

Original Article

Formulation and In-Vitro SPF Evaluation of Creams Robusta Coffee (*Coffea canephora* L) Fruit Peel Extract

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Abstract: This study evaluated Robusta coffee (*Coffea canephora* L.) fruit peel extract as a natural photoprotective ingredient in topical cream formulations and determined its in vitro Sun Protection Factor (SPF). The ethanolic extract of dried Robusta coffee fruit peel was obtained by maceration and characterized by qualitative phytochemical screening. The extract was incorporated into oil-in-water cream formulations at concentrations of 1%, 3%, and 5%, while a base cream without extract was used as the control. The cream formulations were assessed for organoleptic properties, homogeneity, emulsion type, pH, spreadability, adhesion, viscosity, and accelerated physical stability. SPF was determined using UV spectrophotometry. The results showed that all formulations maintained skin-compatible pH and exhibited appropriate spreadability, adhesion, and viscosity, with satisfactory physical stability under accelerated conditions. Formulas 2 and 3, with extract concentrations of 3% and 5%, met the required organoleptic properties, homogeneity, emulsion type, pH, spreadability, adhesion, and viscosity standards. The base cream showed an SPF value of 5.70 (moderate protection). Incorporation of 1% extract increased the SPF to 6.40 (extra protection), while 3% and 5% extracts yielded SPF values of 12.85 (maximum protection) and 16.32 (ultra protection), respectively. These findings suggest that Robusta coffee fruit peel extract can effectively enhance the photoprotective capacity of sunscreen creams in a concentration-dependent manner. As an agro-industrial by-product, Robusta coffee fruit peel has potential to be utilized as a sustainable natural ingredient in sunscreen formulations. Further in vitro and in vivo studies, including UVA protection, photostability, and long-term stability, are recommended to fully assess its clinical relevance and product applicability.

Keywords: cream formulation, robusta coffee fruit peel, sun protection factor, sunscreen

1. INTRODUCTION

Exposure to solar ultraviolet (UV) radiation is a major environmental factor contributing to acute and chronic skin damage, including erythema, photoaging, and carcinogenesis. Effective photoprotection therefore represents a critical component of dermatological care and public health, and topical sunscreens remain the most widely used strategy to mitigate UV-induced injury. Recent research has increasingly focused on enhancing the efficacy, safety, and multifunctionality of topical photoprotective products by optimizing both active ingredients and formulation approaches. In particular, cream dosage forms incorporating photoprotective agents have attracted considerable attention because they can combine UV filtering, antioxidant defence, and favorable sensory properties within a single system. Concurrently, there is growing interest in exploiting bioactive compounds of natural origin as complementary or alternative UV-protective agents in sunscreen formulations. Plant-derived molecules, especially polyphenols and other antioxidants, have been shown to absorb UV radiation, scavenge reactive oxygen species, and modulate biological responses to UV exposure [1], [2], [3]. These multifunctional properties align with current trends toward safer, more sustainable, and more consumer-acceptable cosmetic and dermopharmaceutical products. At the same time, advances in in vitro testing, including spectrophotometric determination of the Sun Protection Factor (SPF) and the use of reconstructed human epidermis models, have strengthened the methodological basis for screening and developing novel photoprotective agents while reducing reliance on in vivo testing [4],[5], [6], [7]

Within this context, the development of creams containing plant-derived photoprotective agents offers a promising solution. Such systems can leverage botanical extracts that provide both UV filtering and antioxidant activity, while carefully designed emulsions and delivery systems optimize stability and skin performance. However, the translation of plant extracts into effective sunscreen products is not trivial: complex phytochemical compositions, potential instability, and variability in raw materials require rigorous evaluation of phytochemical profiles, in vitro SPF behaviour, and formulation properties. Furthermore, the correlation between in vitro SPF values and expected in vivo performance must be carefully considered, particularly for novel natural actives [8], [9], [10], [11], [12].

