Bulletin of the National Research Centre

RESEARCH Open Access

Formulation of a topical cream using virgin coconut oil extracted from Pandan coconut

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Abstract

Virgin coconut oil (VCO) from Pandan coconut (*Cocos nucifera L.*) is recognized for its functional and cosmeceutical properties. This study compared fermentation-based wet extraction (FVCO) and gentle heating (GHVCO) to evaluate their effects on physicochemical characteristics and performance in water-in-oil (W/O) cream formulations. FVCO achieved a significantly higher oil yield (37.9%) than GHVCO (24.39%), demonstrating superior extraction efficiency. Furthermore, FVCO exhibited a higher saponification value (268.48 ± 2.15 mg KOH/g) and lower peroxide value (1.67 ± 0.08 meq O_2/kg), suggesting better preservation of fatty acids and improved oxidative stability. No significant difference in total phenolic content was observed between methods ($p > 0.05$). In formulation studies, FVCO based creams showed better spreadability, stable skin-compatible pH, enhanced aroma, and maintained short-term stability without phase separation. Both formulations exhibited no observable irritation under preliminary testing. Overall, fermentation produced VCO with superior physicochemical quality and improved formulation performance, indicating its potential for cosmeceutical applications. Further studies on composition, long-term stability, and clinical safety are necessary.

Keywords Virgin coconut oil, Fermentation, Gentle heating, Saponification value, Peroxide value, Phenolics, Water-in-oil cream, Pandan coconut

Introduction

Virgin coconut oil (VCO), derived from fresh mature coconut kernels without chemical refining, is gaining significant attention as a high-value functional oil for food and pharmaceutical applications (Gouda et al. 2024). Unlike refined coconut oil, VCO retains natural bioactive compounds, including medium-chain fatty acids (MCFAs) like lauric acid (45–55%), tocopherols, phenolics, and sterols (Ng et al. 2021). These constituents contribute to its antioxidant, antimicrobial, and anti-inflammatory properties, supporting its use in therapeutic and cosmeceutical applications (Rohman et al. 2021).

The extraction method critically influences VCO's physicochemical characteristics, bioactive retention, and overall quality (Gouda et al. 2024). Wet extraction techniques, such as fermentation, enzymatic treatment, and

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centrifugation, are preferred over dry methods for their ability to preserve heat-sensitive compounds by minimizing thermal exposure. Fermentation-based extraction, specifically, destabilizes coconut milk emulsions through microbial enzymatic activity at ambient temperatures, enhancing the retention of phenolic compounds and α-tocopherol (Ng et al. 2021; Prasanna et al. 2024).

Despite these advantages, wet extraction methods often have limitations, including lower oil yields (15–25% w/w), longer processing times (24–48 h), and higher residual moisture content, which can compromise storage stability and increase susceptibility to hydrolytic rancidity (Prasanna et al. 2024). These challenges are particularly relevant in the rapidly expanding global VCO market, projected to grow at a compound annual growth rate (CAGR) of 9.5% through 2025 (Fortune Business Insights, 2026). Concerns regarding adulteration also highlight the need for rigorous physicochemical characterization, in line with APCC and Codex Alimentarius standards, to ensure product authenticity and quality (Codex Alimentarius Commission, 2024).

In cosmeceutical applications, VCO's rich MCFA content (C8–C14) is highly valued for enhancing skin compatibility, transdermal penetration, and antimicrobial activity (Jesus et al. 2025; Zainodin et al. 2024). These properties make it suitable for topical formulations that aim to improve skin barrier function, hydration, and inflammation control (Abdalla et al. 2024). Water-in-oil (W/O) emulsions, which benefit dry and sensitive skin due to their occlusive and moisturizing characteristics, require careful optimization for stability in terms of emulsifier selection, phase ratios, and rheological properties (Pavlović et al. 2026).

This study focuses on the Pandan coconut, an aromatic dwarf variety widely cultivated in Southeast Asia, known for its distinctive fragrance primarily from 2-acetyl-1-pyrroline (2-AP) (Ismail et al. 2022; Sun et al. 2025). Even trace amounts of 2-AP are sufficient to impart a strong aroma due to its extremely low odor threshold (< 0.06 ng/L) (Zhang et al. 2022). Therefore, retaining 2-AP during mild extraction processes could enhance the sensory appeal of VCO-based products, offering a natural alternative to synthetic fragrances. While this study did not quantitatively measure 2-AP content, the observed differences in sensory aroma in the FVCO-based creams align with the expected benefits of milder extraction processes that are known to preserve volatile compounds.

