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Development of High-SPF Sunscreen Cream Formulation Using Green Tea (*Camellia sinensis* L.) Extract Obtained via Combined Pulsed Electric Field and Microwave–Ultrasound Assisted Extraction (PEF-MUAE)

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ABSTRACT

The tea plant (*Camellia sinensis* L.) is valued for its antioxidant-rich secondary metabolites. Virgin coconut oil (VCO) acts as a natural emollient with mild UV protection, while titanium dioxide (TiO_2) serves as a physical UV filter. This study aimed to develop a high-SPF, eco-friendly sunscreen cream combining these ingredients. A novel pulsed electric field and microwave–ultrasound assisted extraction (PEF-MUAE) method using distilled water was applied to extract bioactive compounds from green tea. This method significantly improved the extraction yield (41.06 ± 0.72%) compared with conventional maceration (23.54 ± 0.69%) and produced a higher SPF at 5000 ppm (46.28 ± 0.52 vs. 21.37 ± 0.73). Four cream formulations were tested: F0 (base), F1 (TiO_2), F2 (green tea), and F3 (green tea + TiO_2). Organoleptically, F0 and F1 appeared ivory colored with a beeswax scent, whereas F2 and F3 were brownish with a herbal aroma. F3 had the firmest texture, due to TiO_2, and showed the best physical stability. SPF values ranged from negligible in F0 to 42.16 ± 0.79 in F3. F3 also showed the highest antioxidant activity (LC_{50} = 1.85 ± 0.09 ppm) and phenolic content (36.88 ± 1.20 mg GAE/g). In conclusion, PEF-MUAE enhanced extraction efficiency and bioactivity, and the formulation of green tea, VCO, and TiO_2 produced a stable, high-performance natural sunscreen.

Key words: *Camellia sinensis*, green-tea, sunscreen, virgin-coconut-oil

INTRODUCTION

The growing demand for safe and environmentally friendly skincare products underscores the need for natural sunscreen formulations that are both effective and sustainable. One promising source of active compounds is green tea (*Camellia sinensis* L.), a plant widely recognized for its health benefits. Green tea is rich in polyphenols, particularly flavonoids such as catechins, with epigallocatechin gallate (EGCG) being the most abundant [1,2]. These compounds are preserved through a rapid wilting process that deactivates polyphenol oxidase, thereby preventing enzymatic oxidation and fermentation during processing [3]. Catechins

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have been shown to possess antioxidant, antiallergic, anti-inflammatory, and antimicrobial properties [4], making them suitable candidates for topical photoprotective applications.

To extract these bioactive compounds efficiently and sustainably, green extraction techniques such as microwave-assisted extraction (MAE) and ultrasonic-assisted extraction (UAE) have been increasingly adopted. These methods offer advantages including reduced solvent use, shorter extraction time, and enhanced compound recovery. In this study, distilled water is selected as a safe, non-toxic alternative to conventional organic solvents such as n-hexane, chloroform, ethyl acetate, acetone, and methanol, which are associated with significant health and environmental hazards [5,6]. MAE and UAE represent modern, eco-conscious approaches that align with the principles of green chemistry and are well-suited for the development of safer cosmetic formulations [7].

This study adopts a novel approach by combining pulsed electric field (PEF) treatment and microwave ultrasound-assisted extraction (MUAE) using distilled water as a nontoxic and environmentally friendly solvent to enhance yield and preserve thermolabile compounds [8-10]. The application of PEF-MUAE increases cell permeability, which facilitates the release of catechins and improves overall extraction efficiency [11].

The resulting green tea extract was formulated into a sunscreen cream with virgin coconut oil (VCO) and titanium dioxide (TiO_2). VCO serves as a natural emollient with moisturizing and mild ultraviolet filtering properties, while TiO_2 acts as a physical ultraviolet filter that scatters and reflects harmful rays [12], [13]. The formulation was evaluated for sun protection factor (SPF) using UV Vis spectroscopy and ultraviolet diffuse reflectance spectroscopy (UV DRS), antioxidant activity through the DPPH assay, total phenolic content using the Folin-Ciocalteu method, and physical stability under various storage and stress conditions [14-16].

The objective of this study was to evaluate the effectiveness of the combined PEF-MUAE green extraction method using distilled water for isolating active compounds from green tea and to formulate a stable and effective natural sunscreen cream by synergistically incorporating green tea extract, VCO, and TiO_2.