Polyphenolic antioxidants from diverse botanical sources provide another important avenue for improving photoprotection. Green tea catechins and grape seed proanthocyanidins, for instance, exhibit robust antioxidant and anti-photoaging effects and can stabilize synthetic UV filters within formulations [2], [3], [13], [14]. Xanthone derivatives have been shown to protect against UV-induced oxidative damage while maintaining structural stability under varying conditions, and extracts of *Baccharis antioquensis* have demonstrated promise as natural sunscreens due to their high antioxidant capacity [15], [16], [17]. The co-formulation of these phytochemicals with synthetic filters can yield synergistic effects, offering improved photoprotection, better photostability, and ancillary benefits such as anti-inflammatory or barrier-supporting actions [2], [3], [18].

Coffea canephora L (Robusta coffee) fruit peel has recently emerged as an attractive source of bioactive compounds with strong antioxidant potential. Studies have shown that coffee fruit peel is rich in phenolic compounds, flavonoids, alkaloids (including caffeine), and tannins, which collectively contribute to substantial radical-scavenging activity, often with DPPH IC₅₀ values below 100 µg/mL [19], [20], [21]. Comparative analyses indicate that Robusta coffee peel may possess higher antioxidant potential than several other fruit peels, attributable to its dense polyphenolic content ([22], [23]. Synergistic interactions among the diverse phytochemicals present in coffee peel have been suggested to enhance overall antioxidant efficacy [24]. These properties have stimulated interest in the use of coffee peel extracts as natural preservatives in food and cosmetic applications, including face serums and other topical products [20].

Despite this emerging evidence, the application of *Coffea canephora* L fruit peel extract as a photoprotective agent in sunscreen cream formulations remains insufficiently investigated. Although plant-derived polyphenols and caffeine have been associated with photoprotective, antioxidant, and anti-inflammatory effects in topical systems [1], [2], [3], [25], systematic evidence regarding the in vitro Sun Protection Factor (SPF) of Robusta coffee fruit peel extract and its performance in cream formulations is still limited. In addition, the influence of this extract on the critical quality attributes of topical creams, including pH, rheology, spreadability, adhesion, viscosity, and stability, has not been comprehensively characterized. This lack of integrated phytochemical, functional, and formulation-based evaluation highlights the need for further investigation to support the development of Robusta coffee peel as a natural and sustainable sunscreen active [26], [27], [28], [29], [30], [31], [32], [33], [34], [35].

This study was conducted to formulate oil-in-water creams containing *Coffea canephora* L fruit peel extract at different concentrations and to evaluate their potential as topical photoprotective preparations. Specifically, the study aimed to characterize the phytochemical constituents of the extract, determine the in vitro SPF of the extract and the resulting cream formulations, and assess the physicochemical properties of the creams, including organoleptic characteristics, homogeneity, emulsion type, pH, spreadability, adhesion, viscosity, and accelerated stability. Based on previous reports on the antioxidant activity of Robusta coffee peel and the photoprotective roles of plant polyphenols and caffeine, it was hypothesized that incorporation of the extract into the cream formulation would enhance SPF while maintaining acceptable stability and topical performance. In addition to its potential functional value, the use of Robusta coffee fruit peel as an agro-industrial by-product may also support sustainability and circular-economy approaches in cosmetic development [19], [20], [21], [25].

2. MATERIALS AND METHODS

2.1. Sample Collection and Preparation

2.1.1. Collection of Plant Material

Robusta coffee (*Coffea canephora* L.) fruit peels were obtained from fresh coffee processing waste collected from a coffee processing plant located in Tanah Toraja, specifically in Buntu Pepasan Subdistrict, Tanah Toraja Regency, South Sulawesi, Indonesia. The plant material was collected from freshly processed coffee fruits and used as the raw material for extract preparation. The taxonomic identification of the plant material was carried out at the Plant Determination Unit, Pharmacognosy-Phytochemistry Laboratory, Faculty of Pharmacy, Universitas Muslim Indonesia, Makassar, Indonesia. The determination result confirmed that the plant material was *Coffea canephora* L., with determination certificate number 0015/UD-FF/UMI/2023.

