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Comparative analysis of coconut testa oil recovered by dry and wet processing methods

D.G.C.S. Ilangarathne[a,b], J.M.N. Marikkar[b], B.G.R.R. Bandara[a], H.P.D.T. Hewa Pathirana[a] and L.L.W.C. Yalegama[a,✉]

[a]Coconut Research Institute, Lunuwila, Sri Lanka
[b]National Institute of Fundamental Studies, Hanthana Road, Kandy, Sri Lanka
✉Corresponding author: chandi_yalegama@cri.gov.lk

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SUMMARY: The aim of this study was to compare the quality indices and antioxidant capacity of coconut testa oil (CTO) produced by dry and wet processes. In the dry process, coconut testa from fresh nuts was dehydrated and subjected to oil extraction using a screw-press expeller. In the wet process, testa milk was extracted and chilled for subjecting it to centrifugation in order to collect the cream layer under different temperatures and centrifugation speeds. The oil samples of the two processes were evaluated for yield recoveries and various quality indices. The shelf-life stability of the CTO was monitored over a period of 3-months by keeping it under ambient temperature (28-30 °C). The oils obtained by the dry and wet-centrifuge processes displayed considerable differences with regards to physicochemical parameters, phenolic content, and antioxidant capacity. The CTO recovered by the dry process displayed better shelf-life stability, while oils recovered by the wet-centrifuge process exhibited better antioxidant properties.

KEY-WORDS*: Antioxidant capacity; Coconut testa oil; Dry processing; Phenolic content; Physicochemical properties; Wet processing.*

RESUMEN: ***Análisis comparativo del aceite de testa de coco recuperado mediante métodos de procesamiento seco y húmedo.*** El objetivo de este estudio fue comparar índices de calidad y capacidad antioxidante del aceite de testa de coco (CTO) extraído por procesos secos y húmedos. En el proceso seco, la testa de coco de frutos frescos se deshidrató y se sometió a extracción de aceite mediante una prensa de tornillo. En el proceso húmedo, la leche de testa se extrajo y se enfrió para someterla a centrifugación para obtener la capa de crema a diferentes temperaturas y velocidades de centrifugación. Los aceites de los dos procesos fueron evaluados en cuanto a rendimiento y diferentes índices de calidad. La estabilidad durante la vida útil del CTO se controló durante un período de 3 meses manteniendo las muestras a temperatura ambiente. Los aceites obtenidos por los procesos de centrifugación seca y húmeda mostraron diferencias considerables con respecto a parámetros físico-químicos, contenido fenólico y capacidad antioxidante. El CTO recuperado mediante el proceso seco mostró una mejor estabilidad durante la vida útil, mientras que los aceites recuperados mediante el proceso húmedo exhibieron mejores propiedades antioxidantes.

PALABRAS CLAVE: *Aceite de testa de coco; Capacidad antioxidante; Contenido fenólico; Procesamiento en seco; Procesamiento húmedo; Propiedades fisicoquímicas.*

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1. INTRODUCTION

Coconut testa (CT) is the thin brown outer layer of the white edible endosperm of the coconut fruit. In traditional coconut processing for products such as virgin coconut oil, desiccated coconut, coconut milk, and coconut milk powder, the testa is usually removed to prevent the brown color from affecting finished products. Removal of the testa from the coconut would result in a substantial loss of kernel and hence have negative economic implications given the current value of coconuts (Gunarathne *et al*., 2022a). Owing to its high lipid content, CT is a potential raw material for the extraction of coconut testa oil (CTO). According to previous research, CTO has shown a higher tocopherol content and an increased level of phenolic constituents when compared to coconut kernel oils (Narayanakutty *et al*., 2022). Additionally, the fatty acid profile of CTO was found to contain a greater concentration of oleic and linoleic acids (Marikkar and Nasyrah, 2012). The results of the *in vitro* studies demonstrated its effectiveness in scavenging peroxide and DPPH radicals. Furthermore, analyses have revealed that the extract from CTO was found to contain elevated levels of phenolic acids and flavonoids, highlighting its nutritional and pharmacological significance for applications in both the food and pharmaceutical industries (Narayanakutty *et al*., 2022). In the past, various methods including the dry process, wet boiling process, cream separation method, centrifugation methods, and fermentation methods were tried for CTO production. As reported previously, CTO differs slightly from regular coconut oil in terms of fatty acid composition, iodine value, appearance, odor, etc. (Marikkar and Nasyrah, 2012). Often, CTO is undervalued in the oil trade and business as an industrial-grade oil (Gunarathne *et al*., 2022b). This undervaluation may be attributed to myths prevailing in society suggesting that CTO is unsuitable for human consumption due to high acidity or the presence of toxic compounds. In practical terms, high acidity in CTO might occur if there are delays in the processing of the testa after its removal from the coconut flesh. Such delays would result in microbial invasion, leading to the deterioration of the quality parameters of CTO. It is imperative for local industries to promptly utilize CT in order to enhance the quality of CTO. Hence, research and development initiatives are imperative to optimize methods for extracting high-quality CTO. To address the prevailing research gap, experiments were conducted to compare CTO extracted by the dry-process and wet-centrifuge methods.

2. MATERIALS AND METHODS

2.1. Materials

CT Samples were brought to the laboratory from a desiccated coconut factory located at Bujjampola, Sri Lanka. All chemicals used in this study were analytical grade unless otherwise specified.

2.2. Methods

2.2.1. Dry processing of coconut testa oil

The raw CT samples were pulverized into medium-sized particles using a locally fabricated disintegrator (Unitex Engineers, Sri Lanka). The pulverized CT samples were dried at 70 °C in a cabinet-type dehydrator (Udaya Dehydrators, Sri Lanka) for about 8 hours. The dried samples were then fed into a micro-screw press expeller (GOYUM 20) to extract oil. The extracted crude oil was purified through gravity filtration using a layer of cotton wool.

