C for 5 days.

Only samples with microbial counts below 10^4 CFU/mL (Center for Food Safety, 2014) were considered safe for sensory evaluation.

Sensory Evaluation

Thirty untrained panelists from the local community evaluated the six jam samples. Each panelist received 3 g of jam on a small bread slice and rinsed with water between samples. Sensory attributes assessed included appearance, texture, aroma, taste, sweetness, sourness, aftertaste, spreadability, and overall acceptability.

A 5-point hedonic scale was used:
- 5 = Very Like
- 1 = Strongly Dislike

Samples were coded and presented in randomized order under controlled lighting conditions.

Statistical Analysis

All measurements were performed in triplicate. Results were expressed as mean ± standard deviation (SD). Statistical significance between two treatments was evaluated using independent t-tests, while one-way ANOVA was used to analyze the effect of storage time. Post-hoc comparisons were performed using Fisher's Least Significant Difference (LSD) test at $p \leq 0.05$.

III. Result

Effect of Osmotic Dehydration on Physical Properties of Cocoa Pod

The physical quality of food ingredients plays a vital role in determining their processing behavior, microbial stability, and shelf life. In this study, the impact of osmotic dehydration (OD) on the **total soluble solids (TSS)** and **water activity (aw)** of cocoa pod was investigated, and the results are summarized in Table 2.

Table 2. Physical qualities of osmotically and non-osmotically dehydrated cocoa pod husk

TSS (^{0}Brix)		a_w	
OD	NO	OD	NO
24.667 ± 0.577^a	4.667 ± 0.289^b	0.964 ± 0.003^b	0.997 ± 0.001^a

The values are expressed as mean ± SD (n=3).
a, b: The results in the same row with the same letter are not significantly different (Comparison t-test,$p \leq 0.05$).

Total Soluble Solids (TSS)

TSS, measured in degrees Brix (°Brix), indicates the concentration of soluble substances, predominantly sugars, in a food matrix. The cocoa pod sample subjected to osmotic dehydration exhibited a significantly higher TSS (24.667 ± 0.577 °Brix) compared to the non-osmotically dehydrated (NO) sample (4.667 ± 0.289 °Brix) ($p \leq 0.05$). This considerable increase in soluble solids in the OD treatment reflects the **mass transfer phenomena** during the osmotic process, whereby water diffuses out of the cocoa pod cells while sugar from the osmotic solution permeates into the tissue.

The sugar solution used for OD was initially at 40 °Brix, and after treatment, the remaining solution decreased to 35.667 ± 0.289 °Brix. This decrease confirms **dilution due to water migration** from the cocoa pod into the osmotic medium. Simultaneously, the cocoa pod absorbed sugar, enhancing its TSS. This aligns with findings by Lech et al. (2017), who described the bidirectional mass transfer characteristic of osmotic dehydration, which is key to enriching product solids and improving texture and flavor retention.

In contrast, the NO sample, lacking exposure to the sugar solution, retained its naturally low sugar content and therefore exhibited low TSS values. This low concentration is expected in untreated cocoa pods due to their fibrous, high-moisture nature.

Water Activity (a_w)

Water activity is a crucial indicator of **microbial stability** and **shelf-life potential** of food products. OD samples demonstrated significantly lower aw (0.964 ± 0.003) than NO samples (0.997 ± 0.001) ($p \leq 0.05$). The higher aw in NO samples suggests that **free water remains readily available** for microbial activity, increasing the risk of spoilage and reducing storage stability.

In contrast, the OD treatment effectively lowered aw without requiring thermal drying. Osmotic dehydration reduces the water content by establishing an osmotic gradient, where water is removed from the tissue without a phase change. As reported by Oyeyinka et al. (2011) and Yadav & Singh (2012), this non-thermal method offers a **gentle water-removal technique** that helps retain heat-sensitive nutrients and color while improving microbial stability. The decrease in aw after OD in this study confirms the treatment's efficacy in preconditioning the cocoa pod material for further processing steps such as jam production. Prosapio & Norton (2017) similarly observed aw reduction through osmotic dehydration, reinforcing its use as a method to extend the shelf life and improve the safety profile of plant-based materials.

Effect of Dehydration and Storage Time on the Physical Properties of Cocoa Pod Husk Jam at 4°C

Effect of Osmotic Dehydration and Storage Time on Physicochemical Properties of Cocoa Pod Jam

Table 3 presents the effects of osmotic dehydration (OD) and non-osmotic dehydration (NO) treatments on the pH, moisture content, and ash content of cocoa pod jam during two months of refrigerated storage.