2.1.2 Preparation of Plant Material

Fresh coffee fruit peels were first subjected to wet sorting to remove foreign matter and damaged material. The selected peels were washed under running water and cut into small pieces. The material was then dried, followed by dry sorting, and subsequently milled to obtain dried plant material (simplesia), which was further coarsely powdered (10/40 mesh) [20].

2.1.3 Preparation of Robusta Coffee Fruit Peel Extract

The extract was prepared by maceration. A total of 1000 g of coarsely powdered robusta coffee fruit peel was macerated with 96% ethanol at a ratio of 1:7 (w/v) for 3 × 24 h with manual agitation every 6 h. The macerate was filtered to obtain the first filtrate. The residue was then remacerated with the same solvent under identical conditions for 3 × 24 h, and all filtrates were combined. The pooled filtrate was concentrated under reduced pressure using a rotary evaporator to obtain a viscous extract, which was subsequently dried using a freeze dryer to yield a dry extract. The dried extract was evaluated for residual ethanol using a qualitative ethanol-free test. Briefly, a small amount of the dried extract was placed in a test tube, followed by the addition of acetic acid and concentrated sulfuric acid, and then gently heated. The absence of a characteristic ethyl acetate odor indicated that the extract was free from residual ethanol [19]. Therefore, the final dried extract was considered suitable for further formulation into cream preparations and in-vitro SPF evaluation.

2.2. Qualitative Phytochemical Screening

2.2.1. Flavanoid Identification

An aliquot of 1 ml of sample solution was placed in a test tube, followed by the addition of 0.5 g of magnesium turnings and 10 drops of concentrated HCl (Shinoda reagent). A positive reaction for flavonoids was indicated by the development of an orange, pink, or red coloration [21].

2.2.2. Polyphenol Test

An aliquot of 1 ml of sample solution was mixed with 10 drops of 1% FeCl₃ solution. A positive reaction for polyphenols was indicated by the appearance of a strong green, red, purple, blue, or black color [36], [37].

2.2.3. Alkaloid Test

An aliquot of 1 ml of sample solution was treated with 2–3 drops of Dragendorff's reagent. The formation of an orange-red precipitate indicated the presence of alkaloids [37].

2.3. Determination of Sun Protection Factor (SPF)

The extract (25 mg) was accurately weighed and dissolved in ethanol p.a. to a final volume of 50 mL to obtain a stock solution with a concentration of 500 ppm. From this stock solution, dilutions were prepared to obtain concentrations of 100, 200, 300, and 400 ppm. The absorbance of each solution was measured at 5 nm intervals, and the SPF value was then calculated according to the following equation 1 [38]:

$$SPF_{Spectrophotometric} = CF \times \sum_{290}^{320} EE \times I \times Abs \dots \dots \dots (1)$$

where: CF = correction factor (CF = 10); $EE(\lambda)$ = erythral effect spectrum at wavelength λ ; $I(\lambda)$ = solar intensity spectrum at wavelength λ ; $Abs(\lambda)$ = measured absorbance of the sample at wavelength λ .

2.4. Formulation of Robusta Coffee Fruit Peel Cream

Table 1. Formulations of Robusta Coffee Fruit Peel Cream

Ingredient	Formula (% w/v)				Function
	I	II	III	IV	
Coffee fruit peel extract	1	3	5	0	Active agent
Novemer®	0.5	0.5	0.5	0.5	Emulsifier
Glycerin	5	5	5	5	Emollient
Propylene glycol	3	3	3	3	Humectant
Cetyl alcohol	3	3	3	3	Stabilizer
DMDM hydantoin	0.1	0.1	0.1	0.1	Preservative
Phenoxyethanol	1	1	1	1	Preservative
Distilled water (q.s to 100%)	100	100	100	100	Vehicle