2.2.2. Wet-centrifuge processing of coconut testa oil

The pulverized wet CT samples were subjected to coconut testa milk extraction with the help of a hydraulic press machine (MPH10 model). The wet-centrifuge method (Thermo Fisher Scientific- ST 8) involves four different treatments employed to produce CTO. The detail given in Table 1 represents the four treatments allocated for expelling CTO and the oil yield recoveries coming from them. In brief, freshly extracted coconut testa milk was chilled at 4 ^{o}C for 24 hours until the water layer was separated. The creamy oil-rich layer was

separated after 24 hours and the contents were allowed to stand at 30 °C until all solidified lipids became melted. The contents were then loaded into centrifugal tubes and subjected to centrifugation at 2000, 4000, and 6000 rpm for 15 and 30 min at temperatures of 20 and 30 °C for the different treatments (Table 1). At the end of the centrifugation process, the oil was separated as the supernatant and filtered through a cotton-wool layer. Finally, clear CTO was collected and stored in the refrigerator until further analysis.

TABLE 1. Dry and wet processing treatment conditions for extraction of coconut testa oil

Processing method	Treatment	Processing conditions		
		Temperature ºC	Centrifugation speed (rpm)	Time duration
Dry Processing (Oven drying)	T0	70	-	8 h
Wet Processing (Centrifugation method)	T1	20	2000	15 min
	T2	20	2000	30 min
	T3	30	2000	15 min
	T4	30	2000	30 min
	T5	20	4000	15 min
	T6	20	4000	30 min
	T7	30	4000	15 min
	T8	30	4000	30 min
	T9	20	6000	15 min
	T10	20	6000	30 min
	T11	30	6000	15 min
	T12	30	6000	30 min

2.2.3. Determinations of physicochemical properties of coconut testa oil

Moisture, volatile matter content in the oil, peroxide value, color, free fatty acid (FFA) content, and iodine values of the samples were determined according to AOAC methods (AOAC, 2019).

2.2.4. Determination of total phenolic content

Determination of the total phenolic content in CTO was made using the Folin– Ciocalteu reagent based on the procedure reported by Gutfinger (1981). A 5-g portion of the sample was measured and the phenolic compounds were extracted with 3 mL of 80 % methanol for 2 min by means of a vortex system. The methanol phase was separated by centrifugation (Thermo Fisher Scientific- ST 8) at 2500 rpm for 10 min. Then, 1 mL of 80 % methanol was added and it was centrifuged again. These steps were repeated four times. Then the solution was made up to a total volume of 4 mL with 80 % methanol, followed by the addition of 0.2 mL of 10 % Folin–Ciocalteu reagent. After 3 min, 1 mL sodium carbonate solution (15%, wt/vol) was added to the reaction mixture, which was finally diluted with 7 mL of distilled water. After 45 min, the absorbance of the solution was measured against a blank sample using a Shimadzu UV-1800 spectrophotometer at a wavelength of 725 nm.

2.2.5. Antioxidant property analysis

The DPPH assay was performed to determine the antioxidant capacity of CTO samples. A 10-g portion of the oil sample was mixed with 2 mL of 80 % methanol and vortexed for 2 min. Then it was centrifuged (Thermo Fisher Scientific- ST 8) at 2000 rpm for 10 min. The supernatant was separated and incubated with a freshly prepared DPPH solution by dissolving DPPH in methanol to a concentration of 0.2 mM. The reaction mixture was allowed to incubate in the dark for a specific period of 30 min at room temperature. During this time, the antioxidants in the sample reacted with DPPH, leading to a color change. The absorbance value of the reaction mixture was measured at the wavelength of 765 nm using a spectrophotometer (Shimadzu UV-1800). The decrease in absorbance indicates the scavenging activity of the antioxidants.

$$RSA\ (\%) = [(\delta A\ control - \delta A\ sample) / \delta A\ control] \times 100$$

Where; δA control = Absorbance control – Absorbance control blank,
δA sample = Absorbance sample – Absorbance sample blank;
RSA %, Radical scavenging activity expressed as a percentage of inhibition

2.2.6. Determination of fatty acid composition

The constituent fatty acids present in the lipids of CTO were determined by adopting the procedure described by Gunarathne *et al*. (2022b). In brief, fatty acid methyl esters (FAME) were prepared by dissolving a 50-mg portion of the oil in 0.8 mL hexane and adding a 0.2-mL portion of a 1-M solution of sodium methoxide (PORIM 1995). The mixture was centrifuged (Thermo Fisher Scientific- ST 8) to separate the top layer and analyzed on a gas chromatograph (Agilent Technologies, Singapore) connected to an FID detector. The column type and instrumental conditions adopted for the analysis were as described previously by Gunarathne *et al*. (2022b). The identification of the peaks of the samples was done with reference to a standard chromatographic profile containing thirty-seven FAME standards (Supelco, Bellefinte, PA). The percentage of individual fatty acids was calculated as the ratio of the partial area to the total peak area in the chromatogram.

2.2.7. Storage stability of the coconut testa oil

The shelf-life stability of the selected CTO samples was evaluated over a period of 3 months at ambient temperature conditions by determining the moisture content, FFA content, peroxide value, total phenolic content, and antioxidant capacity.

2.2.8. Statistical analysis

The statistical analysis was performed using the MINITAB (version 15) statistical package at a 0.05 probability level. All the parameters were tested in triplicate and the results were expressed as the mean value ± standard deviation. Data was statistically analyzed by one-way analysis of variance (ANOVA), using Tukey's post-hoc test for mean separation.