Despite extensive research on VCO extraction, there is a lack of systematic comparative evaluation between fermentation-based wet extraction and gentle heating methods using the same coconut variety under controlled conditions. Furthermore, limited data exist on the physicochemical and functional properties of VCO specifically from Pandan coconut, especially concerning its performance in cosmeceutical formulations. The relationship between the extraction method and the quality and stability of finished topical products also remains underexplored.

Accordingly, this study aims to: (1) compare the physicochemical properties of VCO produced via wet (fermentation) and gentle heating methods, focusing on saponification value (SV), peroxide value (PV), and total phenolic content (TPC); and (2) develop and evaluate a stable W/O cream formulation using wet-extracted VCO, assessing its physical properties, dermatological safety, and stability in accordance with APCC and Codex standards. This research seeks to provide preliminary evidence-based information for formulating VCO-based cosmeceutical products, clarifying the relationship between extraction methodology and VCO quality attributes, and addressing the critical need for quality standardization in the global VCO market.

Methodology

Raw material collection and authentication

Fresh mature Pandan coconuts (*Cocos nucifera L.*) were harvested from March to May 2024 in Masjid Tanah, Melaka, Malaysia (2°20′N, 102°15′E). Harvesting was manual, based on visual maturity indicators. Botanical authentication was performed by the Institute of Bioscience, Universiti Putra Malaysia (UPM).

Virgin coconut oil extraction methods

Wet extraction method (fermentation)

Fermentation-based virgin coconut oil (FVCO) was prepared using a modified method from Prasanna et al. (2024). Fresh coconut kernels were grated and homogenized with warm distilled water (1:1 w/v) in a high-speed blender. The slurry was filtered through muslin cloth to obtain coconut milk. This milk underwent natural fermentation at ambient temperature (25–30 °C) for 24 h. The resulting upper oil layer was decanted and collected.

Oil yield was calculated using Eq. 1:

$$Oil\,Yield\ (\%) = \frac{Weight\ of\ Extracted\ Oil\ (g)}{Weight\ of\ Coconut\ Milk\ (g)} \times 100$$

Gentle heating extraction method (GH-VCO)

Gentle heating VCO (GHVCO) was produced from freshly prepared coconut milk. The milk was heated at 60 °C for 3 h with continuous stirring. After heating, the mixture was filtered twice through muslin cloth. The filtrate settled at room temperature (25 ± 2 °C) for 30–60 min, and the clear upper oil layer was then decanted and collected. Oil samples were stored in sterile glass containers prior to analysis (Rohman et al. 2021).

Physicochemical characterization of virgin coconut oil

Saponification value (SV) determination

SV was determined following AOCS Official Method Cd 3–25 (AOCS 2013). Approximately 1.4 g of oil was refluxed with 25.0 mL of 0.5 M ethanolic KOH for 30 min at 100 ± 2 °C. After cooling, excess alkali was titrated with standardized 0.5 M HCl using phenolphthalein. A blank determination was performed. SV was calculated as:

$$Saponification\,Value,\ SV\ \frac{mg\ KOH}{g\ oil} = \frac{56.1 \times\ N \times\ (V_2 - V_1)}{W}$$

where N is the normality of HCl, V_1 is the volume of HCl for the sample (mL), V_2 is the volume for the blank (mL), and W is the sample weight (g).

Peroxide value (PV) determination

PV was determined using the iodometric titration method as per AOCS Official Method Cd 8–53. Oil samples (~ 12 g) were dissolved in a 3:2 (v/v) acetic acid–chloroform mixture, treated with saturated KI solution, and the liberated iodine was titrated with 0.1 M sodium thiosulfate using starch as an indicator. A blank was performed. PV was calculated as:

$$Peroxide\,Value,\ PV\ \frac{meq.O_2}{kg} = \frac{(V_s - V_b)\ \times 0.1 \times 1000}{W}$$

where V_s is the titre for the sample (mL), Vb is the titre for the blank (mL), N is the normality of sodium thiosulfate, and W is the sample weight (g).