EXPERIMENT

Chemicals and instrumentation

The green tea leaves were sourced from the Ciwidei Tea Plantation in West Java, Indonesia. Virgin coconut oil (VCO) was obtained from local Indonesian products. TiO_2 (MERCK). ascorbic acid (MERCK), ethanol (MERCK), gallic acid (MERCK), Folin-Ciocalteu (MERCK), Na_2CO_3 (MERCK), $FeCl_3$ (MERCK), anhydrous acetic acid (MERCK), potassium sorbate (MERCK), and sodium benzoate (MERCK). DPPH (Sigma Aldrich), magnesium powder (Sigma Aldrich), beeswax (Sigma Aldrich), Mayer's (Sigma Aldrich), Dragendorff's (Sigma Aldrich), chloroform (Sigma Aldrich), sulfuric acid (Sigma Aldrich), and HCl (Sigma Aldrich). Tween 80 (Bratachem), PEG 400 (Bratachem), xanthan gum (Fufeng, made in China), and distilled water.

Procedure reaction

Extraction of green tea leaves

Green tea leaves were extracted using a combination of PEF-MUAE methods. A total of 40 grams of dried green tea leaves was accurately weighed and placed into an Erlenmeyer flask, followed by the addition of 400 mL of distilled water. The extraction process commenced with PEF treatment for 2 minutes at a frequency of 5000 Hz and a voltage of 1000 watts. This was

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followed by microwave-assisted extraction at 450 watts for 4 minutes and subsequently by ultrasonic (Branson 5210) assisted extraction conducted at 40°C with 20% amplitude for 45 minutes. The method was adapted from previous studies [9, 10], with specific modifications in treatment duration and energy input parameters to enhance extraction efficiency.

For comparison, a conventional maceration method was also employed. In this method, 40 grams of green tea leaves were steeped in 400 mL of boiling distilled water and allowed to stand for 24 hours with occasional stirring. After the extraction period, both the PEF-MUAE and maceration extracts were filtered using Whatman filter paper, and the resulting filtrates were collected. The extracts were then freeze-dried to obtain dry extracts, which were subsequently weighed. The extraction yield was calculated to evaluate and compare the efficiency of each method.

Phytochemical determination of the extract

The extract was placed in a test tube and analyzed for flavonoid content, as well as for the presence of steroids, saponins, and tannins, following methods established in prior studies. Alkaloid testing was conducted in accordance with the methodology outlined in previous research [19].

In vitro sun protection factor (SPF) of green tea extract

A green tea solution at a concentration of 5000 ppm was prepared in distilled water. Absorbance measurements were recorded at 5 nm intervals within the range of 290–320 nm, using distilled water as the blank. The SPF values of the solutions were calculated following methods outlined in previous research [21]. The SPF evaluation was conducted on green tea extracts obtained from both the conventional maceration method and the combined PEF-MUAE extraction method in order to compare their photoprotective potential.

Table 1. Composition of sunscreen cream formulations

Ingredients	F0 (%)	F1 (%)	F2 (%)	F3 (%)
extract	-	-	5.0	5.0
TiO_2	-	1.0	-	1.0
VCO	10.0	10.0	10.0	10.0
Tween 80	6.0	6.0	6.0	6.0
PEG 400	4.0	4.0	4.0	4.0
Beeswax	12.0	12	12.0	12
Xanthan gum	1.2	1.2	1.2	1.2
potassium sorbate	0.2	0.2	0.2	0.2
sodium benzoate	0.3	0.3	0.3	0.3
Distilled water	until 100%			

Note: F0 (base cream without active ingredients), F1 (cream with TiO_2 only), F2 (cream with green tea extract only), and F3 (cream with both green tea extract and TiO_2),

Development of sunscreen cream formulation

Sunscreen formulations are prepared by combining the oil and water phases. The compositions of the various formulations are shown in Table 1. The oil phase includes virgin coconut oil (VCO), Tween 80, PEG 400, beeswax, and glycerin [20]. The oil phase mixture is

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heated on a hotplate at 80°C until fully melted. For the water phase, distilled water is combined with xanthan gum as a thickening agent, along with potassium sorbate and sodium benzoate as preservatives, and heated at 80°C until dissolved. The oil and water phases are then blended, followed by the addition of green tea leaf extract in the formulation outlined in Table 1. The mixture is stirred until homogeneous, resulting in a final weight of 25 grams. This procedure is based on prior research [22], with modifications in certain ingredients.