3. RESULTS AND DISCUSSION

3.1. Oil yield and physicochemical parameters

3.1.1. Oil yield

The yield recoveries of CTO extracted by the dry process (T0) and wet-centrifuge method (Treatments: T1 to T12) are shown in Figure 1. The wet processing method is generally adopted in some Asian and African countries for small-scale extraction of coconut oil using fresh coconut kernel. Nonetheless, the adoption of the same method for extracting CTO from fresh coconut testa is a novel research initiative. In the initial step, coconut testa milk (CTM) extraction was done, followed by cream layer separation using a centrifugation method. Only clean tap water was used to extract coconut testa milk in the aqueous method. For the energy requirement of the centrifuge process, single-phase electricity was found to be sufficient. For separation of the cream layer, centrifugation was executed at 2000, 4000, and 6000 rpm for 15 and 30 min at 20 and 30 °C (Table 1). The aqueous bottom layer was discarded through a drain after the recovery of the cream.

As shown in Figure 1, the dry process produced a higher yield recovery of CTO while the wet-centrifuge method tended to give a lower oil yield. For the energy requirement of the dry process, three- phase electricity was adopted to operate the dryer and screw-press expeller machine. According to Figure 1, in the wet process, treatment T5 (at 20 °C with centrifugation at 4000 rpm for 15 min) gave the highest yield recovery when compared to other treatments. Nonetheless, the effect of temperature and time on the yield recovery of CTO was not obviously seen (Figure 1). In a previous study, Nwadinobi and Ikeme (2021) noticed that the dry

process for coconut kernel produced a yield recovery of 42.13 % coconut oil while the wet process produced only 31.94 %. The improved oil yield achieved through the dry process can be attributed to an extended thermal exposure at 70 °C for 8 hours. This duration effectively reduces the viscosity of the oil within the kernels, allowing it to migrate more easily to the surface area during extraction. Furthermore, the increased pressure generated by the micro-screw expeller employed in the dry process helps to extrude the lipids, effectively breaking down the cellular structures of the kernels to maximize the oil recovery (Famurewa *et al*., 2021). According to Figure 1, the yield recovery of the wet centrifuge method was found to range from 7.5 to 22.5 % while the dry process yielded 35 % oil. Based on the statistical analysis of data, significant differences ($p < 0.05$) were detected in yield recoveries among the treatments; the highest mean yield value of 340.50 ± 24.24 g/kg was recorded for the dry process (T0). Out of the treatments carried out according to the wet-centrifuge method, only T5 (212.10 ± 6.55 g/kg), T6 (207.98 ± 2.79 g/kg), T7 (187.23 ± 8.51 g/kg), and T8 (202.88 ± 4.66 g/kg) displayed substantially higher mean values of yield recoveries. Hence, only these four treatments (T5, T6, T7, and T8) were selected for further analysis after considering their significantly high yield recoveries.

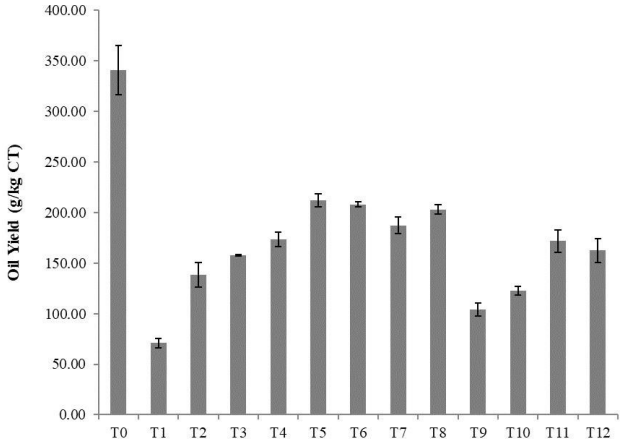

Figure 1. Yield of coconut testa oil extracted from the dry process and wet-centrifuge method Results are expressed as mean ±SD (n=3). Statistically significant differences were determined by One Way ANOVA and Tukey's post-hoc test. See Table 2 for treatments.

3.1.2. Color and iodine value

Table 2. Dry and wet processing treatment conditions for extraction of coconut testa oil

Treatment	Color (as Y+5R in Lovibond color scale)	Iodine Value (g I_2/ 100 g)
T0	$2.37^{a} \pm 0.06$	$13.84^{b} \pm 0.25$
T5	$1.60^{c} \pm 0.00$	$13.24^{bc} \pm 1.65$
T6	$1.67^{c} \pm 0.75$	$14.21^{b} \pm 0.60$
T7	$2.30^{ab} \pm 0.35$	$16.49^{a} \pm 0.35$
T8	$2.13^{b} \pm 0.06$	$11.49^{c} \pm 0.20$

Results are expressed as mean ±SD (n=3). Statistically significant differences were determined by One Way ANOVA and Tukey's Post-hoc test. Means within each column sharing a different superscript are significantly (α=0.05) different at 95% confidence level. Treatments: T0, Coconut testa oil extracted from Dry Process; T5 to T8, Coconut testa oil extracted from Wet process – centrifuge (T5, 4000 rpm 20 °C 15 min; T6, 4000 rpm 20 °C 30 min; T7, 4000 rpm 30 °C 15 min; T8, 4000 rpm 30 °C 30 min.

The color values for the oils extracted by the dry process (T0) and centrifuge methods (T5, T6, T7, and T8) are compared as shown in Table 2. The T5 and T6 samples, centrifuged at 20 °C, exhibited significantly lower color values compared to the T7 and T8 samples, which were centrifuged at 30 °C, regardless of the centrifugation time. This indicated that elevating the centrifugation temperature could increase the color value for the oil samples significantly. Furthermore, there was no significant difference between the color value of the oil obtained by dry processing (T0), where the samples were centrifuged at 30 °C for 15 and 30 min (T7 and T8, respectively). The color of the oil is a crucial factor in deciding satisfactory consumer acceptance. The yellow color of the oils is indicative of the release of pigments in the coconut testa into the oil. Nonetheless, the yellow color formation might also result from caramelization and Maillard reactions taking place at elevated temperatures (Rangana and Wickramasinghe, 2023). As per the guideline in SLS standards, the maximum allowable color value for edible grade CTO is 5. According to the results of our study, the color values for all samples under each treatment fell within this limit. This tends to suggest that the oil was not exposed to high-processing temperatures, leading to the caramelization of the coconut meat during the expelling and dehydration processes.

