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Ultrasonication-Assisted Preparation of Virgin Coconut Oil-Kelulut Honey-Vitamin E Emulsion and Its Bioactivity for Lip Balm Application

Nur Safiah Esrifadli[1], Sity Aishah Mansur[1,2]*, Angzzas Sari Mohd. Kassim[1,2], Noor Akhmazillah Mohd. Fauzi[1,2], Aliff Hisyam A. Razak[1,2], Mohhar Mohammed[3]

[1] *Department of Chemical Engineering Technology, Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia, (Pagoh Campus), 84600 Pagoh, Johor, MALAYSIA*
[2] *B-SMAT Focus Group, Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia (Pagoh Campus), 84600 Pagoh, Johor, MALAYSIA*
[3] *Alur Bina, 112 Kampung Panjang Sari, 84600 Pagoh, Johor, MALAYSIA*

*Corresponding Author: sity@uthm.edu.my
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Abstract

The growing demand for natural and eco-friendly skincare products has spurred innovation in cosmeceutical formulations, including lip balms. This study developed an emulsion-based lip balm incorporating Virgin Coconut Oil, Kelulut honey, and vitamin E, utilizing ultrasonication to enhance stability and bioactivity. The moisturizing, antibacterial, and antioxidant properties of these ingredients were combined with surfactants (Tween 20, soy lecithin, or a 50:50 blend) and processed through ultrasonication and/or homogenization. Bioactivity was assessed using pH, Total Phenolic Content (TPC), Total Flavonoid Content (TFC), 2,2-Diphenyl-1-Picrylhydrazyl (DPPH), and Ferric Reducing Antioxidant Power (FRAP) assays. Sample F (50:50 blend with ultrasonication) demonstrated the highest TPC (38.95 µg GAE/mL), TFC (5.59 µg QE/mL), DPPH inhibition (17.14%), and FRAP activity (2.68 µg GAE/mL), with a skin-compatible pH (4.80–5.50). The storage stability test conducted at 4°C for one week revealed visible phase separation in all samples, with samples B, D, and F (with ultrasonication) demonstrating comparatively less separation than their respective counterparts A, C, and E, (homogenization only) indicating enhanced emulsion stability under chilled conditions. Sensory evaluation identified Sample F as the most preferred, excelling in texture, spreadability, and absorption. This study underscores the significance of ultrasonication, surfactant synergy, and ingredient selection in developing sustainable, high-performance cosmeceutical formulations.

1. Introduction

The growing consumer preference for sustainable, chemical-free and effective solutions has led to a significant surge in demand for organic and environmentally conscious skincare products in recent years. Among cosmeceutical formulations, lip balms have gained significant attention for their dual role in enhancing aesthetics and providing therapeutic benefits. Conventional formulations often fall short in delivering optimal antioxidant

protection, long-term stability, and desirable sensory qualities, creating opportunities for innovative advancements in lip care products [1].

Malaysia, with its rich biodiversity, offers a wealth of natural resources such as VCO and Kelulut honey which are increasingly recognized for their moisturizing, antibacterial, and antioxidant properties. VCO is a versatile ingredient known for its high lauric acid content and remarkable moisturizing capabilities, while Kelulut honey, produced by stingless bees, boasts potent antioxidants and humectant properties [2]. In combination, vitamin E which was sourced externally, enhances skin health by protecting against oxidative stress and promoting cellular repair [3].

The advent of nanotechnology has enabled the development of emulsion systems that improve the bioavailability and stability of these natural ingredients. Ultrasonication, a high-energy processing technique, has emerged as a promising method for producing stable nanoemulsions by reducing droplet sizes and preserving bioactive components [4]. In addition to ultrasonication, the selection and combination of surfactants play a critical role in enhancing emulsion stability. Synergistic surfactant systems, such as blends of Tween 20 and soy lecithin, leverage the unique properties of each emulsifier to create stable and long-lasting formulations. This approach ensures the effective encapsulation and delivery of bioactive compounds while maintaining desirable sensory characteristics [5].