Evaluation of sunscreen cream

Physical parameters

The sunscreen cream formulations were systematically evaluated for their organoleptic properties, including color, aroma, texture, and homogeneity, by a panel of 15 trained volunteers. Each participant was provided with coded samples of all four formulations: F0 (base cream without active ingredients), F1 (cream containing TiO_2 only), F2 (cream containing green tea extract only), and F3 (cream containing both green tea extract and TiO_2). The assessment procedure was adapted from a previously established protocol [23], with appropriate modifications for cosmetic topical products. Approximately 0.5 grams of each cream formulation was applied to the inner forearm of the volunteers. Participants were instructed to visually observe the color, identify the aroma, and gently rub the cream to evaluate its texture and uniformity. Observations were recorded using a structured descriptive questionnaire designed to capture qualitative assessments of each sensory characteristic.

Washability test

The washability test was conducted to evaluate how easily the cream could be removed from the skin after application, following the method described by [24]. Approximately 1 gram of cream was evenly applied to the back of a clean, dry hand and left for 5 minutes. The area was then rinsed under running tap water for 30 seconds without rubbing. The ease of removal was assessed visually to determine whether any residue remained, providing an indication of the product's user-friendliness and suitability for daily use.

Determination of total phenol content in cream

The determination of total phenol content was performed by weighing 0.2 grams of cream, which was then dissolved in 10 mL of ethanol. A 0.5 mL aliquot of the solution was pipetted into a 5 mL volumetric flask and diluted with ethanol p.a. to the mark, yielding a concentration of 100 ppm. Then, 1 mL of the test solution was pipetted and mixed with 2.5 mL of 10% Folin-Ciocalteu reagent. Subsequently, 2 mL of 10% Na_2CO_3 was added. The mixture was vortexed for 2 minutes until homogeneous and incubated for 30 minutes. The absorbance was then measured at 752 nm.

Determination of *in vitro* antioxidant activity of sunscreen cream

The *in vitro* antioxidant potential of the sunscreen cream was assessed using the DPPH method [12]. Samples were prepared at concentrations of 1.0, 1.5, 2.0, 2.5, and 3.0 ppm, transferred into vials, and thoroughly mixed using a vortex. Each solution was pipetted (3 mL) into capped test tubes, followed by the addition of 1 mL of 0.2 mM DPPH solution. After vortexing, the mixtures were incubated at 37°C for 30 minutes. Absorbance was measured at 515 nm, with methanol used as the blank. The absorbance of the methanolic DPPH solution

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served as the control, and the LC_{50} was calculated. All experiments were conducted in triplicate [25].

Determination of SPF cream formulation

A total of 5 grams of each cream formulation (F0, F1, F2, F3) was tested using a Thermo Scientific Evolution 220 UV-DRS spectrophotometer, covering a wavelength range of 290-320 nm. SPF values were determined following the method outlined in previous research [26].

Centrifugation stability

The formulations were subjected to centrifugation at 5000 rpm for 30 minutes at room temperature and then examined for any phase separation [23, 27].

Freeze thaw studies

The cream was stored at a temperature of 4±2°C for 24 hours, then transferred to an oven at 40±2°C for another 24 hours. The storage period under these two temperature conditions is considered one cycle. Stability testing was conducted over six cycles, observing for any signs of phase separation and organoleptic properties [28].

RESULT AND DISCUSSION

Green tea leaf extracts

The filtrate obtained from the PEF-MUAE method produced an extract yield of 41.06 ± 0.72%, significantly higher than the 23.54 ± 0.69% yield from the maceration method. PEF-MUAE combines uniform heat distribution from microwave radiation with the mechanical disruption caused by ultrasonic waves, effectively enhancing cell wall breakdown and phenolic compound release. This method has been shown to improve both extract yield and active compound concentration [29], consistent with previous studies on brown macroalgae, where combined microwave–ultrasonic extraction outperformed single methods such as microwave, ultrasonic, or maceration [30].