The degree of unsaturation of fats and oils is usually expressed by the iodine value (IV), which gives the amount of iodine absorbed by an oil sample (de Man *et al*., 2018). As shown in Table 2, the IV of CTO samples by the dry process (T0) and wet-centrifuge method (i.e samples T5 and T6), were not significantly ($p > 0.05$) different. According to regulations given in the SLS standard, the specified range for the IV of CTO is 9.0 to 16.0. Based on the results of this study as given in Table 2, the IV of CTO obtained from all treatments fell within the recommended range, except for T7, which showed slight deviation from the SLS standard. Additionally, there is a possibility that the color values for CTO could partly be due to pigments in the coconut testa.

3.1.3. Moisture and other volatile content

TABLE 3. Moisture content, free fatty acid content, and peroxide value of coconut testa oil by dry and wet-centrifugate methods

Quality Parameter	Time	Treatments				
		T0	T5	T6	T7	T8
Moisture content (%)	Initial stage	$0.23^{(B)r} \pm 0.03$	$0.59^{(B)p} \pm 0.06$	$0.47^{(B)q} \pm 0.06$	$0.45^{(B)q} \pm 0.04$	$0.77^{(A)q} \pm 0.10$
	1st Month	$0.33^{(C)q} \pm 0.03$	$0.66^{(AB)p} \pm 0.11$	$0.56^{(B)pq} \pm 0.05$	$0.48^{(B)q} \pm 0.05$	$0.79^{(A)q} \pm 0.11$
	2nd Month	$0.38^{(C)q} \pm 0.00$	$0.68^{(B)p} \pm 0.14$	$0.61^{(B)p} \pm 0.05$	$0.58^{(B)p} \pm 0.04$	$0.94^{(A)pq} \pm 0.06$
	3rd Month	$0.43^{(C)p} \pm 0.03$	$0.71^{(B)p} \pm 0.17$	$0.66^{(B)p} \pm 0.07$	$0.60^{(B)p} \pm 0.03$	$1.02^{(A)p} \pm 0.11$
FFA content (as % of lauric acid)	Initial stage	$0.27^{(E)r} \pm 0.02$	$1.05^{(B)q} \pm 0.01$	$0.98^{(C)r} \pm 0.05$	$0.79^{(D)s} \pm 0.09$	$1.73^{(A)p} \pm 0.03$
	1st Month	$0.32^{(C)r} \pm 0.03$	$1.08^{(B)q} \pm 0.02$	$1.06^{(B)q} \pm 0.15$	$1.04^{(B)q} \pm 0.16$	$1.85^{(A)p} \pm 0.01$
	2nd Month	$0.32^{(C)r} \pm 0.04$	$1.06^{(B)q} \pm 0.03$	$1.06^{(B)q} \pm 0.17$	$1.13^{(B)q} \pm 0.20$	$2.03^{(A)p} \pm 0.09$
	3rd Month	$0.33^{(C)r} \pm 0.03$	$1.20^{(B)q} \pm 0.02$	$1.17^{(B)q} \pm 0.16$	$1.15^{(B)q} \pm 0.19$	$2.04^{(A)p} \pm 0.04$
Peroxide value (meq O_2/kg)	Initial stage	$0.90^{(A)q} \pm 0.31$	$0.73^{(A)r} \pm 0.12$	$0.73^{(A)r} \pm 0.23$	$0.47^{(A)r} \pm 0.12$	$0.86^{(A)q} \pm 0.30$
	1st Month	$1.25^{(B)q} \pm 0.11$	$1.06^{(B)r} \pm 0.22$	$2.13^{(A)q} \pm 0.76$	$1.45^{(AB)q} \pm 0.60$	$1.26^{(AB)q} \pm 0.12$
	2nd Month	$1.90^{(AB)p} \pm 0.50$	$1.53^{(B)q} \pm 0.12$	$2.59^{(A)q} \pm 0.20$	$1.86^{(AB)pq} \pm 0.82$	$2.25^{(A)p} \pm 0.42$
	3rd Month	$2.13^{(C)p} \pm 0.11$	$3.17^{(AB)p} \pm 0.60$	$4.27^{(A)p} \pm 0.62$	$2.98^{(B)p} \pm 0.60$	$3.70^{(AB)p} \pm 0.28$

Results are expressed as mean ±SD (n=3). Statistically significant differences were determined by One Way ANOVA and Tukey's Post-hoc test. Means sharing different superscripts horizontally within a row starting from 'A' are significantly (α=0.05) different at the 95 % confident level; while means belonging to each quality parameter represented in different superscripts along a column starting from 'p' are significantly different. Abbreviations: FFA, free fatty acid. See Table 2 for treatments.

Maintaining the moisture content (MC) of the oil as low as possible would increase the shelf-life by preventing spoilage (Mermelstein, 2009). The MC of CTO samples by dry process (T0) and wet-centrifuge methods (T5, T6, T7, and T8) are compared as shown in Table 3. It is clear that the MC of the CTO samples differed significantly ($p < 0.05$) among the treatments. The T0 Sample displayed the lowest MC at 0.23±0.03 %, while the highest MC in T8 was shown as 0.77±0.10 %. The CTO samples obtained from the rest of the treatments (being wet-centrifuge methods) were found to have relatively higher moisture contents (T5= 0.59±0.06 %, T6=0.47±0.06 %, T7=0.45±0.04 %, and T8= 0.77±0.10 %). The dry process (T0) was found to show the lowest MC (0.23 ± 0.03 %) probably because it involved a pre-dehydration step of the raw material.