There is a lack of extensive study on the utilisation of ultrasonication to prepare emulsions using natural ingredients for lip care, which opens a chance for innovation in this field. This study focuses on formulating a stable emulsion-based lip balm using VCO, Kelulut honey, and vitamin E, processed primarily through ultrasonication. The physicochemical properties, antioxidant activities, and sensory characteristics of the formulations were evaluated to identify an optimal product that aligns with consumer preferences for natural, sustainable, and high-performing skincare solutions.

2. Methodology

2.1 Materials and Equipment

The raw materials used in this study included Kelulut honey (MaduCun, Malaysia), virgin coconut oil (VCO) (Bagan Datuk Best Farm, Malaysia), and vitamin E (Germany). Tween 20 (ChemTrade, Malaysia), soy lecithin emulsifier (Taiwan), and a 50:50 blend of these two were employed as surfactants for the emulsions. Analytical-grade chemicals were used for all assays, including TPTZ (Sigma-Aldrich), DPPH (Merck), ascorbic acid (Chemiz, Malaysia), gallic acid (Merck), ferric chloride (Element Chemicals Sdn Bhd), methanol (Chemiz, Malaysia), acetate buffer (pH 3.6), Folin-Ciocalteu reagent (Sigma-Aldrich), sodium carbonate (Sigma-Aldrich), and aluminium chloride (Element Chemicals Sdn Bhd). The equipment used included an ultrasonic probe sonicator (Straits Scientific), homogenizer (IKA RW 20 Digital), pH meter (Hanna Sdn Bhd) and UV-Vis spectrophotometer (Thermofisher Scientific) for sample preparation and analysis.

2.2 Preparation of Lip Balm Emulsions

The emulsions were prepared using ultrasonication, a high-energy technique that enhances the stability of nanoemulsions [6]. Three different surfactant systems were tested: Tween 20, soy lecithin, and a 50:50 blend of both. Table 2.2 provides the detailed weight in grams of each ingredient used in the lip balm emulsion formulations, including VCO, Vitamin E, Soy Lecithin, Tween 20, Kelulut Honey and Distilled Water.

Table 1 *Ratio for each formulation*

	VCO (g)	Vit E (g)	Soy Lecithin (g)	Tween 20 (g)	Kelulut Honey (g)	Distilled Water (g)
A	36	6	-	0.6	12	6
B	36	6	-	0.6	12	6
C	36	6	0.6	-	12	6
D	36	6	0.6	-	12	6
E	36	6	0.3	0.3	12	6
F	36	6	0.3	0.3	12	6

The formulations were labeled as follows:

- Sample A: Tween 20 with homogenization
- Sample B: Tween 20 with ultrasonication
- Sample C: Soy Lecithin with homogenization
- Sample D: Soy Lecithin with ultrasonication
- Sample E: Tween 20 + Soy Lecithin with homogenization
- Sample F: Tween 20 + Soy Lecithin with ultrasonication

For each formulation, precise quantities of VCO, Kelulut honey, vitamin E, and the chosen surfactant were mixed. The samples of B, D and F were processed using an ultrasonic probe at 20 kHz, 750 watts, 100% amplitude for 10 minutes, with pulse duration of 30 sand a resting interval of 5 sin ice bath. A control group of samples A, C, and E was prepared using a homogenizer alone for comparison.

2.3 Evaluation of Physicochemical Properties

2.3.1 pH Measurements

The pH of the emulsions was measured using a calibrated pH meter. The emulsions were placed in a clean beaker, and the pH probe was immersed in the sample. Readings were taken at room temperature, with triplicate measurements for accuracy. The pH values were used to ensure the suitability of the emulsions for skin application [7].

2.3.2 Total Phenolic Content (TPC)

The measurement of TPC was determined using the Folin-Ciocalteu method. A known volume of each emulsion was mixed with the Folin-Ciocalteu reagent and sodium carbonate solution. After incubation for 30 minutes, absorbance was measured at 765 nm using a spectrophotometer [8]. TPC was calculated from a gallic acid standard curve and expressed as µg gallic acid equivalent per mL (µg GAE/mL) [8].

2.3.3 Total Flavonoid Content (TFC)

The measurement of TFC was determined by the aluminum chloride colorimetric method. A known volume of emulsion was mixed with aluminum chloride and potassium acetate solutions. After 30 minutes of incubation, absorbance was measured at 430 nm [9]. The TFC was expressed in µg quercetin equivalent per mL (µg QE/mL) [9].