SPF and the phytochemicals extract

Phytochemical analysis was conducted on both extracts, those obtained through the PEF-MUAE and conventional maceration, to determine the presence of secondary metabolites in green tea (*Camellia sinensis* L.). The classes of metabolites analyzed included flavonoids, alkaloids, triterpenoids, tannins, and saponins, while no steroid compounds were detected in either extract. The sun protection factor (SPF) of the extracts was measured using a UV-visible spectrophotometric method. Assessing the SPF is essential for evaluating the photoprotective potential of the extracts in sunscreen formulations. At a concentration of 5000 ppm, the green tea extract obtained from the combined method exhibited a relatively high SPF value of 46.28 ± 0.52, whereas the macerated extract showed a lower SPF of 21.37 ± 0.73.

Evaluation of sunscreen cream formulation

Physical parameters

The organoleptic evaluation provided valuable insights into the visual and sensory characteristics of the sunscreen cream formulations (Figure 1). In terms of color, the majority of volunteers described F0 and F1 as ivory, which is consistent with the absence of green tea extract. F2 was perceived as brown, attributable to the presence of green tea extract, which

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imparts a naturally dark pigment to the formulation. Meanwhile, F3 was described as light brown, likely due to the presence of TiO_2, which contributes to a lighter appearance by partially masking the color intensity of the extract.

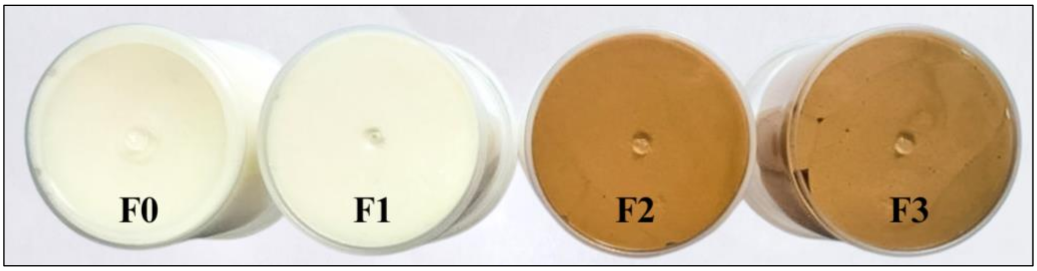

Figure 1. Color appearance of sunscreen cream formulations F0, F1, F2, and F3

Aroma assessments indicated that F0 and F1 exhibited a characteristic beeswax scent, whereas F2 and F3 were noted for their distinct herbal fragrance, attributed to the inclusion of green tea extract. These results underscore the influence of botanical components on the olfactory properties of topical formulations.

Texture evaluation revealed perceptible differences among the creams. F1 was perceived as having a very soft consistency; F0 and F2 were categorized as soft, while F3 was characterized as denser and firmer compared to F2. This increased density in F3 is likely due to the presence of TiO_2, which, in combination with green tea extract, contributes to greater structural rigidity. This observation aligns with findings reported [3], which highlight that both botanical extracts and inorganic UV filters, such as TiO_2, can significantly impact the viscosity and spreadability of emulsified formulations.

All formulations were reported to be homogeneous, with no evidence of phase separation or clumping, suggesting effective emulsification and component compatibility. These parameters are crucial for ensuring product stability and consumer appeal. Overall, the combined incorporation of green tea extract and TiO_2 was shown to improve the sensory and functional attributes of the cream formulations, supporting their potential application in natural-based sunscreen products.

Washability test

The washability test, which measures how easily sunscreen creams can be removed under running water, provides insight into their water resistance, an important attribute for topical sunscreen products. As summarized in Table 2, the formulations showed varying degrees of washability. F0 (base cream without active ingredients) was removed in 24 seconds, while F1 (cream with TiO_2 only) required only 20 seconds, suggesting that TiO_2 may reduce adherence due to its particulate nature. F2 (cream with green tea extract only) took 25 seconds to remove, likely due to the polyphenolic content and viscous characteristics of the extract. F3 (cream with both TiO_2 and green tea extract) exhibited the highest wash resistance, requiring 28 seconds for complete removal. This indicates a synergistic interaction between TiO_2 and the extract that enhances film formation and adhesion to the skin surface.

These results are consistent with prior research showing that creams formulated with virgin coconut oil or botanical extracts possess good washability [31]. No visible residue was observed on the skin post-rinsing, indicating favorable removal characteristics. The longer

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removal time of F3 also corresponds with its denser texture as observed in the organoleptic evaluation, further supporting its enhanced adherence. Despite the variation in resistance, all formulations remained easy to rinse off, ensuring both functional protection and consumer comfort.