In the shelf-life evaluation, CTO samples were kept at ambient temperature for 3 months to monitor the variations in MC on a monthly basis (Table 3). According to Table 3, the MC of all samples tended to rise significantly ($p < 0.05$) during the 3-month storage period. For instance, the initial MC of T0 increased significantly ($p < 0.05$). The initial MC of T6 did not increase significantly ($p > 0.05$) during the 1st and 2nd months, but the MC value showed a significant ($p < 0.05$) increase in the 3rd month. For T7, the initial MC did not increase significantly ($p > 0.05$) until the end of 1st month but showed a significant ($p < 0.05$) difference during the 2nd and 3rd months. The recommended MC for edible CTO according to SLS standards (SLS 32:2017) is 1.0 %, while for edible coconut kernel oil, it is 0.4 %. As indicated in Table 3, the MC of samples T0, T5, T6, and T7 fell within the acceptable range established by these standards for edible CTO. Notably, the CTO extracted using the dry process (T0) was significantly below the maximum acceptable value defined by these standards. The oil obtained from the dry process demonstrated greater stability over three months, likely due to the pre-dehydration step implemented during the extraction of T0. In contrast, all oil samples extracted using centrifuge methods (T5, T6, T7, and T8) exceeded the limits set for coconut oil, even at the initial stage. However, over 3 months of storage, except T8, all other oil samples remained below the standards set for edible CTO, despite exceeding the limits for edible coconut oil.

3.1.4. Free fatty acid content

The free fatty acid (FFA) contents in the CTO samples from the dry process (T0) and wet-centrifuge methods (T5, T6, T7, and T8) are compared as shown in Table 3. The highest FFA content was displayed by T8 (1.73 ± 0.03 %) while the lowest FFA value was found in T0 (0.27 ± 0.03 %). The FFA content in the T0 sample was found to increase significantly ($p < 0.05$) to reach 0.33 ± 0.03 % within the storage period. Nevertheless, this value is far below the maximum permissible level recommended FFA for edible-grade coconut oil (0.8 %) (SLS 32: 2017). On the other hand, the CTO samples obtained from the other treatments of centrifuge methods exceeded this limit even at the time of production.

The FFA contents in plant oils and fats indicate the extent of lipolysis of the fatty molecules. Generally, oils exhibiting high FFA are more susceptible to a foul smell more quickly (Dayrit, 2015). According to Dayrit *et al*. (2007), the generation of additional FFAs during the extraction and storage could be due to a reaction with residual moisture in the oil. As discussed earlier, the high moisture contents in T5 (0.59 ± 0.06), T6 (0.49 ± 0.06), and T8 (0.77 ± 0.10) could be attributed to the high FFA content in the CTO as shown in Table 3. According to SLS standards, the maximum allowable FFA content for edible CTO should remain below 1.0 % (percentage as lauric acid by mass). The FFA content in sample T0 remained stable throughout the storage period, significantly below the threshold established for edible coconut oil. Conversely, the CTO samples obtained via wet centrifugation exhibited varying stability in FFA levels. While T6 and T7 demonstrated comparable FFA stability to T0, with storage their values nonetheless surpassed the acceptable limits for edible-grade CTO. Sample T5 exhibited no significant increase in FFA content ($p > 0.05$) during the initial two months; however, a notable rise ($p < 0.05$) was recorded after the third month, with all measurements remaining slightly above the recommended FFA levels outlined in the SLS standards. Sample T8 exhibited the highest FFA values overall, with significant increases ($p < 0.05$) noted during the 2nd and 3rd months of storage. As detailed in Table 3, the initial FFA levels for T0, T6, and T7 fell within the acceptable range, but those of T5 and T8 exceeded the upper limit. Notably, T0 maintained its FFA levels within the recommended range even after three months, contrasting sharply with the CTO samples produced through the wet-centrifuge method, all of which exceeded the maximum FFA limit specified in the standard. Hewa-Pathirana *et al*. (2021) previously pointed out that the FFA content in the extracted oil is generally influenced by the moisture content. This is in agreement with Dayrit *et al*. (2007), who stated that FFAs in oil can be generated due to the action of residual water in the oil during storage.

3.1.5. Peroxide value

The peroxide values (PV) of CTO samples produced by different treatments are presented in Table 3. Peroxide value (PV) is an estimate of the oxidative deterioration of oils and fats through peroxide formation

due to double bonds (de Man *et al*., 2018). As shown in Table 3, the PV of samples obtained by different methods was found to range between 0.9±0.31 and 0.47±0.12 meq O_2/kg. The CTO sample by dry processing (T0) was not significantly different ($p > 0.05$) from those of the samples obtained by wet-centrifuge methods (T5, T6, T7 and T8). There was an increasing trend in PV during the storage of CTO of all treatments (Table 3). The PV of CTO produced by the dry process (T0) increased significantly ($p < 0.05$) at the end of the 2nd month, but it did not change significantly ($p > 0.05$) after the 3rd month. The PV of CTO samples T5, T6, T7, and T8 showed lower PV values during the 2nd and 3rd months of storage. According to SLS standards (SLS32:2017), the maximum permissible peroxide value (PV) for edible CTO is set at 10.0 meq O_2/kg; while the threshold for edible coconut oil is considerably lower at 3.0 meq O_2/kg. Analysis of the CTO samples indicated that all tested samples fell below the acceptable limit for edible CTO. However, when evaluating against the stringent criteria for edible coconut oil, only sample T0 exhibited a PV that remained under the allowable threshold throughout the storage period, indicating superior quality compared to the samples extracted via the wet-centrifugation method. Among the CTO samples produced through the wet-centrifuge process, only T7 was found to show a value within the recommended range for edible coconut oil after 3 months of storage.