All ingredients were accurately weighed according to the composition in Table 1. The oil phase was prepared by melting the components in order of their decreasing melting points (cetyl alcohol, propylene glycol, and DMDM hydantoin). The aqueous phase, consisting of glycerin, phenoxyethanol, and distilled water, was heated separately to 70 °C. The cream base was formed by slowly adding the oil phase to the aqueous phase under continuous stirring with a homogenizer at 70°C. Novemer® was then incorporated into the emulsion and mixing was continued until a homogeneous base was obtained. The coffee fruit peel extract was gradually added to the cream base with continuous stirring until a uniform cream was formed. The resulting Robusta coffee fruit peel cream formulations were subsequently evaluated [39], [40].

2.5. Evaluation of Cream Formulations

2.5.1 Organoleptic Evaluation

Organoleptic characteristics were evaluated visually by observing the physical appearance of the cream, including color, form (consistency), and odor, both initially and during storage[41].

2.5.2 Homogeneity

A small amount of cream was placed between two glass slides and pressed gently. The preparation was examined visually for the presence of coarse particles or phase separation. A homogeneous cream showed no visible particles under these conditions [42].

2.5.3 Determination of Emulsion Type

Dilution Method

A portion of the cream was placed in a vial and diluted with water. If the cream was readily diluted with water without separation, the emulsion was classified as an oil-in-water (o/w) type [43].

Dye Dispersion Method

A few drops of methylene blue solution were added to the cream in a vial and mixed. If the blue color dispersed uniformly throughout the emulsion, the system was identified as an oil-in-water (o/w) emulsion [43].

2.5.4 pH Measurement

The pH of the cream was measured using a calibrated pH meter. One gram of cream was dispersed in 10 mL of distilled water in a beaker to form a uniform suspension. The electrode of the pH meter was immersed in the preparation, and the pH value was recorded once stable [44].

2.5.5 Spreadability Test

Spreadability was determined by placing 0.5 g of cream at the center of a glass plate. A second glass plate was placed on top, and weights of 50 g and then 100 g were applied sequentially. The

diameter of the spread cream was measured. A spreading diameter of 5–7 cm was considered indicative of a semi-solid consistency suitable for comfortable topical application.

2.5.6 Adhesion Test

For the adhesion test, 0.25 g of cream was placed on a glass slide and covered with a second slide. A 50 g weight was placed on top for 5 min. After removing the weight, the time required for the two slides to separate was recorded; longer separation times indicated greater adhesiveness [39].

2.5.7 Viscosity Measurement

Viscosity was measured using a rotational viscometer (Brookfield), which is commonly used for measuring the flow resistance of semi-solid materials such as creams. To ensure accuracy, spindle number 3 was selected, as recommended by the manufacturer for testing creams, and the rotational speed was set to 3 rpm. Before starting the measurement, a sufficient amount of the cream was carefully placed into the sample container of the viscometer. The sample was allowed to stabilize for a few minutes to ensure that no air bubbles were present and that the cream temperature was uniform. The instrument was then operated, and the viscosity value (in centipoise, cP) was recorded once the reading became stable [40].

2.5.8 Accelerate Stability Test

An accelerated stability test was conducted to evaluate the physical stability of the Robusta coffee fruit peel extract cream. The cream formulations were placed in tightly closed containers and stored in a climatic chamber (Mettler) at $40 \pm 2^\circ\text{C}$ and $75 \pm 2\%$ relative humidity (RH) for 6 weeks. The temperature and relative humidity were controlled using the climatic chamber system and monitored periodically during the storage period to ensure that the storage conditions remained within the specified range [41]. Physical stability evaluations were performed at predetermined intervals during the 6-week storage period. The observed parameters included organoleptic properties, homogeneity, pH, viscosity, spreadability, adhesion, and signs of physical instability such as phase separation, color change, odor change, or changes in consistency. Quantitative data obtained from the physical evaluations were expressed as mean $\pm$ standard deviation (SD). Statistical analysis was performed to determine whether storage time caused significant changes in the physical properties of the cream. The data were analyzed using one-way analysis of variance (ANOVA), followed by a post hoc test when significant differences were found. A value of $p < 0.05$ was considered statistically significant. The formulation was considered physically stable when no significant changes were observed during storage and the physical characteristics remained within acceptable limits.