Table 3. Physical value of osmotically dehydrated and non-osmotically dehydrated cocoa pod jam during storage

Storage time	pH		Moisture content (%)		Ash (%)	
	OD	NO	OD	NO	OD	NO
0	3.637 ± 0.006^{a,x}	3.633 ± 0.006^{a,x}	49.520 ± 0.010^{b,x}	54.975 ± 0.127^{a,z}	0.598 ± 0.003^{a,x}	0.497 ± 0.001^{b,x}
1	3.607 ± 0.012^{a,y}	3.603 ± 0.006^{a,y}	49.243 ± 0.051^{b,y}	52.164 ± 0.413^{a,y}	0.593 ± 0.001^{a,x}	0.495 ± 0.010^{b,x}
2	3.59 ± 0.01^{a,y}	3.583 ± 0.015^{a,z}	48.873 ± 0.110^{b,z}	51.981 ± 0.034^{a,y}	0.592 ± 0.003^{a,x}	0.487 ± 0.001^{b,x}

The values are expressed as mean ± SD (n=3).
a, b: The results in the same row with the same letter are not significantly different (Comparison t-test, $p \leq 0.05$).
x, y, z: The results in the same column with the same letter are not significantly different (Fisher comparison test, $p \leq 0.05$).

pH

At the start of storage, the pH of the OD and NO jams was 3.637 and 3.633, respectively, with no statistically significant difference observed between treatments ($p > 0.05$). This trend persisted throughout the two-month storage period, with both treatments exhibiting similar pH values at each time point (Table 3). However, a progressive decline in pH was evident across the storage duration for both treatments. In OD samples, pH decreased from 3.637 at month 0 to 3.590 at month 2, while NO samples showed a reduction from 3.633 to 3.583 over the same period. The decline in pH over time, although slight, was statistically significant within the NO samples, as indicated by differing superscript letters across time points. This suggests possible biochemical activity, such as the slow formation of organic acids from residual fermentable sugars or microbial metabolism, despite refrigeration. The similar pH trends in both treatments indicate that osmotic dehydration did not significantly alter the acid-base stability of the product during storage.

Moisture Content

Moisture content showed marked differences between the two treatments. Initially, OD jam had a significantly lower moisture content (49.520%) compared to NO jam (54.975%) ($p \leq 0.05$). This discrepancy is attributable to the osmotic dehydration process, which effectively reduced the water content in the OD samples prior to jam preparation. The reduced moisture levels in OD samples were maintained throughout storage, with values ranging from 49.520% to 48.873%. In contrast, the NO samples exhibited a gradual decrease in moisture content, dropping to 51.981% by the end of the two-month storage period. The reduction in moisture content over time, particularly in the NO samples, is likely due to slow water loss via evaporation, even under refrigerated conditions. The consistent difference between the two treatments underscores the effectiveness of osmotic dehydration in producing a more concentrated product with lower water activity. This is advantageous for microbial stability and may contribute to an extended shelf life of OD jams.

Ash Content

Ash content, representing the total mineral residue, also differed significantly between treatments. OD samples exhibited higher ash content (~0.59%) compared to NO samples (~0.49%) throughout the storage period ($p \leq 0.05$). This elevated ash content in OD jams is likely a result of the concentration effect induced by water removal during the osmotic dehydration process, which preserves and concentrates mineral components. No significant changes in ash content were observed over the storage period for either treatment, as indicated by the consistent superscript letters across time points. This stability suggests that mineral content remains intact during refrigerated storage, and is not subject to leaching or degradation.

Color Stability of Osmotically Dehydrated and Non-Osmotically Dehydrated Cocoa Pod Jam During Storage

Color is a critical quality attribute in fruit-based products, influencing consumer acceptance and indicating chemical and physical changes during processing and storage. The color parameters of osmotically dehydrated (OD) and non-osmotically dehydrated (NO) cocoa pod jam were evaluated over a two-month storage period (Table 4).