The lower PV of oils is generally indicative of the samples that have not undergone significant peroxidation during processing (Dayrit *et al*., 2007). At the initial stage, the PV of the dry process (T0) was higher than those of all wet-centrifuge treatments. After three months of storage, the PV of T0 showed only a slight increase when compared to those obtained through wet-centrifuge methods. The PV serves as a key indicator of the oxidation and rancidity levels in CTO. The low PV observed in the CTO produced via the wet centrifuge method in this study suggests a state of freshness or minimal oxidation. In contrast, the elevated PV of the CTO extracted through the dry method (T0) can be attributed to the oxidation processes affecting the dried testa prior to oil extraction (Ghani *et al*., 2018). It is presumed that the time taken to complete the dry process could be a probable reason for T0 to have a higher PV. It is important to note that both peroxide formation and degradation reactions might occur concurrently during storage, leading to fluctuations in the PV over time (Turan, 2018).

3.1.6. Total Phenol Content

TABLE 4. Total phenolic content (TPC) and DPPH radical scavenging activity of coconut testa oil extracted from dry and wet-centrifugate methods

Quality parameter	Time	T0	T5	T6	T7	T8
TPC (µg/100g)	Initial Stage	$35.35^{(A)r}$ ±1.27	$284.47^{(A)q}$ ± 7.11	$370.90^{(A)p}$ ±23.27	$360.70^{(A)p}$±15.10	$347.63^{(A)p}$± 25.65
	1st Month	$33.38^{(A)r}$ ±3.02	$280.55^{(A)q}$ ±10.07	$359.41^{(A)p}$ ±19.81	$349.01^{(A)p}$ ±10.73	$335.14^{(A)p}$ ± 19.12
	2nd Month	$32.65^{(A)r}$±2.28	$281.54^{(A)q}$ ±11.01	$340.69^{(AB)p}$ ± 7.87	$346.89^{(A)p}$ ± 11.03	$333.53^{(A)p}$± 15.24
	3rd Month	$31.72^{(A)s}$ ±1.17	$269.71^{(A)r}$ ± 2.53	$307.69^{(B)pq}$±14.52	$299.08^{(B)q}$±15.96	$329.03^{(A)p}$ ± 15.59
DPPH radical scavenging activity (%)	Initial Stage	$33.87^{(A)r}$ ±3.23	$50.77^{(A)q}$ ± 2.32	$63.41^{(A)p}$ ± 3.83	$51.53^{(A)q}$ ± 4.64	$61.87^{(A)p}$ ± 1.36
	1st Month	$29.80^{(A)br}$±2.85	$46.46^{(A)q}$ ± 4.07	$54.79^{(A)p}$ ± 3.15	$43.75^{(AB)q}$ ± 6.96	$53.75^{(B)p}$ ± 1.88
	2nd Month	$28.00^{(AB)r}$±1.60	$46.38^{(A)q}$ ± 4.07	$53.38^{(A)p}$ ± 4.11	$39.67^{(AB)q}$ ± 4.63	$53.34^{(BC)p}$ ± 1.96
	3rd Month	$27.39^{(B)t}$± 1.69	$43.03^{(A)r}$± 3.11	$54.73^{(A)p}$± 6.69	$35.57^{(B)s}$ ± 0.43	$49.50^{(C)q}$ ± 0.43

Results are expressed as mean ±SD (n=3). Statistically significant differences were determined by One Way ANOVA and Tukey's Post-hoc test. Means belonging to each quality parameter sharing different superscripts vertically within a parameter starting from 'A' are significantly different, and means sharing different superscripts horizontally within a parameter starting from 'p' are significantly (α=0.05) different at the 95 % confidence level. Abbreviation: TPC, Total phenolic content, DPPH, 2,2-diphenyl-1-picrylhydrazyl. See Table 2 for treatments.

The total phenolic content (TPC) of CTO samples extracted by the dry process (T0) and wet-centrifuge method (T5, T6, T7, and T8) are shown in Table 4. According to multiple reports, coconut testa is a rich source of phytochemicals which range from simple phenolic acid to polyphenols like flavonoids, anthocyanins,

tannins, etc (Gunarathne *et al*., 2022b; Ojha *et al*., 2019; Arivalagan *et al*., 2018). Data from Table 4 show that the TPC of T0 (Dry process) was significantly lower (35.35 ± 1.27 µg/100g) than those of CTO samples extracted by wet-centrifuge methods (T5 to T8); and ranged between 284.4 and 370.90 µg/100g. The results further showed that the TPC of CTO obtained by treatments T6 and T7 was significantly ($p < 0.05$) reduced during the storage period of 3 months. In contrast, T0, T5, and T8 did not show any significant ($p > 0.05$) changes during storage. Early reports have already indicated that the extractability of phytochemical constituents from coconut testa was dependent on the extracting solvent systems. This is in conformity with several previous reports that provided evidence for the dependency of phenolic extractability on the polarity of the solvents employed. The reduced phenolic content in CTO extracted through dry processing aligns with the previous findings of Jayathilaka and Senevirathne (2022), who pointed out that the wet extraction of coconut oil by a coconut-milk-boiling method yielded higher levels of phenolic compounds. In contrast to this, Appaiah *et al*. (2014) reported that the TPC of the coconut oil extracted from the whole copra blended with both white kernel and brown testa was 1.4 ± 0.19 mg/100 g; while those of coconut oil extracted from the white coconut kernel, copra testa, and wet coconut testa were 1.1 ± 0.11 mg/100g, 1.9 ± 0.12 mg/100 and 0.5±0.02 mg/100g, respectively. Zhang *et al*. (2016) previously demonstrated that the phenolic compound extracts from CTO showed significant potential to attenuate oxidative damages inflicted by hydrogen peroxide on human serum albumin. This study further highlighted the therapeutic prospects of these phenolics, indicating their applicability in interventions aimed at mitigating oxidative stress-related damages to vital proteins in humans. In addition, Geetha *et al*. (2016) emphasized the presence of a broad spectrum of bioactive constituents within the phenolic concentrates of CTO, which might have a pivotal role in addressing disorders linked to stress. These findings collectively suggest that CTO possesses a substantial potential for being utilized in food and pharmaceutical applications.