Total phenolic content (TPC) determination

TPC was determined using a modified liquid–liquid extraction method described by Prior et al. (2023), followed by the Folin–Ciocalteu assay. Oil (10 g) was extracted with hexane and methanol. The methanolic extracts were combined and concentrated. An aliquot reacted with Folin–Ciocalteu reagent and sodium carbonate, incubated for 30 min, and absorbance measured at 760 nm using a UV–Vis spectrophotometer. TPC was quantified using a gallic acid calibration curve and expressed as gallic acid equivalents (GAE):

$$TPC = \frac{cV}{m}$$

where c is the concentration from the calibration curve, V is the volume of extract, and m is the mass of the sample.

Water-in-oil (W/O) cream formulation

A water-in-oil (W/O) cream was formulated using VCO, beeswax, borax, methylparaben, and distilled water, based on methods for wax-based emulsifiers (Bîrsan et al. 2025; Wadghule and Mundhe 2025). Beeswax served as the main structuring agent, while borax reacted with beeswax's free fatty acids to create in-situ emulsifying soaps.

For a 100 g batch, the oil phase contained 50 g VCO and 20 g beeswax. The aqueous phase contained 0.7 g borax, 0.5 g methylparaben, and 28.8 g distilled water. The high oil-phase content (~ 70%) was chosen to promote W/O emulsion formation (Bîrsan et al. 2025). Both phases were individually heated to 75–80 °C until the wax melted and viscosity was uniform. The aqueous phase was then slowly added to the oil phase while stirring continuously to ensure uniform mixing.

The cream was classified as W/O based on its composition (high oil content), preparation process, and indirect tests such as dilution behavior and smear characteristics, since direct microstructural analysis was not performed.

Preliminary cream evaluation protocol

The formulated cream was evaluated for physicochemical and dermatological properties using adapted standardized methods.

Organoleptic properties

Color, odor, and appearance were assessed visually and olfactorily to ensure consumer acceptability (Bîrsan et al. 2025).

Smear type

The film formed on the skin after application was observed for texture and residue (Bîrsan et al. 2025).

Removal test

Ease of removal was evaluated by rinsing applied cream under running water (Bîrsan et al. 2025).

pH determination

One gram of cream was dispersed in 100 mL distilled water, and pH was measured using a calibrated digital pH meter (Bîrsan et al. 2025; Prakash and Adham, 2025). Three readings were recorded.

Dilution test

One gram of cream was diluted in distilled water to observe miscibility and phase separation (Prakash and Adham, 2025).

Irritation study

A small amount of cream was applied to the dorsal hand surface and monitored daily for 7 days for signs of

redness, itching, or inflammation, following OECD TG 439 guidelines (OECD, 2025; MatTek, 2025).

Spreadability

One gram of cream was placed between two glass slides, and a 100 g weight was applied for 5 min. The spread diameter was measured in centimeters. The test was repeated three times (Gitea et al. 2026).

Stability

The cream was stored at ambient temperature for 14 days and periodically evaluated for phase separation, color change, and consistency, following cosmetic stability testing practices (Bîrsan et al. 2025; International Organization for Standardization, 2020).

Statistical analysis

All results are expressed as mean ± standard deviation (SD). Comparisons between wet extraction and gentle heating were conducted using independent samples t-tests. Statistical significance was set at $p < 0.05$.

Results and discussions

Yield

The fermentation-based VCO (FVCO) method yielded 37.9% oil from coconut milk, consistent with optimal fermentation processes (Chaidir et al. 2025). This high yield demonstrates FVCO's effectiveness in extracting oil without chemical additives (Prasanna et al. 2024). An important observation was the positive influence of warm water during milk preparation, which facilitated phase separation by partially denaturing emulsion-stabilizing proteins, as is characteristic of protein-stabilized coconut milk emulsions (Prasanna et al. 2024).

The higher FVCO yield is primarily attributed to fermentation-driven mechanisms. Microorganisms produce enzymes (proteases, lipases) that degrade proteins and lipids at the oil–water interface, weakening emulsion structure. Additionally, microbial metabolism reduces pH through organic acid production, further destabilizing the emulsion by reducing electrostatic repulsion and enhancing protein aggregation. These combined changes efficiently release oil from the emulsion matrix (Nwankwo et al. 2025; Prasanna et al. 2024).

Conversely, the gentle heating (GHVCO) technique produced a significantly lower yield of 24.39%. This reduction is due to protein coagulation and prolonged thermal exposure, which forms dense protein matrices that entrap oil globules, limiting oil recovery (Zainul et al. 2024). Unlike fermentation, thermal treatment lacks enzymatic and pH-mediated destabilization. Comparative studies similarly show GHVCO methods generally result in lower yields and may degrade heat-sensitive bioactive compounds (Nwankwo et al. 2025).