2.4 Determination of Antioxidant Activities

2.4.1 DPPH Assay

The antioxidant activity of each emulsion was assessed using the DPPH method. A known volume of emulsion was added to a 2,2-Diphenyl-1-picrylhydrazyl (DPPH) solution in methanol. The mixture was incubated in the dark for 30 minutes, and the absorbance was measured at 517 nm [10]. The percentage of DPPH inhibition was calculated using Eq. (1):

$$\%\ DPPH = \frac{Absorbance\ Control - Absorbance\ Sample}{Absorbance\ Sample} \times 100 \quad (1)$$

2.4.2 FRAP Assay

The FRAP assay was used to determine the reducing power of the emulsions. The FRAP reagent, prepared by mixing acetate buffer, 2,4,6-Tris(2-pyridyl)-s-triazine (TPTZ) solution, and ferric chloride, was added to each emulsion. The mixture was incubated for 30 minutes at room temperature, and absorbance was measured at 593 nm [11]. Results were expressed as µg gallic acid equivalent per mL (µg GAE/mL) [11].

2.5 Sensory Evaluation

The sensory evaluation involved 30 participants from UTHM Pagoh Campus. The evaluation was conducted to assess the texture, spreadability, and absorption of the lip balm formulations. Participants rated the formulations based on a structured questionnaire using a 5-point Likert scale [12]. Statistical analysis was performed to determine the most preferred formulation.

2.6 Statistical Analysis

All experimental data were statistically analyzed using analysis of variance (ANOVA). Significant differences ($p < 0.05$) between the formulations were determined to identify the optimal lip balm emulsion [6].

3. Results and Discussions

3.1 Physicochemical Properties

3.1.1 pH Analysis

The natural skin pH ranges from 4.5 to 6.5, supporting its acid mantle, which protects against environmental stressors and prevents Transepidermal Water Loss (TEWL), thereby maintaining hydration and reducing irritation [13]. Lip care products with neutral pH ~7 can disrupt this balance, leading to irritation, particularly in sensitive skin [14]. Slightly acidic formulations enhance safety and the efficacy of active ingredients like humectants and emollients [13]. Table 3.1 illustrates the pH values of six emulsions formulated with Tween 20, Soy Lecithin, and their combination, processed via homogenization or ultrasonication.

Table 2 *pH values for six formulations with two different types of surfactants of emulsion*

Sample	pH reading
A (Tween 20, non-ultrasonicated)	4.34
B (Tween 20, ultrasonicated)	4.52
C (Soy lecithin, non-ultrasonicated)	4.73
D (Soy lecithin, ultrasonicated)	4.62
E (Lecithin + Tween 20, non-ultrasonicated)	5.12
F (Lecithin + Tween 20, ultrasonicated)	5.54

pH values ranged from 4.34 (Sample A) to 5.54 (Sample F), aligning with the ideal skin pH (4.5–5.5). Formulations with combined surfactants (Samples E and F) showed higher pH values, suggesting improved emulsion stability [15]. Apart from sample D, ultrasonication resulted higher pH values than homogenization, likely due to enhanced dispersion and stability [16]. Tween 20 formulations (Samples A and B) had lower pH values, consistent with its stabilizing effect. Soy Lecithin (Samples C and D) exhibited moderate pH, reflecting its amphiphilic properties [17]. Combining Tween 20 and Soy Lecithin provided optimal stability and physicochemical balance [18]. All formulations were suitable for skin applications, with ultrasonication preferred for improved stability and higher pH values.

3.1.2 TPC Analysis

TPC is a key parameter for evaluating the antioxidant potential and bioactivity of cosmetic emulsions containing natural extracts like Kelulut honey and Vitamin E. Phenolic compounds, known for their strong antioxidant properties, protect the skin from oxidative stress caused by UV radiation and pollution while improving formulation stability and shelf life by inhibiting lipid peroxidation. These compounds also confer dermatological benefits such as anti-inflammatory and wound-healing properties [19]. The TPC values of six emulsions were determined using the Folin-Ciocalteu method and expressed as µg GAE/mL [20].