3.1.7. DPPH Radical scavenging activity

The DPPH radical scavenging activity (%) of the CTO samples from the dry process (T0) and wet-centrifuge methods (T5, T6, T7, and T8) is presented in Table 4. According to a previous study by Taghvaei and Jafari (2015), DPPH radical scavenging activity is a reliable indicator of the ability of an oil to resist auto-oxidation. DPPH radical scavenging activity is heavily dependent on the proportion of anti-oxidants and their extractability by different methods. It is clear from Table 4 that the radical scavenging activity of the CTO extracted by the dry process (33.87 ± 3.23) was found to be relatively lower compared to that of the CTO extracted by the centrifuge method (ranging from 50.77 to 63.4). The highest DPPH scavenging activity was observed for T6 (63.41 ± 3.83), while the lowest activity was detected in T0 (33.87 ± 3.23). In fact, the DPPH scavenging activity of T0 was significantly ($p < 0.05$) different from those of all other treatments. Among the samples extracted by wet-centrifuge methods, DPPH scavenging activity displayed by T6 and T8 were not significantly ($p > 0.05$) different. Likewise, no significant difference ($p > 0.05$) in DPPH scavenging activity was observed between T5 and T7. The DPPH free radical scavenging activity of CTO samples was monitored over a 3-month storage period. The DPPH free radical scavenging activity tended to decrease in all treatments after the 3-month storage period when compared to the initial values. Nevertheless, there is hardly any study reported on the radical scavenging activity of CTO in long-time storage for comparison purposes. Some information on radical scavenging activities of VCO, however, is available in the literature. According to Ghani *et al*. (2018), the radical scavenging activities of VCO were significantly affected by different processing conditions of oil extraction; higher radical scavenging activities of VCO were found among the samples extracted with the chilling and centrifugation processes when compared to VCO by the dry process. This is in line with the DPPH radical scavenging activity of the CTO observed in this experiment (Table 4). Hence, it may be rationalized that the low-temperature conditions employed in the wet- centrifuge method might have helped preserve the thermally unstable antioxidant compounds in CTO.

The findings of Ghani *et al*. (2018) previously implied that the antioxidant activity of the VCO was heavily dependent on the type of processing methods. Their findings were compatible with the results presented in Table 4, which show that the radical scavenging activity of CTO in the dry process was low when compared to the wet-centrifuge method. The radical scavenging activities of oils by dry process and

wet-centrifuge method tended to decline during the three months of storage. Further, research indicates that the primary antioxidant constituents in crude CTO are tocopherols and tocotrienols (Ramesh *et al*., 2023), both of which may exhibit significant health-promoting properties. This underscores the potential of CTO extract for incorporation into nutraceutical formulations, given its bioactive profile and possible therapeutic applications.

3.1.8. Fatty acid profile

The fatty acid distributions in the CTO samples obtained by dry and wet-centrifuge processes are given in Table 5. There were significant ($p < 0.05$) differences among individual fatty acids in all the CTO samples obtained by different treatments. According to Table 5, total saturated fatty acids (SFA) present in CTO obtained by T0, T5, T6, T7, and T8 were 85.57±0.01 %, 86.97±0.02 %, 86.46±0.01 %, 86.74±0.03 %, and 89.36±0.01 %, while unsaturated fatty acids (USFA) were 14.43±0.01 %, 13.04±0.02 %, 13.54±0.01 %, 13.26±0.03 %, and 10.64±0.01 %, respectively. Among the SFA, lauric acid (C12:0) was the most abundant in CTO, ranging between 39.46±0.01 and 42.74±0.05 %. Short-chain fatty acids such as caproic, caprylic, and capric acids were present in all the CTO obtained from all the treatments with 0.43-0.58, 5.99-7.53, and 4.3-5.0 %, respectively. Further, significantly lower lauric acid (C12:0) content and significantly higher oleic acid (C18:1) content were noticed in the dry process (T0) CTO, while a definite pattern could not be seen for other fatty acids.

TABLE 5. Fatty acid composition (%) of coconut testa oil extracted by dry process and wet centrifugate method

Component	T0	T5	T6	T7	T8
Butyric acid (C4:0)	$0.25^{b} \pm 0.00$	$0.00^{c} \pm 0.00$	$0.00^{c} \pm 0.00$	$0.00^{c} \pm 0.00$	$0.86^{a} \pm 0.02$
Caproic acid C6:0	$0.47^{b} \pm 0.01$	$0.45^{bc} \pm 0.00$	$0.43^{c} \pm 0.01$	$0.46^{bc} \pm 0.01$	$0.58^{a} \pm 0.01$
Caprylic acid C8:0	$6.24^{b} \pm 0.01$	$6.13^{c} \pm 0.02$	$6.07^{cd} \pm 0.01$	$5.99^{d} \pm 0.02$	$7.53^{a} \pm 0.04$
Capric acid C10:0	$4.30^{c} \pm 0.02$	$4.36^{bc} \pm 0.02$	$4.35^{bc} \pm 0.02$	$4.41^{b} \pm 0.01$	$5.00^{a} \pm 0.02$
Lauric acid C12:0	$39.46^{e} \pm 0.01$	$40.21^{c} \pm 0.01$	$39.98^{d} \pm 0.03$	$41.67^{b} \pm 0.02$	$42.74^{a} \pm 0.05$
Myristic acid C14:0	$21.02^{d} \pm 0.01$	$21.71^{b} \pm 0.01$	$21.48^{c} \pm 0.01$	$22.09^{a} \pm 0.01$	$20.59^{e} \pm 0.02$
Palmitic acid C16:0	$11.70^{b} \pm 0.01$	$11.83^{a} \pm 0.01$	$11.81^{a} \pm 0.01$	$9.70^{d} \pm 0.02$	$10.06^{c} \pm 0.01$
Stearic acid C18:0	$2.13^{c} \pm 0.01$	$2.29^{b} \pm 0.02$	$2.36^{b} \pm 0.03$	$2.46^{a} \pm 0.00$	$1.92^{d} \pm 0.02$
Oleic acid C18:1	$10.55^{a} \pm 0.01$	$10.07^{d} \pm 0.02$	$10.33^{b} \pm 0.01$	$10.14^{c} \pm 0.01$	$8.22^{e} \pm 0.11$
Linoleic acid C18:2	$3.88^{a} \pm 0.01$	$2.94^{d} \pm 0.01$	$3.18^{b} \pm 0.01$	$3.08^{c} \pm 0.01$	$2.51^{e} \pm 0.03$
Saturated Fatty Acids	$85.57^{e} \pm 0.01$	$86.97^{b} \pm 0.02$	$86.46^{d} \pm 0.01$	$86.74^{c} \pm 0.03$	$89.36^{a} \pm 0.01$
Unsaturated Fatty Acids	$14.43^{a} \pm 0.$	$13.04^{d} \pm 0.02$	$13.54^{b} \pm 0.01$	$13.26^{c} \pm 0.03$	$10.64^{e} \pm 0.01$