Table 2. Washability test result data of formulations F0, F1, F2, and F3

Formula	Washability
F0	Clean in 24 seconds
F1	Clean in 20 seconds
F2	Clean in 25 seconds
F3	Clean in 28 seconds

Note: F0 is the formulation without extract or TiO_2; F1 is the formulation containing only TiO_2; F2 is the formulation containing only the extract; and F3 is the formulation containing both extract and TiO_2.

Total phenol content

The total phenol content is expressed in gallic acid equivalents (GAE). The results of the total phenol content measurement are summarized in Table 3. F0 had a lower average total phenol content compared to F1. F0 is a cream formulated without extract and TiO_2, whereas F1 is a cream formulated without extract but with TiO_2. Similarly, F2 had a lower average total phenol content than F3. F2 is a cream formulated with extract but without TiO_2, while F3 contains both extract and TiO_2. The average total phenol content in F2 and F3 was higher than in F0 and F1. This indicates that creams containing extract have phenolic compounds with hydroxyl groups that react with the Folin-Ciocalteu reagent, forming a blue phosphotungstate-phosphomolybdate complex.

Table 3. Total phenol content of formulations F0, F1, F2, and F3

Formulas	Total Phenol Content (mgGAE/g)
F0	156.51 ± 10.82^{a}
F1	266.39 ± 13.76^{b}
F2	604.98 ± 12.82^{c}
F3	680.87 ± 15.88^{d}

Information: $^{a,\ b,\ c,\ \text{and}\ d}$ denoted significant differences in total phenol content using one-way ANOVA with post-hoc Tukey test ($P < 0.05$). F0 is the formulation without extract or TiO_2; F1 is the formulation containing only TiO_2; F2 is the formulation containing only the extract; and F3 is the formulation containing both extract and TiO_2.

In vitro antioxidant

Antioxidant activity, or the ability to scavenge free radicals, is an important factor in preventing and repairing skin damage caused by ultraviolet radiation. In this study, the

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antioxidant properties of sunscreen cream formulations containing green tea extract, virgin VCO, and TiO_2 were evaluated using the DPPH method, with ascorbic acid as the standard reference. The IC_{50} values, which represent the concentration needed to inhibit 50 percent of DPPH radicals, were used to quantify antioxidant strength. As shown in Figure 2, the IC_{50} values for formulations F0, F1, F2, and F3 were 30.98 ± 1.12 ppm, 32.87 ± 0.95 ppm, 34.66 ± 1.08 ppm, and 28.17 ± 1.04 ppm, respectively.

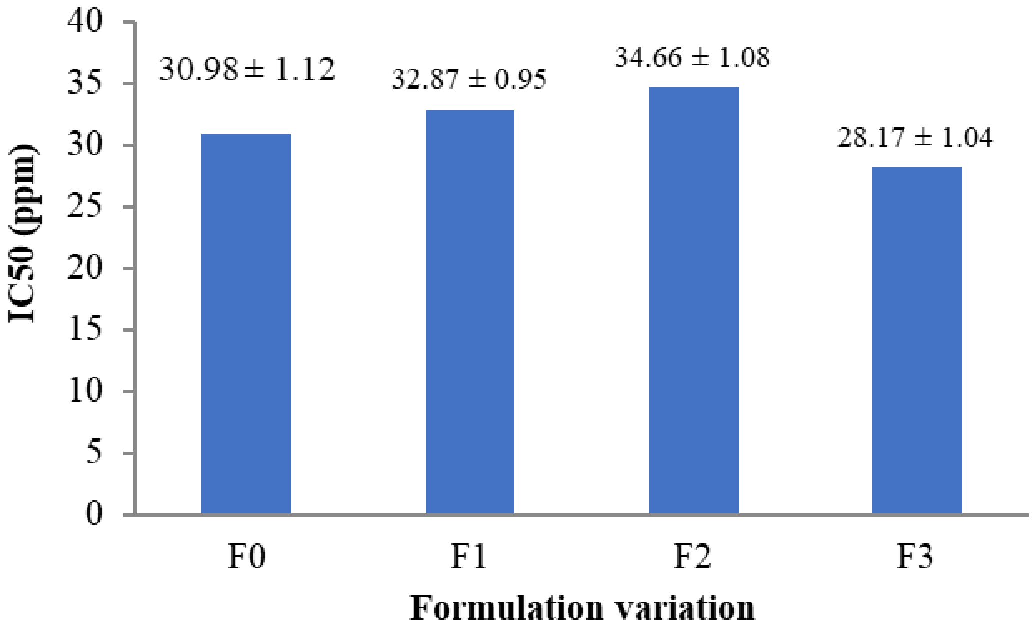

Figure 2. Antioxidant activity in various cream formulations of formulations F0, F1, F2, and F3.