Table 3 *TPC of different samples (µg GAE/mL)*

Sample	Concentration (µg GAE/mL)
A (Tween 20, non-ultrasonicated)	2.47
B (Tween 20, ultrasonicated)	37.52
C (Soy lecithin, non-ultrasonicated)	22.61
D (Soy lecithin, ultrasonicated)	29.28
E (Lecithin + Tween 20, non-ultrasonicated)	23.35
F (Lecithin + Tween 20, ultrasonicated)	38.95

As shown in Table 3.2 TPC of Different Samples (µg GAE/mL), the TPC ranged from 2.47 µg GAE/mL (Sample A) to 38.95 µg GAE/mL (Sample F). Values represent the average of three replicates (n = 3). Ultrasonicated samples, particularly Sample F (Tween 20 + Soy Lecithin) and Sample B (Tween 20), showed the highest TPC,

demonstrating the efficacy of ultrasonication in preserving phenolic compounds by enhancing dispersion and reducing droplet size [21]. In contrast, homogenized samples, such as Sample A, exhibited lower TPC values, indicating reduced effectiveness in preserving phenolics. Soy Lecithin-based emulsions (Samples C and D) displayed moderate TPC values, with ultrasonication (Sample D) achieving higher retention than homogenization (Sample C). The combination of Tween 20 and Soy Lecithin further increased TPC, with Sample F showing the highest value, highlighting the synergistic effect of these surfactants in stabilizing phenolic compounds [17]. These findings underscore the importance of achieving TPC levels of 20–40 µg GAE/mL for phenolic-rich emulsions and the role of advanced processing techniques like ultrasonication in maintaining bioactivity. Ultrasonication significantly enhances TPC compared to homogenization ($F=329263.5$, $p<0.0001$), while the combination of surfactants further improves stability and antioxidant capacity. The cavitation effect disrupted cell structures and enhanced the release and dispersion of phenolic compounds within the nanoemulsion matrix. Additionally, reduced droplet size improved the solubilization and stability of phenolics, contributing to enhanced emulsion homogeneity and antioxidant potential [27]. These results emphasize the role of optimized processing methods and surfactant selection in developing bioactive, antioxidant-rich cosmetic formulations like lip balms.

3.1.3 TFC Analysis

TFC quantifies flavonoids, a class of polyphenolic compounds known for their antioxidant, anti-inflammatory, and skin-protective properties. Flavonoids play a critical role in cosmeceuticals by neutralizing free radicals, reducing oxidative stress, and improving skin health. TFC in emulsions is typically measured using the aluminum chloride colorimetric assay, where flavonoids form a yellow complex measurable at 415 nm, and results are expressed in quercetin equivalents (QE). As shown in Table 3.3 TFC of Different Samples (µg QE/mL), Sample F (Tween 20 + Soy Lecithin with ultrasonication) exhibited the highest TFC at 5.59 µg QE/mL, significantly outperforming other formulations. Values represent the average of three replicates (n = 3). Conversely, Sample E (Tween 20 + Soy Lecithin with homogenization) had the lowest TFC at 1.53 µg QE/mL, indicating the limitations of homogenization in extracting and stabilizing flavonoids. Samples B, C, and D showed moderate TFC values, with ultrasonication enhancing flavonoid extraction in Tween 20-based emulsions more effectively than in lecithin-based formulations. These results highlight the critical role of ultrasonication in improving TFC by disrupting emulsion interfaces, breaking down lipid membranes, and enhancing flavonoid diffusion. The combination of Tween 20 and Soy Lecithin further amplified TFC, as the dual-surfactant system promoted better emulsification and stabilization while reducing flavonoid degradation during processing [19]. However, formulations like Sample E demonstrated that insufficient energy input during homogenization can leave flavonoids trapped within the lipid phase, emphasizing the need for optimized processing. In conclusion, advanced techniques such as ultrasonication significantly improve flavonoid retention in emulsions, as evidenced by the highest TFC in Sample F. The statistical analysis using ANOVA further supports this finding, showing a significant difference in total flavonoid content (TFC) across the samples ($p < 0.05$). This indicates that ultrasonication has a measurable and positive impact on flavonoid preservation compared to other methods tested. These findings underscore the importance of optimizing surfactant selection and processing methods to enhance the bioactivity of emulsions, paving the way for the development of more effective cosmeceutical formulations.