Color parameter	Storage time	Treatment	
		OD	NO
L	0	$38.820 \pm 0.035^{a,x}$	$22.983 \pm 0.029^{b,x}$
	1	$38.580 \pm 0.026^{a,y}$	$22.837 \pm 0.035^{b,y}$
	2	$36.683 \pm 0.015^{a,z}$	$22.530 \pm 0.036^{b,z}$
a	0	$30.140 \pm 0.036^{a,x}$	$22.597 \pm 0.055^{b,x}$
	1	$30.033 \pm 0.058^{a,y}$	$22.543 \pm 0.045^{b,x}$
	2	$29.797 \pm 0.006^{a,z}$	$22.370 \pm 0.044^{b,y}$
b	0	$45.567 \pm 0.058^{a,x}$	$31.487 \pm 0.050^{b,x}$
	1	$44.720 \pm 0.053^{a,y}$	$31.267 \pm 0.006^{b,y}$
	2	$44.597 \pm 0.055^{a,z}$	$54.333 \pm 0.111^{b,xy}$
Hue	0	$56.517 \pm 0.050^{a,x}$	$54.333 \pm 0.111^{b,xy}$
	1	$56.113 \pm 0.076^{a,y}$	$54.230 \pm 0.095^{b,y}$
	2	$56.253 \pm 0.031^{a,z}$	$54.420 \pm 0.053^{b,x}$
Chroma	0	$54.633 \pm 0.047^{a,x}$	$38.756 \pm 0.009^{b,x}$
	1	$53.869 \pm 0.033^{a,y}$	$38.568 \pm 0.038^{b,y}$
	2	$53.635 \pm 0.046^{a,z}$	$38.445 \pm 0.023^{b,z}$

Table 4. The changes in color properties of osmotically dehydrated and non-osmotically dehydratedcocoa pod jam during storage

The values are expressed as mean ± SD (n=3).
a, b: The results in the same row with the same letter are not significantly different (Comparison t-test,$p \leq 0.05$).
x, y, z: The results in the same column with the same letter are not significantly different (Fisher comparison test, $p \leq 0.05$).

Parameters assessed included lightness (L*), redness (a*), yellowness (b*), chroma, and hue angle.

The initial superiority of OD jam in color quality can be attributed to the osmotic dehydration process. Immersing cocoa pod slices in a sugar solution likely reduced water activity and protected color-sensitive compounds by minimizing enzymatic and non-enzymatic browning. Sugars can act as barriers to oxygen diffusion and inhibit polyphenol oxidase activity, which collectively preserve color integrity (Torres et al., 2012).

A gradual and statistically significant decline ($p \leq 0.05$) in color parameters was observed in both OD and NO jam samples over the 2-month storage period. This degradation was more pronounced in the NO treatment, where L*, a*, and b* values declined more steeply than in OD samples. For instance, the L* value in OD jam decreased from 38.820 to 36.683, while in NO jam it declined from 22.983 to 22.530. A similar trend was seen for a* and b*, indicating loss of brightness and red-yellow hues, likely due to pigment degradation and oxidative reactions.

Despite the overall decline, OD jam retained significantly higher color values throughout storage, suggesting improved stability. Notably, OD samples maintained color saturation (chroma) and hue angle better than their NO counterparts. Chroma values decreased slightly from 54.633 to 53.635 in OD jam, while NO samples decreased from 38.756 to 38.445. Hue angle remained stable in OD jam (~56), confirming that the red-orange color tone persisted.

These results align with findings by Wicklund et al. (2005), who observed similar color trends in strawberry jam during storage at 40°C. The hue angle remaining above 50 across treatments suggests a consistent dominance of orange-red tones, desirable for fruit preserves.

Although both treatments experienced color fading, OD jam’s superior initial color and slower degradation rate suggest enhanced consumer appeal over storage time. Sensory analysis (Table 12, not shown) further supports this, indicating that OD jam maintained acceptable appearance and color ratings throughout the testing period.

The osmotic treatment, therefore, offers a viable pre-treatment method for improving the visual and possibly nutritional stability of cocoa pod-based jams. Given cocoa pod is typically an underutilized by-product, such value-added processing may enhance its market potential.

Chemical composition Cocoa Pod Husk Jam

Protein Content

As shown in Table 5, the protein content of the cocoa pod husk jam was significantly higher in the OD (osmotic dehydration) treatment (0.461 ± 0.002%) compared to the NO (non-osmotic) treatment (0.352 ± 0.004%) at the beginning of storage ($p \leq 0.05$). This significant difference is attributed to the impact of osmotic dehydration in reducing moisture content prior to cooking, which minimized thermal degradation during processing. Over the two-month refrigerated storage period, both treatments exhibited a slight decrease in protein content. However, these reductions were not statistically significant ($p > 0.05$). By the end of storage, the OD jam retained a protein content of 0.447 ± 0.009%, while the NO jam declined slightly to 0.348 ± 0.001%.