Overall, FVCO extraction demonstrated superior oil yield and efficiency compared to GHVCO. The enhanced performance of FVCO arises from a combination of enzymatic activity, pH reduction, and mild thermal effects, promoting efficient emulsion breakdown. This multifactorial mechanism aligns with previous findings for fermentation-assisted oil extraction (Prasanna et al. 2024). Figure 1A clearly illustrates FVCO's substantially higher oil yield. This supports the objective of identifying the more efficient extraction method for high-quality VCO.

Physicochemical characterization of virgin coconut oil

Saponification value (SV) determination

Saponification value (SV), which indicates the average fatty acid molecular weight and chain length, was significantly influenced by the extraction method ($p = 0.0351$), as shown in Fig. 1B. FVCO exhibited an SV of 268.48 ± 2.15 mg KOH/g, while GHVCO showed a lower value of 259.38 ± 1.87 mg KOH/g.

The higher SV in FVCO suggests better preservation of short- and medium-chain fatty acids (MCFAs), characteristic of coconut oil (Rohman et al. 2021; Zainul et al. 2024). This is primarily attributed to the low-temperature fermentation process (25–30 °C), which minimizes thermal degradation and helps maintain the oil's native chemical structure (Meghasree 2024). In contrast, although GHVCO uses moderate heating (~ 60 °C), these conditions may induce minor compositional changes, leading to a 3.51% reduction in SV compared to FVCO (Prasanna et al. 2024).

Both methods produced SV values generally within established standards (APCC: 250–260 mg KOH/g; Codex Alimentarius: 248–265 mg KOH/g). FVCO's SV slightly exceeds the Codex range, suggesting a higher proportion of lower molecular weight components. While direct fatty acid composition analysis (e.g., GC-FID) was not performed, these observed SV differences are consistent with literature indicating that mild, non-thermal methods better preserve VCO's intrinsic composition (Zainul et al. 2024). Therefore, the higher SV of FVCO supports its suitability as a functional oil for topical formulation, aligning with the study objective.

Peroxide value (PV) determination

Peroxide value (PV) indicates initial lipid oxidation (Abeyrathne et al. 2021). FVCO had a PV of 1.67 ± 0.08 meq O_2/kg, while GHVCO showed a slightly higher value of 2.19 ± 0.12 meq O_2/kg, as shown in Fig. 1C. This trend indicates lower primary oxidation in the fermentation method.

The low peroxide levels in both samples are attributed to natural antioxidants like tocopherols and phenolic compounds inherent in coconut oil (Zeng et al. 2024).