Table 4 *TFC of different samples (µg QE/mL)*

Sample	Concentration (µg QE/mL)
A (Tween 20, non-ultrasonicated)	1.81
B (Tween 20, ultrasonicated)	2.25
C (Soy lecithin, non-ultrasonicated)	1.75
D (Soy lecithin, ultrasonicated)	1.70
E (Lecithin + Tween 20, non-ultrasonicated)	1.53
F (Lecithin + Tween 20, ultrasonicated)	5.59

3.2 Antioxidant Activities

3.2.1 DPPH Assay Analysis

The DPPH assay quantified the antioxidant activity of emulsion lip balm samples by measuring their free radical scavenging capacity at 517 nm. The DPPH inhibition percentage reflects the effectiveness of bioactive components like Kelulut honey, virgin coconut oil, and vitamin E in neutralizing oxidative species. To ensure data reliability, absorbance measurements for each sample were conducted in triplicate, minimizing experimental error and variability.

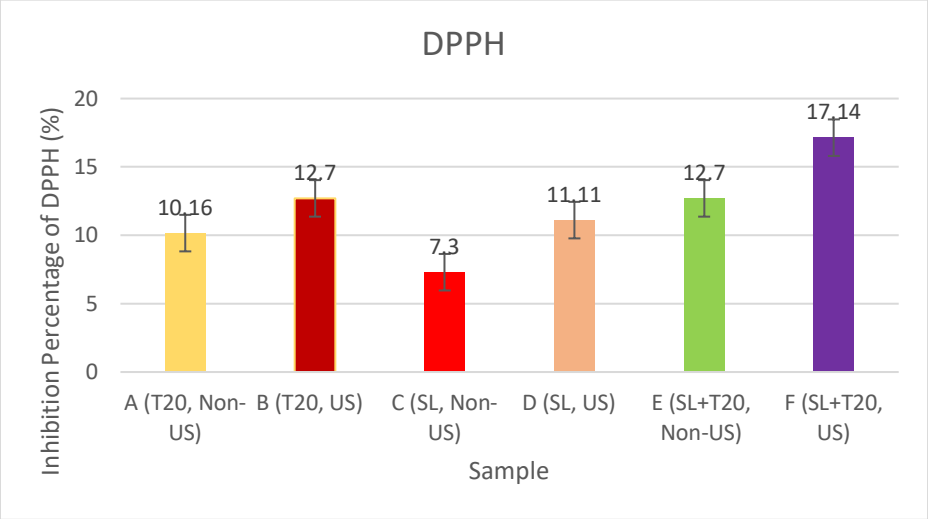


Fig. 1 *The inhibition percentage of DPPH for emulsion lip balm samples for absorbance at 517 nm. (n=3)*

As illustrated in Fig. 1 The inhibition percentage of DPPH for emulsion lip balm samples for absorbance at 517 nm, Sample F demonstrated the highest DPPH inhibition at 17.14%, highlighting the efficacy of combining Soy Lecithin and Tween 20 with ultrasonication. Values represent the average of three replicates (n = 3). Ultrasonication enhances antioxidant activity by disrupting emulsion interfaces, reducing droplet size, and increasing the surface area for antioxidant compounds to interact with free radicals. Soy Lecithin exhibited stronger antioxidant activity than Tween 20 due to its amphiphilic properties, which restrict free radical diffusion across emulsion interfaces [22]. Samples B and E showed the second-highest antioxidant activity at 12.70%. Sample B (Tween 20 with ultrasonication) underscores the role of high-energy processing, while Sample E (Soy Lecithin + Tween 20 with homogenization) demonstrates the potential of surfactant blends, though less effective than ultrasonication. Sample D (Soy Lecithin with homogenization) exhibited moderate activity (11.11%), outperforming Sample A (Tween 20 with homogenization, 10.16%) due to lecithin's superior antioxidant properties. Sample C (Soy Lecithin with homogenization) had the lowest inhibition (7.30%), reflecting the limitations of lecithin under low-energy processing. These findings emphasize lecithin's oxidative stability and its ability to enhance antioxidant protection at oil-water interfaces [22]. The highest antioxidant activity in Sample F demonstrates the synergistic effects of combining Soy Lecithin and Tween 20, enhanced further by ultrasonication. This method improves the dispersion and stabilization of bioactive compounds, resulting in greater interaction with DPPH radicals and increased inhibition. The results underscore the significant impact of ultrasonication on antioxidant activity, particularly when paired with synergistic surfactants. Statistical analysis (one-way ANOVA, $F=329263.5$, $p<0.0001$) confirmed the influence of processing methods and surfactant combinations. The superior performance of Sample F establishes it as the most effective formulation for cosmeceutical applications, emphasizing the need for optimized processing and surfactant selection to enhance antioxidant retention and bioactivity.