Table 5. Protein content of cocoa pod husk jam during storage

Storage times (month)	OD (%)	NO (%)
0	0.461 ± $0.002^{a,x}$	0.352 ± $0.004^{b,x}$
1	0.449 ± $0.006^{a,y}$	0.349 ± $0.001^{b,xy}$
2	0.447 ± $0.009^{a,y}$	0.348 ± $0.001^{b,xy}$

The values are expressed as mean ± SD (n=3).

a, b: The results in the same row with the same letter are not significantly different (Comparison t-test,$p \leq 0.05$).

x, y, z: The results in the same column with the same letter are not significantly different (Fisher comparison test, $p \leq 0.05$).

The higher initial protein content observed in the OD-treated jam underscores the protective effect of osmotic dehydration against heat-induced protein degradation. By reducing the moisture content before thermal processing, the OD treatment allowed for a shorter cooking time, thereby limiting protein denaturation and Maillard reactions. In contrast, the NO jam, which underwent longer cooking to achieve the desired consistency, likely experienced greater protein loss through these thermal mechanisms. While the overall protein values (0.348–0.461%) are considerably lower than those reported in native cocoa pod husk (4.21–10.74%), they remain within the expected range for fruit jams (0.04–0.79%). The absence of significant protein decline during storage suggests that protein in both jam formulations remained relatively stable under refrigerated conditions. These findings highlight the potential of osmotic dehydration as an effective pretreatment method for improving the nutritional quality of cocoa pod husk-based jams.

Crude Fiber

As presented in Table 6, the crude fiber content of cocoa pod husk jam remained stable throughout the two-month refrigerated storage period for both OD and NO treatments. At the start of storage, both treatments recorded identical values of 2.878 g/100g. Minor fluctuations were observed over time; however, these differences were not statistically significant ($p > 0.05$), as indicated by the consistent superscript letters across all rows and columns. By the end of the storage period, fiber content ranged from 2.874 to 2.883 g/100g in OD samples and from 2.878 to 2.882 g/100g in NO samples. The crude fiber content of the cocoa pod husk jam was unaffected by the type of dehydration treatment or by refrigerated storage over two months. The lack of significant variation between OD and NO samples suggests that neither osmotic pretreatment nor the thermal processes involved in jam preparation significantly altered the fiber components. Furthermore, the short duration and low temperature of storage likely contributed to the fiber stability, as fiber constituents such as cellulose and lignin are resistant to degradation under mild conditions. These results highlight the robustness of dietary fiber in cocoa pod husk and suggest that its incorporation into value-added products like jam can retain functional fiber benefits over time, regardless of processing method.

Table 6. Crude fiber content of cocoa pod husk jam during storage

Storage times (month)	OD (g/100g)	NO (g/100g)
0	$2.878 \pm 0.003^{a,x}$	$2.878 \pm 0.007^{a,x}$
1	$2.883 \pm 0.003^{a,x}$	$2.879 \pm 0.006^{a,x}$
2	$2.874 \pm 0.011^{a,x}$	$2.882 \pm 0.002^{a,x}$

The values are expressed as mean ± SD (n=3).
a, b: The results in the same row with the same letter are not significantly different (Comparison t-test,$p \leq 0.05$).
x, y, z: The results in the same column with the same letter are not significantly different (Fisher comparison test, $p \leq 0.05$).

Total Phenolic Content (TPC)

Table 7 shows the total phenolic content (TPC) of cocoa pod husk jam subjected to osmotic (OD) and non-osmotic (NO) dehydration and stored at 40 °C for two months.

Table 7. Total Phenolic Content of cocoa pod husk jam during storage

Storage times(month)	TPC (mgGAE/100g)	
	OD	NO
0	$105.616 \pm 0.160^{a,x}$	$56.976 \pm 0.577^{b,x}$
1	$104.229 \pm 0.647^{a,x}$	$45.349 \pm 0.647^{b,y}$
2	$86.469 \pm 3.029^{a,y}$	$37.883 \pm 0.244^{b,z}$

The values are expressed as mean ± SD (n=3).
a, b: The results in the same row with the same letter are not significantly different (Comparison t-test,$p \leq 0.05$).
x, y, z: The results in the same column with the same letter are not significantly different (Fisher comparison test, $p \leq 0.05$).