2.6. Determination of Sun Protection Factor (SPF)

A total of 25 mg of each cream formulation (Formula I, II, III, IV) was accurately weighed and dissolved in 50 ml of ethanol p.a. to obtain a stock solution with a concentration of 500 ppm. From this stock solution, a series of dilutions were prepared to obtain concentrations of 100 ppm, 200 ppm, 300 ppm, and 400 ppm. The absorbance of each solution was measured in the UV range at 5 nm intervals between 290 and 320 nm. Each of the four cream formulations was tested individually for SPF determination. The SPF values were calculated using the spectrophotometric method according to the following equation [45], [46], [47]:

$$\text{SPF}_{\text{spectrophotometric}} = \text{CF} \times \sum_{290}^{320} \frac{\text{EE}(\lambda)}{\text{Abs}(\lambda)} \times I(\lambda)$$

where:

CF = correction factor (CF = 10)

EE(λ) = erythemal effect spectrum at wavelength λ

I(λ) = solar intensity spectrum at wavelength λ

Abs(λ) = measured absorbance of the sample at wavelength λ

3. RESULTS AND DISCUSSION

3.1. Extraction Yield and Preliminary Phytochemical Screening

3.1.1. Extraction Yield

Maceration of 1.000 g of dried Robusta coffee (*Coffea canephora* L.) fruit peel simplicia with 96% ethanol followed by concentration and freeze-drying produced 58.85 g of dry extract, corresponding to an extraction yield of 5.88%. This yield is in line with previous reports indicating that coffee by-products such as peels and pulp typically provide moderate extractive yields when ethanolic solvents are used, reflecting their substantial but not excessive content of ethanol-soluble secondary metabolites [19], [22], [23].

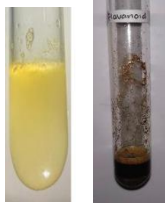
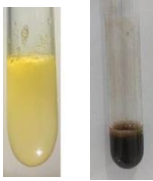
The use of 96% ethanol is particularly relevant for cosmetic and dermopharmaceutical applications because it efficiently extracts phenolic and flavonoid compounds while remaining acceptable for topical use and compatible with SPF spectrophotometric assays [7], [8]. The moderate yield obtained suggests a concentrated preparation of phenolic-rich material rather than a crude, highly diluted extract, which is desirable for further incorporation into sunscreen formulations [19], [21].

3.1.2. Preliminary Phytochemical Screening

Qualitative phytochemical screening of the Robusta coffee fruit peel extract confirmed the presence of flavonoids, polyphenols, and alkaloids (Table 2). A reddish-brown coloration in the Shinoda test indicated flavonoids, a greenish-black color with FeCl_3 confirmed polyphenols, and a brown precipitate with Dragendorff's reagent demonstrated the presence of alkaloids. These findings are consistent with the known phytochemical profile of *Coffea canephora* by-products, which are rich in phenolic acids, flavonoids, and alkaloidal compounds such as caffeine [19], [20], [21]. The strong antioxidant capacity of Robusta coffee peels reported in DPPH and related assays has been attributed to these polyphenolic constituents, often yielding IC_{50} values below 100 $\mu\text{g/mL}$, indicative of high radical-scavenging activity [19], [20]. Comparative data further show that coffee peels may exhibit higher antioxidant potential than several fruit peels due to their dense polyphenolic content [22], [23].