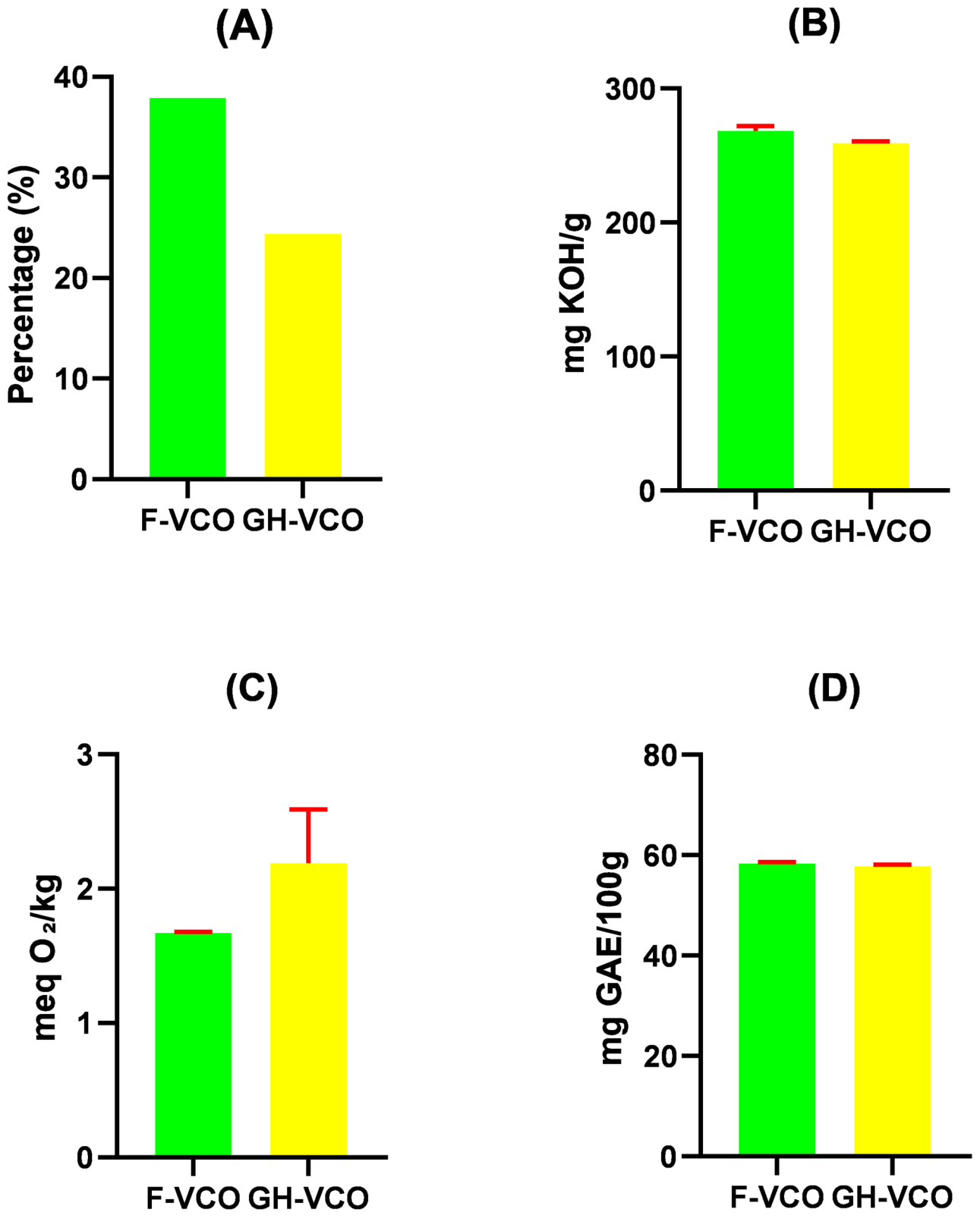


Fig. 1 Physicochemical characterization of Virgin Coconut Oil (VCO) obtained by F-VCO and GH-VCO: **A** Oil yield (%)*, **B** *Saponification value (mg KOH/g)**, **C** Peroxide value (meq O_2/kg)*, *and* **D** *Total phenolic content (mg GAE/100 g)*^{ns}. Data are presented as mean ± SD. Statistical significance between samples was determined using an independent t-test ($p < 0.05$). Significant differences are indicated by (*), while "ns" denotes no significant difference. FVCO showed significantly higher yield, saponification value, and lower peroxide value compared to GHVCO, whereas no significant difference was observed in total phenolic content

FVCO's even lower PV may also be supported by fermentation-related factors, such as the production of organic acids and additional antioxidant metabolites (Xiao et al. 2025; Chaidir et al. 2025). Both oils complied with international quality standards (APCC: 3.0 meq O_2/kg; Codex Alimentarius: 10.0 meq O_2/kg) (Ministry of Agriculture Fiji, n.d.; Codex Alimentarius Commission, 2024).

A low PV is crucial for product safety and stability, particularly in cosmeceuticals, as it minimizes secondary oxidation products that can cause skin irritation (Li Pomi et al. 2025; Bakır and Kastrati 2024). Consequently, the fermentation-based approach, consistently yielding lower PV, offers advantages in preserving oxidative stability and enhancing product shelf-life (Prasanna et al. 2024). This highlights FVCO's superior quality for stable cosmeceutical formulations.

Total phenolic content (TPC) determination

Total phenolic content (TPC) is a key indicator of VCO's antioxidant capacity. FVCO yielded a TPC of 58.32 ± 1.45 mg GAE/100 g, which was comparable to GHVCO's 57.83 ± 1.28 mg GAE/100 g, as shown in Fig. 1(D). Statistical analysis detected no significant difference ($p = 0.0906$), suggesting both methods preserved phenolic content similarly under the applied conditions (Antony and Farid 2022).