3.2.2 FRAP Assay Analysis

The FRAP assay evaluated the antioxidant activity of emulsion lip balm samples by measuring their ability to reduce ferric ions (Fe^{3+}) to ferrous ions (Fe^{2+}) at 593 nm, reflecting the reducing power of bioactive compounds. This method is effective for assessing antioxidant activity in formulations, as it directly quantifies electron-donating capacity under acidic conditions, similar to biological systems [23]. The assay is particularly relevant for cosmeceuticals, where antioxidant potential protects the skin from oxidative stress [24].

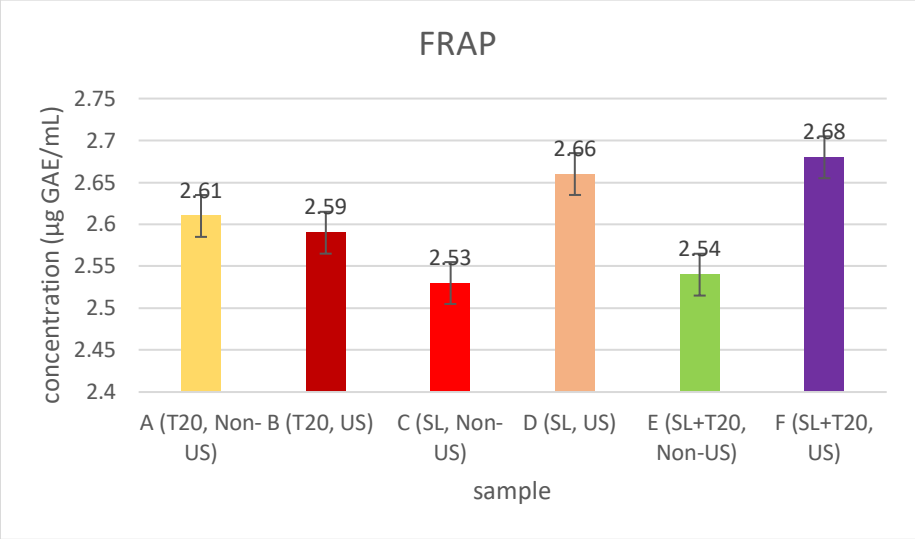


Fig. 2 *Ferric Reducing Antioxidant Power of sample emulsions. (n=3)*

As illustrated in Fig. 2 Ferric Reducing Antioxidant Power of Sample Emulsions, sample F (Soy Lecithin + Tween 20 with ultrasonication) exhibited the highest FRAP value (2.68 µg GAE/mL), demonstrating the efficacy of ultrasonication in enhancing antioxidant activity by improving dispersion and stabilization of bioactive compounds [21]. Values represent the average of three replicates (n = 3). Sample D (Soy Lecithin with homogenization) showed the second-highest value (2.66 µg GAE/mL), highlighting the stabilizing properties of lecithin in retaining phenolic and flavonoid compounds [23]. Samples A and B (Tween 20 emulsions) achieved FRAP values of 2.61 µg GAE/mL and 2.59 µg GAE/mL, respectively, indicating adequate antioxidant stabilization by Tween 20, although its efficacy is limited without lecithin or ultrasonication. Samples E and C (2.54 µg GAE/mL and 2.53 µg GAE/mL, respectively) exhibited the lowest FRAP values, with minor improvements from surfactant combinations but limited by the absence of ultrasonication. These results emphasize the critical role of ultrasonication and surfactant synergy in optimizing antioxidant activity in emulsions. This improvement is likely due to better dispersion and stabilization of antioxidant compounds, as ultrasonication produced smaller, more uniform droplets that enhanced the interaction between antioxidants and the FRAP reagent [28]. The statistical analysis using ANOVA confirmed a significant difference in FRAP values across the samples ($F=21.11$, $P<0.000014$), further supporting the critical role of ultrasonication and surfactant synergy in optimizing antioxidant activity in emulsions.