Among all formulations, F3 demonstrated the strongest antioxidant activity, indicated by the lowest IC_{50} value. This suggests a synergistic interaction between green tea extract and TiO_2 that enhances free radical neutralization. Although green tea extract is known to be rich in polyphenols such as EGCG, which contribute to its antioxidant properties, formulation F2, containing only the extract, showed a higher IC_{50} value than F0 and F1, indicating relatively lower antioxidant activity in this context. This unexpected result may be due to formulation factors that affect the availability or stability of active compounds.

Formulation F1, which contains only TiO_2, showed slightly lower antioxidant activity compared to the base cream F0, reinforcing the notion that TiO_2 primarily functions as a physical ultraviolet blocker with limited biochemical activity. VCO, included in all formulations, contributes to skin moisturization and barrier protection, potentially supporting overall skin health without directly influencing antioxidant capacity.

Overall, the combination of green tea extract and TiO_2 in formulation F3 provided the most effective antioxidant performance. This result underscores the potential benefit of combining physical and biochemical protective agents in sunscreen formulations to achieve enhanced skin protection against oxidative stress.

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***In vitro* sun protection factor (SPF) of sunscreen cream**

Figure 3 shows that the formulation containing only TiO_2 (F1) and the formulation without extract or TiO_2 (F0) exhibit a higher SPF compared to the formulations containing extracts (F2 and F3).

The phenolic compounds in green tea extract, particularly polyphenols, act as powerful antioxidants that protect the skin from oxidative damage caused by UV radiation. These antioxidants neutralize free radicals generated by UV exposure, extending the duration of UV protection by absorbing harmful rays [3]. In sunscreen formulations, the addition of TiO_2 enhances this effect and reflects UV radiation, preventing it from penetrating the skin. This combination allows polyphenols to absorb energy while TiO_2 reflects it, providing a more comprehensive shield against UV damage Figure 3.

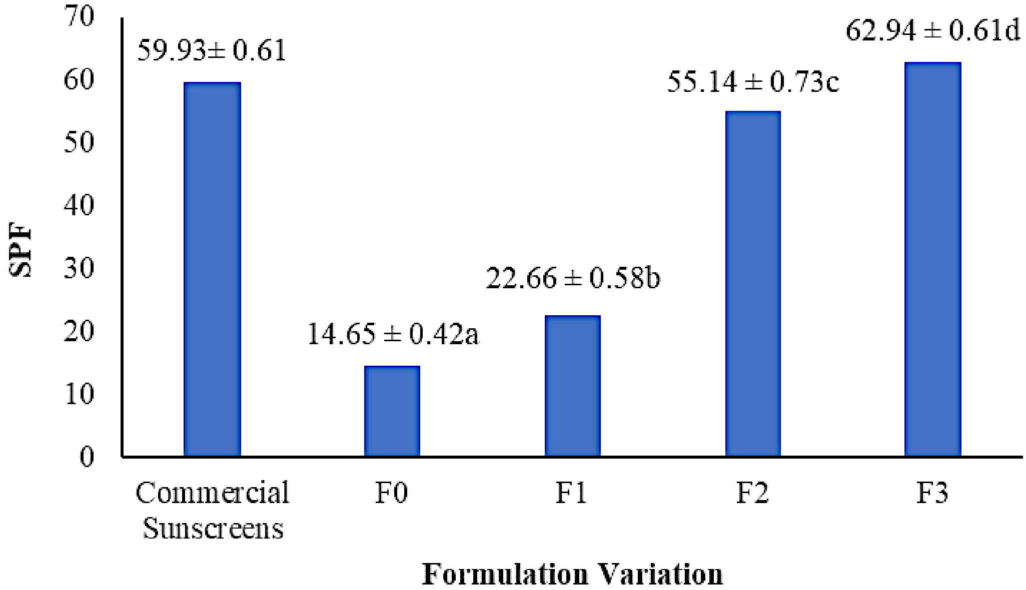

Figure 3. The SPF values of commercial sunscreen, cream formulations F0, F1, F2 and F3. Notation a, b, c, and d denoted significant different SPF values using one-way ANOVA with post-hoc Tukey test ($P < 0.05$).