The presence of multiple classes of bioactive compounds also supports the likelihood of synergistic antioxidant effects, as described for complex plant matrices where interactions among phenolics and other constituents enhance overall radical scavenging and protective activities [24]. In the context of photoprotection, these phytochemicals are particularly relevant because polyphenols, flavonoids, and certain alkaloids can both absorb UV radiation and neutralize UV-induced reactive oxygen species [1], [2], [3]. Specifically, caffeine, an alkaloid, specifically has been reported to stabilize chemical UV filters and confer anti-inflammatory effects in sunscreen systems [25], suggesting that the alkaloidal fraction of *Coffea canephora* peel may contribute additional functional benefits within topical formulations.

Table 2. Preliminary Phytochemical Screening

No	Preliminary test	Color/precipitate	Result
1	Flavonoid test	Reddish-brown solution	 Positive (+)
2	Polyphenol test	Greenish-black color	 Positive (+)

...continue Table 2

3	Alkaloid test (wagner)	Brown precipitate	
			Positive (+)

3.2. In Vitro SPF of Robusta Coffee Fruit Peel Extract

The in vitro SPF values of the Robusta coffee fruit peel extract measured by the spectrophotometric method (Mansur-type equation) across 290–320 nm at various concentrations are presented in Table 3. At 100 ppm, the extract showed an SPF of 1.42 (no formal category assigned), which increased to 5.57 at 200 ppm, classified as moderate protection. A slight decrease was observed at 300 ppm (SPF 4.58, still moderate), followed by an increase to 5.98 at 400 ppm (moderate) and 7.53 at 500 ppm, categorized as extra protection.

Table 3. In Vitro SPF values of Robusta Coffee Peel Extract (n=3)

Sample	Concentration (ppm)	SPF $\bar{X} \pm SD$	Category
Robusta coffee fruit peel extract	100	1.42 $\pm$ 3.64	–
	200	5.56 $\pm$ 2.86	Moderate
	300	4.58 $\pm$ 6.45	Moderate
	400	5.98 $\pm$ 4.59	Moderate
	500	7.53 $\pm$ 5.34	Extra

The overall trend indicates that Robusta coffee peel extract possesses intrinsic photoprotective activity, with SPF values progressing into the moderate to extra protection range at higher concentrations. Such behavior is compatible with other plant extracts rich in polyphenols and flavonoids that have demonstrated appreciable SPF values and antioxidant activity when evaluated in vitro [7], [12], [48].

The non-linear relationship between concentration and SPF, particularly the dip observed at 300 ppm, may reflect experimental variability and limitations intrinsic to in vitro spectrophotometric methods, including potential aggregation, light scattering at higher concentrations, or uneven spectral contributions across the UVB range [9], [10]. Similar behavior has been noted when testing complex botanical extracts, in which optimal absorbance and linearity are not always strictly proportional to concentration [5], [8].

The methodology employed is aligned with widely adopted in vitro SPF protocols using UV spectrophotometry and the Mansur equation, which offer a safe and efficient means to screen photoprotective ingredients prior to in vivo testing [7], [8], [9]. However, as highlighted in previous work, in vitro SPF values should be interpreted as indicative rather than definitive, since they do not fully reflect interactions with the stratum corneum or realistic application conditions [10], [11]. More sophisticated approaches, including the use of reconstructed human epidermis (RhE) or artificial skin substrates, have been proposed to better approximate in vivo performance [4], [6], [49].

Nonetheless, the present data support the concept that Robusta coffee fruit peel extract constitutes a promising natural photoprotective agent. This aligns with extensive evidence that plant-derived polyphenols such as ferulic acid and other antioxidants can function as dual-action UV absorbers and radical scavengers, enhancing the efficacy and stability of sunscreen systems [1], [16], [36], [50].

3.3. Evaluation of Cream Formulations

Four cream formulations were prepared: three containing Robusta coffee fruit peel extract at 1%, 3%, and 5% (Formulas I–III), and a base cream without extract (Formula IV) (Table 1). All

formulations were evaluated for organoleptic characteristics, homogeneity, emulsion type, pH, spreadability, adhesion, viscosity, and accelerated stability.