At the start of storage, the OD jam exhibited a significantly higher TPC (105.616 ± 0.160 mg GAE/100 g) than the NO jam (56.976 ± 0.577 mg GAE/100 g) ($p \leq 0.05$). This trend persisted throughout storage. After one month, TPC declined to 104.229 ± 0.647 mg GAE/100 g in OD samples and 45.349 ± 0.647 mg GAE/100 g in NO samples, and by the second month, values dropped further to 86.469 ± 3.029 mg GAE/100 g and 37.883 ± 0.244 mg GAE/100 g, respectively. All reductions over time were statistically significant ($p \leq 0.05$), with NO samples showing more pronounced degradation. These findings are consistent with those of Kumar et al. (2017), who noted that heat processing disrupts fruit cell structures, rendering phenolic compounds more susceptible to non-enzymatic oxidation. The sharp decline in TPC over the two-month storage period, particularly under elevated temperature (40 °C), further supports this. Oxidative degradation of phenolics during storage is a well-documented phenomenon, as also reported in papaya jam (Nafri et al., 2021) and black carrot marmalades (Kamiloglu et al., 2015). Despite the decline, OD samples consistently retained more phenolic compounds than NO samples, reinforcing the protective effect of osmotic dehydration on antioxidant retention. These results underscore the importance of processing methods in preserving the functional quality of fruit-based products.

Microbiological Quality

Table 8 presents the microbiological quality of cocoa pod husk jam processed via osmotic (OD) and non-osmotic (NO) dehydration and stored for two months. Total aerobic bacteria, as well as yeast and mold counts, were consistently below the detectable threshold of 1.0 × 10^6 CFU/g across all treatments and time points. No microbial growth was observed immediately after processing or during storage, regardless of the dehydration method used. These results confirm that both OD and NO jams remained microbiologically safe throughout the two-month storage period.

Table 8. Microbiological analysis of osmotically and non-osmotically dehydrated cocoa pod jam during storage.

Storage times (month)	Total aerobic bacteria (CFU/g)		Yeast and mold (CFU/g)	
	OD	NO	OD	NO
0	< 1.0 x 10^6	< 1.0 x 10^6	< 1.0 x 10^6	< 1.0 x 10^6
1	< 1.0 x 10^6	< 1.0 x 10^6	< 1.0 x 10^6	< 1.0 x 10^6
2	< 1.0 x 10^6	< 1.0 x 10^6	< 1.0 x 10^6	< 1.0 x 10^6

After the treatment process, both bacteria, yeast and mold were not found (< 1.0 x 10^6 CFU/g). Following that, after 2 months of storage, the jam's microbial load remained constant and met the requirement set by the Center for Food Safety in 2014, which stated that the examined samples must be below 10^4 CFU/mL is the permissible limit of microbiological criteria for ready-to-eat food. The extreme heat used during jam manufacture, the low pH (4.6 or lower) and sugar content (higher than 45°Brix) and high content of polyphenolic chemicals of the product could all be contributing factors to the decrease in microbe levels (Makanjuola et al., 2019, Perumpuli et al., 2018). The results were compared to those from Rubio-Arraez et al., (2016) indicating that no citrus jelly samples were discovered to contain mesophilic bacteria, yeasts, or molds after 1, 15, or 30 days of storage at 4ºC or Perumpuli et al., (2018) reporting that the developed product was stored under refrigeration for six months with a total plate count and yeast and mold counts of 10^2 CFU/g which was in a safety limit for jam products. Therefore, osmotic dehydration may significantly affect the microbiological property of cocoa pod jam due to the removal of the water activity of fruits, the addition of sugar solution, etc. (Yadav & Singh, 2012).

Sensory quality

Table 9 presents the average sensory scores for cocoa pod husk jam samples processed using osmotic (OD) and non-osmotic (NO) dehydration techniques, evaluated over a two-month storage period.