In line with this, previous research by Torbati and Javanbakht [18] has shown that advanced sunscreen formulations have incorporated nanocomposites such as TiO_2, Zn_2TiO_4, and Ag, which significantly enhance UV protection. These nanocomposites, with particle sizes below 100 nanometers, exhibit a high UV absorption rate and possess an energy gap of 3.01 electron volts, which is comparable to that of pure TiO_2. This contributes to their effectiveness as active components in sunscreens. Additionally, the low toxicity profile of the nanocomposites, demonstrated by high cell viability in safety tests, supports their suitability for cosmetic applications. Therefore, the combination of green tea extract, known for its antioxidant properties, with TiO_2 nanocomposites can enhance sunscreen efficacy by offering strong UV protection while also promoting additional skin health benefits.

SPF is calculated based on the % reflectance value measured at wavelengths between 290 and 320 nm, which corresponds to the UV-B spectrum. In addition to its role in calculation,

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the % reflectance value can also be used to determine the mechanism by which a cream functions, whether as a chemical or physical sunscreen.

The SPF level of the formulation containing both green tea extract and TiO_2 (F3) was significantly higher than that of the formulations containing only TiO_2 (F1) or only green tea extract (F2) or the base cream without active ingredients (F0). Formulation F2 showed a substantial increase in SPF compared to F1, highlighting the superior photoprotective effect of green tea extract. The combination of green tea extract, VCO, and TiO_2 in F3 produced the highest SPF, suggesting a synergistic enhancement in photoprotection.

Formulation F0, containing neither green tea extract nor TiO_2, exhibited the lowest SPF of 14.65 ± 0.42^a, serving as the baseline. Formulation F1, which included TiO_2 but no extract, showed a moderate increase in SPF to 22.66 ± 0.58^b. Formulation F2, with green tea extract but without TiO_2, reached a significantly higher SPF of 55.14 ± 0.73^c. Finally, formulation F3, which incorporated both active ingredients, achieved the highest SPF value of 62.94 ± 0.61^d, slightly surpassing that of the commercial cream with an SPF of 59.93 ± 0.61.

The increase in SPF observed in Formulas F2 and F3 suggests that incorporating a certain concentration of green tea extract into the formulation significantly enhances sun protection. Green tea extract positively influences SPF levels in sunscreen formulations [3], [32], especially when combined with TiO_2. Such a formulation, combining green tea extract and TiO_2, offers an effective and promising alternative for sun protection.