Results are expressed as mean ±SD (n=3). Statistically significant differences were determined by One Way ANOVA and Tukey's Post-hoc test. The means across each row sharing different superscripts are significantly (α=0.05) different at 95 % the confidence level. See Table 2 for treatments.

Long-chain saturated fatty acids such as myristic (C14:0), palmitic (C16:0), and stearic (C18:0) were present in CTO; their proportions in CTO obtained from different treatments are significantly ($p < 0.05$) different. Among the CTO samples produced by dry processed and wet–centrifuge treatments, there were significant ($p < 0.05$) differences in the proportions of myristic acid (20.59-22.09 %), palmitic acid (9.7-12.46 %), and, stearic acid (1.92-2.46 %). According to Codex (1999), coconut kernel oil is found to possess myristic acid (16.8-21 %), palmitic (7.5-10.2 %), and stearic (2-4 %). The proportions of these long-chain fatty acids in CTO samples were slightly different from those of ordinary coconut oil. The overt variations in the proportions of long-chain saturated fatty acids of CTO were reported previously (Marasinghe *et al*., 2019; Marrikar and Nasyrah, 2012; Appaiah *et al*., 2014). According to them, such variations have commonly existed in the CTO from different treatments.

Among the monounsaturated long-chain fatty acids in the CTO from different treatments, the oleic acid contents of different treatments showed significant ($p < 0.05$) differences. The proportions of oleic acid (C18:1) in T0, T5, T6, T7, and T8 were 10.55±0.01, 10.07±0.02, 10.33±0.01, 10.14±0.01 and 8.22±0.11 %, respectively. According to Codex (1999), the oleic acid content in ordinary coconut oil is 5-10 %. Therefore, the oleic acid contents reported for CTO in this study were very close to the oleic acid content in coconut oil. According to Appaiah *et al*., (2014), the oleic acid content in CTO was reported at 12.2±0.1 %, while Marrikar and Nasyrah (2012) reported a higher value ranging from 14.94 to 19.07 %. In contrast, Marasinghe *et al*. (2019) reported lower oleic content values (6.63-7.91 %) for CTO in coconut testa flour from different varieties of coconut. Although the CTOs from different treatments showed significant ($p < 0.05$) changes, they might not be related to the difference in treatments.

Among the polyunsaturated long-chain fatty acids of the CTO from different treatments, the linoleic acid contents in different treatments exhibited significant differences ($p < 0.05$). In this study, the proportion of linoleic acid present in CTO with different treatments was found to range from 2.51 to 3.88 %. According to Codex (1999) standards, the recommended proportion of linoleic acid present in ordinary coconut oil was 1.0-2.5 %. Based on previous reports of Marrikar and Nasyrah, (2012) and Appaiah *et al*. (2014), the average value of linoleic acid contents in CTO was 2.14 -2.92 % and 5.3±0.2 %, respectively. In a separate study, Marasinghe *et al*. (2019) found that 2.09-3.28 % of linoleic acid was present in the CTO of coconut testa flour.

4. CONCLUSIONS

This study showed that the yield recovery of CTO by the dry process was significantly higher than that of CTO obtained by the wet-centrifuge method; the yield recovery of wet centrifuge method was found to range from 7.5 to 22.5 % while the dry process yielded 35 % oil. Except for color, all physicochemical parameters of freshly obtained CTO by dry and wet centrifuge methods showed notable differences. These parameters of CTO were found to show some variations during the 3-month storage period. The TPC and DPPH radical scavenging activity of CTO was strongly influenced by the proportion of anti-oxidants as well as their extractability by different methods. The TPC of T0 (dry process) was significantly ($p < 0.05$) lower than those produced by wet-centrifuge methods. Among the samples, there were significant ($p < 0.05$) differences in fatty acid composition between the dry and wet-method CTO samples, with CTO by the dry process exhibiting significantly higher lauric acid content. Based on the findings, the dry process is preferred over the wet-centrifuge method for the production of CTO. Additionally, the results indicate that the T6 method (20 °C, 4000 rpm for 30 minutes) is the optimal approach for wet processing of CTO.

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DECLARATION OF COMPETING INTEREST

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

AUTHORSHIP CONTRIBUTION STATEMENT

D.G.C.S. Ilangarathne: Investigation, Methodology, Writing original draft
J.M.N. Marikkar: Conceptualization, Supervision– Reviewing & Editing
B.G.R.R. Bandara: Reviewing & Editing
L.L.W.C. Yalegama: Conceptualization, supervision– Review & Editing
H.P.D.T. Hewa Pathirana: Formal analysis

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