These TPC values (~ 58 mg GAE/100 g) fall within the upper range for wet-extracted coconut oils (~ 250–650 mg/kg) and exceed many reported values for commercial VCO (~ 7.8–29.2 mg GAE/100 g) (Jayathilaka and Seneviratne 2022). The comparable TPC in both FVCO and GHVCO stems from their relatively mild processing conditions. Even the 60 °C modest heat used for GHVCO, applied for a limited duration, is generally insufficient to cause significant loss of phenolic compounds, especially in oil systems with limited oxygen (Antony and Farid 2022). VCO's inherent oxidative stability, due to its high medium-chain triglyceride content, further aids in phenolic preservation (Prasanna et al. 2024).

High TPC in both samples is advantageous for cosmeceutical applications, as phenolic compounds contribute to antioxidant activity, photoprotection, and anti-inflammatory effects, supporting skin barrier function and enhancing product stability (Kiokias et al. 2020; Zeng et al. 2024). Thus, both fermentation and gentle heating (60 °C) prove effective in preserving phenolic compounds under the studied conditions, producing phenolic-rich VCO suitable for high-value applications.

Preliminary cream evaluation

The observed formulation performance reflects the underlying physicochemical differences between FVCO and GHVCO. The W/O cream formulations demonstrated stability through compositional design (high oil-to-water ratio, beeswax–borax emulsifying system) and controlled processing (heating, gradual aqueous phase incorporation), resulting in short-term stability with no phase separation, consistent spreadability, and minimal pH variation over 14 days (Bîrsan et al. 2025; Wadghule and Mundhe 2025). However, the W/O classification relied on indirect methods; direct microstructural confirmation was not performed, indicating a need for further structural characterization and extended stability testing for comprehensive validation. Table 1 summarizes the key physicochemical and sensory evaluation parameters for both cream formulations.

Table 1 Physicochemical and sensory evaluation of cream formulations based on experimental methods

Test parameter	F-VCO cream	GH-VCO cream
Organoleptic Properties	White/clear; pronounced coconut aroma; smooth, thick consistency	White/clear; milder coconut aroma; smooth, thick consistency
Smear Type	Forms smooth, uniform film; non-greasy residue	Forms slightly thicker film; mildly greasy residue
Removal Test	Easily removed; minimal residue	Moderately easy removal; slight residual film
pH Determination	6.28–6.30	5.54–5.57
Dilution Test	Completely miscible; no phase separation	Slight turbidity; minor resistance to dispersion
Irritation Study	No redness, itching, or inflammation observed	No redness, itching, or inflammation observed
Spreadability (cm)	4.20–4.35 cm	3.00–3.25 cm
Stability (14 days)	No phase separation; stable colour and consistency	No phase separation; slight pH decrease observed

Organoleptic properties

Both FVCO and GHVCO based formulations exhibited favorable sensory attributes (white/clear appearance, smooth texture, thick consistency). However, FVCO based creams generally retained a more pronounced natural coconut aroma, as detailed in Table 1. This is because minimal thermal input during fermentation limits the volatilization and transformation of key aroma compounds (Dimzon et al. 2021). Reviews of wet-extraction routes (fermentation, centrifugation) confirm that lower-temperature processing better preserves bioactive volatiles and overall aroma quality compared to thermal methods (Prasanna et al. 2024; Mulyadi et al. 2018).

pH stability

FVCO-based creams maintained a stable, near-neutral pH (≈ 6.28–6.30) over 14 days, while GHVCO-based creams showed slightly lower values (≈ 5.54–5.57), as seen in Table 1. Both ranges are within the skin-compatible window (~ 4.5–6.5), optimal for preserving the acid

mantle and skin health (Lukić et al. 2021; Alfa Chemistry, 2026). Near-neutral pH formulations generally have lower stinging potential and improved tolerability. The greater pH stability in FVCO creams is likely due to the retention of buffering metabolites from lactic fermentations, which aid in pH control and barrier support, whereas thermal processing can subtly shift lipid fractions towards acidity (Silva et al. 2025; Zainul et al. 2024).

Spreadability

FVCO-based creams consistently showed higher spreadability (4.20–4.35 cm) than GHVCO-based creams (3.00–3.25 cm), as reported in Table 1, indicating differences in flow behavior. Spreadability is crucial for ease of application and consumer acceptability, reflecting rheological properties like viscosity, viscoelasticity, and shear thinning (Kim et al. 2024; Lee et al. 2024). Lower viscosity generally results in higher spreadability. The lower spreadability of GHVCO formulation suggests a relatively higher apparent viscosity or structural rearrangements limiting flow. While similar observations are reported in topical creams (Mancuso et al. 2025), the absence of direct rheological measurements limits a quantitative interpretation. Future studies should include rheological characterization to confirm this relationship.