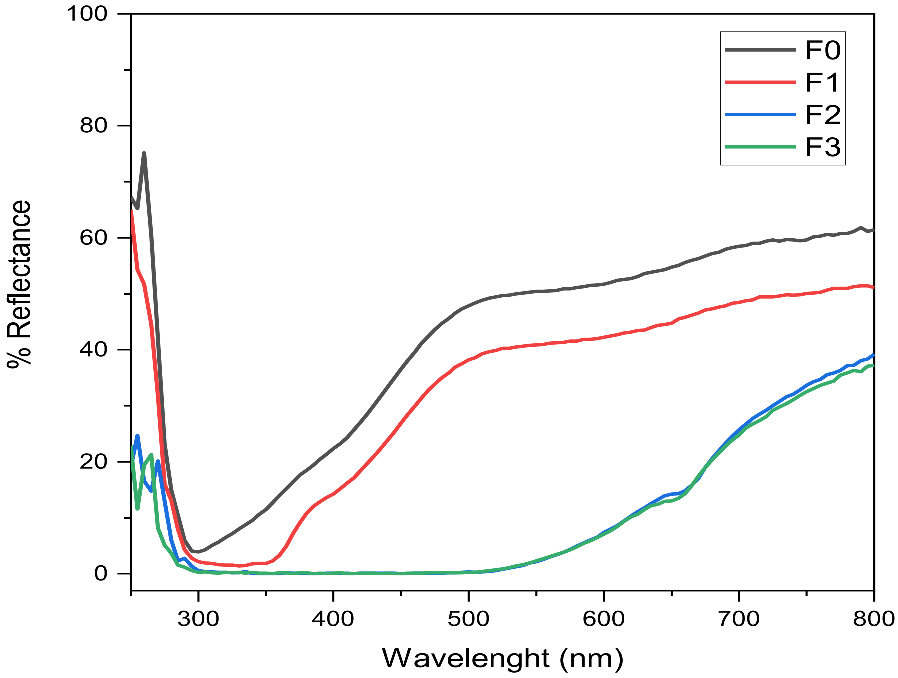

Figure 4. Graph of % Reflectance of cream formulations F0, F1, F2, and F3.

The polyphenolic compounds in green tea, particularly catechins, absorb UV radiation mainly in the UV-B range (290–320 nm), as shown in Figure 4. This absorption reduces the penetration of harmful UV rays into the skin, thereby contributing to higher SPF values. The Differences in absorbance values observed in the reflectance spectra between formulations are

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attributed to the varying concentrations and interactions of active components that affect how UV light is absorbed or scattered. For instance, formulations with higher green tea extract content exhibit increased UV absorption due to the greater presence of polyphenols, whereas TiO_2 primarily contributes by scattering UV radiation. These combined effects result in distinct reflectance spectra and corresponding SPF variations. Previous research indicates that a cream base containing 40% VCO shows improved consistency and superior physical stability compared to formulations without VCO. This VCO concentration correlates with approximately 50% lauric acid content, which not only aids in moisturizing but also contributes mild UV-filtering properties [33].

Centrifugation stability

The results indicate that all formulations remained stable following centrifugation tests, showing no phase separation. In this study, the cream formulation contained 10% virgin coconut oil (VCO). Previous research has demonstrated that a cream base containing 40% VCO exhibits good consistency and physical stability [33]. This method has proven highly effective for evaluating and projecting the shelf life of emulsions in cream formulations.

Observations from centrifugal tests serve as an indicator of the cream's physical stability, which is influenced by gravitational forces. Prior studies have indicated that cream Samples centrifuged at 3750 rpm for 5 hours experience effects equivalent to one year of gravitational impact. Therefore, centrifugation testing is instrumental in assessing the stability of the cream by exposing it to high speeds for a designated duration, effectively simulating long-term storage conditions, and evaluating the cream's response to gravitational forces [28].

Freeze thaw studies

Formulations subjected to six-cycle tests, specifically F0 and F1, showed no changes in organoleptic properties and no phase separation by the study's conclusion. Thus, all formulations demonstrated stability under alternating conditions of refrigeration (4°C) and elevated temperatures (40°C) [34] and were eco-friendly.

F2, which contained only extract, the cream was stable in terms of homogeneity up to the first cycle but began to separate from the second cycle onward. Formulation F3, containing TiO_2, exhibited greater stability, remaining homogeneous until the fourth cycle, with phase separation starting in the fifth cycle. This indicates that the presence of TiO_2 enhances stability, as observed in F1, which contained TiO_2 alone, and in F3, containing both TiO_2 and green tea extract. Moreover, there were no observable changes in organoleptic properties, such as color, aroma, and texture, across all cycles up to the sixth.

CONCLUSION

This study demonstrates the effectiveness of the PEF-MUAE method as a novel and ecofriendly approach for extracting active compounds from green tea leaves. Compared to conventional maceration, PEF-MUAE offers higher efficiency, reduced extraction time, and improved yield and SPF values. Both extraction methods produced extracts containing the same secondary metabolites: flavonoids, alkaloids, triterpenoids, tannins, and saponins, while steroids were absent. When combined with virgin coconut oil (VCO) and titanium dioxide (TiO_2), the green tea extract contributed to a sunscreen cream with enhanced total phenolic content, antioxidant activity, and SPF value. Green tea extract functions as a UV absorber, while titanium dioxide acts as a physical UV blocker by reflecting or scattering ultraviolet rays.

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The combined incorporation of green tea extract, VCO, and titanium dioxide also improved the sensory properties of the cream, particularly its texture. All cream formulations showed good physical stability, with no phase separation after centrifugation and freeze-thaw testing. The inclusion of titanium dioxide further enhanced the cream's stability under extreme temperature fluctuations.

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