3.3 Sensory Evaluation

The sensory evaluation of emulsion lip balm samples assessed attributes such as texture, spreadability, absorption, stickiness, colour, and overall preference. Results showed noticeable variations based on surfactant type and processing method. Sample F (Soy Lecithin + Tween 20 with ultrasonication) was the most favoured, receiving the highest ratings for texture, spreadability, absorption, and overall preference due to its smoothness, ease of application, and optimal absorption. Sample E (Soy Lecithin + Tween 20 with homogenization) and Sample B (Tween 20 with ultrasonication) achieved moderate scores but performed less favourably in stickiness and overall preference compared to Sample F. Samples A (Tween 20 with homogenization) and D (Soy Lecithin with homogenization) received moderate ratings, with concerns about stickiness and suboptimal absorption. Sample C (Soy Lecithin with homogenization) had the lowest scores, described as less smooth and difficult to apply. These findings highlight the impact of processing methods on sensory properties. Ultrasonication improves smoothness, spreadability, absorption, and reduces stickiness by producing smaller, more uniform droplets, as seen in Sample F. In contrast, homogenization results in larger, less uniform droplets, leading to grainier textures, as observed in Sample C. Optimizing processing techniques is crucial for enhancing the sensory appeal and meeting consumer expectations for cosmeceuticals like lip balm.

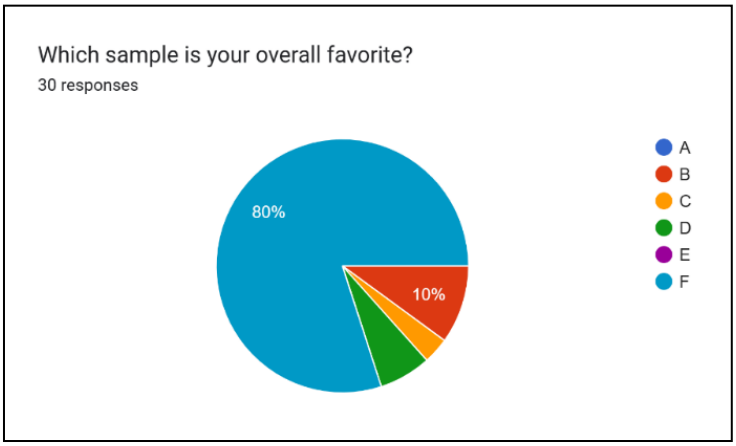


Fig. 3 *A pie chart of overall preference distribution of participants in the sensory evaluation*

Fig. 3 illustrates the overall preference distribution among participants. Sample F emerged as the favorite, with 80% of participants selecting it. Other samples, such as D and E, garnered minimal support, receiving 10% and smaller proportions, respectively. The dominance of Sample F reflects its superior performance across all sensory attributes. Participants were asked an optional "Why?" question in the survey, with 11 responses received. Table 3.4 summarizes their feedback. The most common reasons for selecting Sample F include its smooth texture, optimal spreadability, non-stickiness, good absorption, and pleasant smell. Descriptions like "perfect," "not oily," and "good for lip" highlight its well-balanced formulation, solidifying its status as the preferred option among participants.