3.3.1 Organoleptic

Organoleptic evaluation before and after accelerated storage (40°C, 75% RH, 6 weeks) showed that all formulations maintained a thick, cream-like consistency without visible phase separation (Table 4 and Figure 1). Formulas I–III displayed light brown, brown, and dark brown colors respectively, with characteristic coffee odor, both before and after storage, while the base cream remained white and odorless.

Table 4. Evaluation Organoleptic of Cream Formulations Before and After Stability Testing (n=3)

Parameter	Before				After			
	Formula				Formula			
	I	II	III	IV	I	II	III	IV
Organoleptic:								
- Colour	LB	BR	DB	WH	LB	BR	DB	WH
- Odor	CC	CC	CC	OD	RS	RS	RS	OD
- Texture	TH	TH	TH	TH	TH	TH	TH	TH
Homogeneity	HG	HG	HG	HG	HG	HG	HG	HG
pH	5.19 ^a ± 0.16	5.36 ^a ± 0.37	5.50 ^a ± 0.24	5.06 ^a ± 0.28	5.09 ^a ± 0.14	4.28 ^a ± 0.47	5.39 ^a ± 0.46	5.10 ^a ± 0.24
Spreadability (cm)	4.70 ^a ± 0.16	4.80 ^a ± 0.15	5.30 ^a ± 0.25	5.30 ^a ± 0.84	4.20 ^a ± 0.15	4.80 ^a ± 0.10	5.50 ^a ± 0.20	5.50 ^a ± 0.29
Adhesion (s)	20 ^a ± 0.21	18 ^a ± 0.06	18 ^a ± 0.28	19 ^a ± 0.24	18 ^a ± 0.15	17 ^a ± 0.05	17 ^a ± 0.30	20 ^a ± 0.28
Viscosity (cP)	73.000 ^a ± 0.21	40.000 ^b ± 0.25	30.000 ^b ± 0.35	61.000 ^a ± 0.35	50.000 ^b ± 0.15	42.000 ^b ± 0.40	35.000 ^b ± 0.68	35.000 ^b ± 0.68
Emulsion type	O/W	O/W	O/W	O/W	O/W	O/W	O/W	O/W

Notes : LB= Light Brown; BR = Brown; DB = Dark Brown; WH = White; CC= Characteristic coffee; TH= Thick; O/W = Oil in water emulsion

Different superscript letters indicate statistically significant differences among groups based on ANOVA followed by Tukey's HSD post-hoc test ($p < 0.05$). Values with the same superscript letter are not significantly different.

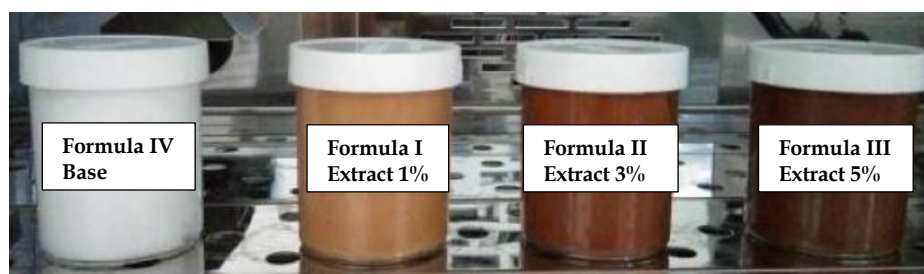


Figure 1. Formulation Cream

The progressive darkening with increasing extract concentration is consistent with the intrinsic color of polyphenol-containing coffee peel extract and is typical for botanical creams [19], [20]. The preservation of color, odor, and texture under stress conditions indicates good physical stability and absence of significant oxidation or degradation of the incorporated extract within the tested period [27], [51]. This is relevant given that some plant-derived actives are susceptible to color change or odor development upon storage, particularly under elevated temperature and humidity.