Table 9. Sensory quality of cocoa pod jam during 2 months of storage

		Treatment		
Sensory attributes	Storage times (month)			
		OD		NO
	0	4.133 ± 0.730^{a,x}		2.433 ± 0.817^{b,x}
Appearance	1	3.933 ± 0.640^{a,x}		2.167 ± 0.986^{b,x}
	2	3.833 ± 0.592^{a,x}		2.4 ± 0.968^{b,x}
	0	3.633 ± 0.999^{a,x}		2.467 ± 0.860^{b,x}
Texture	1	3.567 ± 0.935^{a,x}		2.367 ± 0.964^{b,x}
	2	3.933 ± 0.740^{a,x}		2.267 ± 0.980^{b,x}
	0	4.067 ± 0.583^{a,x}		3.033 ± 0.928^{b,x}
Scent	1	3.8 ± 0.610^{a,x}		3.067 ± 0.907^{b,x}
	2	4 ± 0.587^{a,x}		3.367 ± 0.890^{b,x}
	0	4 ± 0.871^{a,x}		2.933 ± 0.907^{b,x}
Taste	1	4.3 ± 0.535^{a,x}		2.967 ± 1.098^{b,x}
	2	4.067 ± 0.740^{a,x}		3.067 ± 1.112^{b,x}
	0	4.067 ± 0.691^{a,x}		3.3 ± 1.022^{b,x}
Sweetness	1	4.067 ± 0.640^{a,x}		3.133 ± 0.973^{b,x}
	2	4.067 ± 0.640^{a,x}		3.233 ± 0.971^{b,x}
	0	4.133 ± 0.819^{a,x}		3.433 ± 0.898^{b,x}
Sourness	1	3.833 ± 0.791^{a,x}		3.167 ± 1.020^{b,x}
	2	3.8 ± 0.714^{a,x}		3.333 ± 0.884^{b,x}
	0	3.93 ± 0.907^{a,x}		3 ± 0.830^{b,x}
Aftertaste	1	3.867 ± 0.730^{a,x}		3.1 ± 0.712^{b,x}
	2	3.8 ± 0.761^{a,x}		3.033 ± 0.718^{b,x}
	0	3.967 ± 0.928^{a,x}		2.367 ± 0.890^{b,x}
Spreadability	1	4.3 ± 0.837^{a,x}		2.433 ± 1.073^{b,x}
	2	4.067 ± 0.785^{a,x}		2.533 ± 0.860^{b,x}
General acceptability	0	3.967 ± 0.850^{a,x}		2.8 ± 0.664^{b,x}
	1	4.233 ± 0.568^{a,x}		2.6 ± 0.724^{b,x}

	2	4.133 ± 0.507[a,x]		2.833 ± 0.834[b,x]

The values are expressed as mean ± SD (n=30).

a, b: The results in the same row with the same letter are not significantly different (Comparison t-test,$p \leq 0.05$).
x, y: The results in the same column with the same letter are not significantly different (Fisher comparison test, $p \leq 0.05$).

Sensory attributes assessed included appearance, texture, scent, taste, sweetness, sourness, aftertaste, spreadability, and general acceptability, rated on a 5-point hedonic scale. Across all attributes and storage periods, OD jam consistently received significantly higher ratings than NO jam ($p \leq 0.05$). At the initial evaluation, OD jam achieved the highest scores in appearance (4.133 ± 0.730), texture (3.633 ± 0.999), scent (4.067 ± 0.583), taste (4.000 ± 0.871), sweetness (4.067 ± 0.640), sourness (4.133 ± 0.819), aftertaste (3.933 ± 0.907), spreadability (3.967 ± 0.928), and general acceptability (3.967 ± 0.850). In contrast, NO jam scored below 3 in most categories, with the lowest scores observed for appearance (2.433 ± 0.817) and spreadability (2.367 ± 0.890). Throughout the two-month storage period, sensory scores remained statistically unchanged for both treatments ($p > 0.05$), indicating good sensory stability over time. The superior sensory performance of OD jam compared to NO jam can be attributed to the beneficial effects of osmotic dehydration on product quality. The OD process likely helped preserve the color, flavor, and textural integrity of the cocoa pod husk by reducing thermal degradation and improving ingredient integration during cooking (Yadav & Singh, 2012). Panelists consistently favored OD samples, describing them as more visually appealing, better textured, more flavorful, and more pleasant overall. In contrast, the NO jam was criticized for its gritty texture and inconsistent mouthfeel, likely due to incomplete cell breakdown and the presence of fine cocoa pod husk particles that were not fully softened during processing. Importantly, storage time did not significantly affect any sensory parameters for either jam type. This suggests that refrigerated storage preserved sensory quality well over two months, consistent with findings by Touati et al. (2014), who reported that the interaction between storage time and temperature had no significant impact on sensory profiles in fruit-based products.

Overall, the consistently higher scores for OD jam across all attributes and time points highlight the efficacy of osmotic dehydration in enhancing consumer acceptance of cocoa pod husk jam. These findings support its potential as a viable method for developing functional, upcycled fruit spreads with favorable sensory appeal.

IV. Conclusion

Osmotic dehydration significantly enhances the quality and shelf-life of cocoa pod husk jam compared to non-osmotic methods. OD samples showed superior physical, chemical, and sensory characteristics while maintaining microbiological safety throughout two months of storage. This study supports osmotic dehydration as a viable technique for valorizing agricultural waste like cocoa pod husk into functional food products.

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