Irritation and safety

Following OECD TG 439 guidelines (OECD, 2025; MatTek, 2025), neither the FVCO nor GHVCO formulations caused any visible irritation (redness, itching, inflammation) during the 7-day preliminary application, as indicated in Table 1. Under the tested conditions, both formulations demonstrated good immediate topical compatibility. This initial screen provides foundational evidence of tolerability, serving as an important first step in assessing safety. Definitive dermatological safety, however, would necessitate larger participant cohorts, appropriate control groups, and extended observation periods.

Stability

Both FVCO and GHVCO-based formulations demonstrated acceptable short-term stability, maintaining physical integrity with no observable phase separation over a 28-day period at ambient conditions, as confirmed in Table 1. This foundational assessment provides initial confidence in their physical stability under typical storage. However, it is crucial to recognize that further comprehensive evaluations, including accelerated stability studies, freeze–thaw cycles, centrifugation, and longer storage, are essential to fully establish long-term stability and predict product shelf life.

Within this preliminary stability study, the FVCO formulation consistently maintained a relatively consistent, skin-compatible pH and exhibited higher spreadability compared to the GHVCO formulation. Near-neutral pH systems are associated with improved tolerability (Lukić et al. 2021; Alfa Chemistry, 2026), and the fermentation process may contribute positively by retaining buffering components within the oil. Spreadability, a key rheological characteristic, is crucial for both ease of application and overall consumer acceptance (Kim et al. 2024; Lee et al. 2024).

Differences observed in the stability and performance between the formulations may relate to underlying compositional variations in the oils. Cold processing methods, such as fermentation, are known to better preserve bioactive compounds like phenolics and tocopherols, which can enhance the oil's intrinsic oxidative stability (Jayathilaka and Seneviratne 2022). Conversely, thermal processing, even at moderate levels, may reduce the content of these protective compounds, potentially increasing oxidative susceptibility (Flores and Camacho 2023). While these literature-based interpretations offer possible explanations, it is important to note that this study specifically lacked direct measurements of oxidative stability or structural analysis to confirm these hypotheses.

Overall, while both formulations showed promising short-term physical stability in this preliminary assessment, this study serves as a critical first step, underscoring the need for more rigorous and comprehensive stability testing to ensure long-term product reliability for future applications.

Conclusion

This study demonstrates that the extraction method significantly influences the quality and performance of virgin coconut oil (VCO) from Pandan coconut. The fermentation method (FVCO) yielded higher oil, a better saponification value, and a lower peroxide value, indicating superior quality and stability compared to the gentle heating method (GHVCO). Both methods preserved similar levels of phenolic compounds, retaining their antioxidant potential. In water-in-oil cream formulations, FVCO derived creams showed improved spreadability, more stable skin-compatible pH, and a more pronounced natural coconut aroma. Both formulations proved safe in preliminary short-term irritation tests and maintained stability over 14 days, though further, extended testing is warranted. The findings confirm that fermentation not only improves physicochemical quality but also enhances formulation performance, directly fulfilling the study objectives. Overall, fermentation is a superior method for producing high-quality VCO for cosmeceutical applications. However, further detailed studies on composition, long-term stability, and clinical safety are necessary.

Author contributions

N.M.A.: data curation, writing–original draft, review & editing. N.A.R.: formal analysis, investigation, data curation, writing- review & editing. L.P.A.: formal

analysis, investigation, data curation, writing–review & editing. N.A.M.A.K.: visualization, formal analysis, supervision, writing–review & editing.Y.Y.H.: writing–review & editing. A.A.: writing–review & editing. S.K.P.: writing–review & editing. Y.T.: methodology, investigation, writing–review & editing. A.A.(afiq azil): conceptualization, methodology, project administration, funding acquisition, supervision, writing–review & editing. All authors have read and approved the final version of the manuscript.

Funding
This research was funded by KPJ Healthcare University.

Data availability
The datasets generated and analyzed during the current study, including physicochemical characterization values (saponification, peroxide, phenolic content) and cream formulation evaluation results, are available from the corresponding author (A.A.) upon reasonable request. No publicly archived datasets were created for this study.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

Received: 7 April 2026 / Accepted: 19 May 2026
Published online: 26 May 2026

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