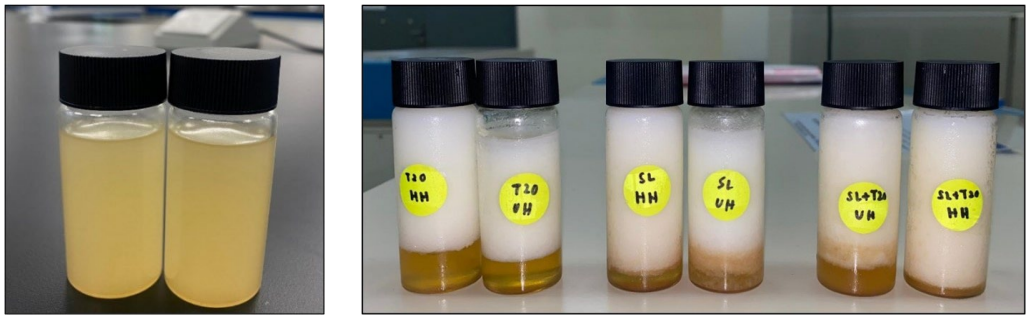
Table 5 *Participant feedback on reasons for selecting their favourite sample*

Participant	Response
1	it spread just nice
2	perfect
3	good for lip
4	non sticky, good absorption
5	Sticky for life
6	absorb evenly
7	The texture and smell for sample F is the best.
8	non sticky
9	Not oily
10	The absorbance and spreadability are quite good.
11	Its good

These qualitative insights reinforce the quantitative findings, establishing Sample F as the most well-received formulation.

3.4 Storage Stability Test

The storage stability test was conducted to assess the emulsion's ability to maintain homogeneity and structural integrity under chilled conditions. The emulsion was stored at approximately 4°C for one week, during which visible phase separation was observed. This instability suggests inadequate emulsification, potentially due to insufficient ultrasonication energy, suboptimal surfactant concentration, or an improper oil-to-water ratio [25]. The observed phase separation indicates inadequate reduction of interfacial tension, leading to coalescence and instability, as shown in Fig. 4 (a) and (b).



(a) **(b)**

Fig. 4 *Stability test of homogenous mixture of VCO-Kelulut-Vitamin E at 4°C observed in 1 week (a) Homogeneous emulsion immediately after preparation; (b) Phase separation observed after one week of storage at 4°C for each formulation*

Future optimization strategies should consider adjusting ultrasonication parameters, such as increasing power or duration, and refining the formulation with stabilizers or emulsifiers at appropriate concentrations to enhance storage stability. Accelerated stability tests are recommended to evaluate long-term behavior and improve formulation robustness [26].

4. Conclusion

This study successfully developed an emulsion-based lip balm using natural ingredients—VCO, Kelulut honey, and vitamin E, processed primarily through ultrasonication. The formulations demonstrated significant bioactive properties, with Sample F (50:50 blend of Tween 20 and soy lecithin with ultrasonication) achieving superior results. Specifically, Sample F exhibited the highest TPC of 38.95 µg GAE/mL, TFC of 5.59 µg QE/mL, DPPH inhibition of 17.14%, and FRAP activity of 2.68 µg GAE/mL, indicating strong antioxidant potential. The storage stability test at 4°C over one week revealed visible phase separation across all samples. However, samples B, D, and F which were prepared using ultrasonication exhibited less separation compared to their homogenized counterparts (A, C, and E), indicating improved emulsion stability under chilled conditions. Additionally, the sensory evaluation revealed that Sample F was the most preferred formulation, excelling in texture, spreadability and absorption. The findings highlight the importance of ultrasonication as a processing technique to enhance the stability, bioactivity and sensory properties of lip balm formulations. Furthermore, the synergy between surfactants, Tween 20 and soy lecithin contributed to the overall stability and performance of the emulsion. These results emphasize the potential of using natural, bioactive-rich ingredients and sustainable processing methods to develop high-performing cosmeceutical products that meet modern consumer preferences for safe, effective and eco-friendly skincare solutions. This study contributes to the development of sustainable cosmeceutical formulations and provides valuable insights for future research in the field of natural skincare products, particularly those that leverage nanotechnology and ultrasonication for improved bioactivity and stability.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design****: SAM, AHAR, MM;* ***data collection****: NSE;* ***analysis and interpretation of results****: Author NSE, Author SAM;* ***draft manuscript preparation****: NSE, SAM, ASMK, NAMF. All authors reviewed the results and approved the final version of the manuscript.*

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