3.3.2. Homogeneity

Visual examination under glass slides confirmed that all formulations were homogeneous, with no coarse particles or visible phase separation before and after accelerated storage (Table 4). The observed level of homogeneity is crucial for ensuring the uniform distribution of the active ingredient across the formulation, which is necessary for reliable and consistent SPF performance [26], [35]. The results suggest that the emulsification procedure and inclusion of Novemer® and cetyl alcohol as emulsifier and stabilizer produced stable, uniform systems that remained structurally intact during thermal stress, similar to other well-structured herbal creams reported in the literature [28], [29], [30].

3.3.3 Emulsion Type

All formulations were classified as oil-in-water (o/w) emulsions based on both dilution and dye dispersion tests, and this classification remained unchanged after accelerated storage (Table 4). An o/w system is appropriate for sunscreen creams intended for daily use, as it generally affords better skin feel, easier spreadability, and lower greasiness compared with water-in-oil systems, thereby improving patient compliance [35], [52]. Maintenance of the emulsion type under stress supports the structural robustness of the formulations and indicates low risk of phase inversion during storage [26], [27].

3.3.4. pH

The pH values of the cream formulations ranged from 5.06 to 5.50 before accelerated storage and from 4.28 to 5.39 afterward (Table 4). All formulations remained within the physiologically acceptable pH range for topical products (approximately pH 4.5–6.5). After accelerated stability testing, the slight decrease in pH observed was minimal and remained within acceptable limits, indicating that the incorporation of the coffee peel extract did not compromise pH stability. Statistical analysis using one-way ANOVA followed by Tukey's HSD post-hoc test showed no statistically significant differences in pH values between the formulations, either before or after stability testing ($p > 0.05$). This suggests that the different concentrations of Robusta coffee fruit peel extract did not significantly affect the pH of the formulations, and the formulations remained stable with respect to pH under accelerated storage conditions.

Maintaining a skin-compatible pH is crucial to avoid irritation and to support the skin's barrier function, particularly for products intended for repeated or prolonged use, such as sunscreens [27], [35]. The formulations in this study thus demonstrated good pH stability, confirming their suitability for topical application.

3.3.5. Spreadability

The spreadability of the cream formulations before and after accelerated storage testing is summarized in Table 4. Before storage, the spreadability under a 100 g load ranged from 4.70 cm (Formula I) to 5.30 cm (Formulas III and IV). After accelerated storage, the spreadability values remained mostly within the desirable 5–7 cm range, with Formulas II, III, and IV showing values of 4.80 cm to 5.50 cm, while Formula I had a slightly lower spreadability at 4.20 cm. Statistical analysis using one-way ANOVA followed by Tukey's HSD post-hoc test indicated no significant differences in spreadability between the formulations, either before or after stability testing ($p > 0.05$). This suggests that the spreadability of the cream formulations was not significantly impacted by the accelerated stability testing.

This finding indicates that all formulations, particularly those with coffee peel extract concentrations between 1–5%, retained their semi-solid consistency, making them suitable for easy application and uniform distribution on the skin. The slight variation in spreadability values could be attributed to minor changes in the internal structure and viscosity profile of the emulsions, possibly due to the presence of hydrophilic phytochemicals in the coffee peel extract. These changes did not result in significant differences, confirming that stability testing did not adversely affect the spreadability of the creams. Overall, the formulations demonstrated good spreadability, in line with the recommended spreadability thresholds for cosmetic and pharmaceutical creams [29], [33].

3.3.6. Adhesion

The adhesion values of the cream formulations ranged from 18 to 20 s before accelerated stability testing and from 17 to 20 s after stability testing (Table 4). Before storage, the adhesion time slightly varied among the formulations, with Formula I showing the highest adhesion value,

followed by Formulas IV, II, and III. After accelerated stability testing, a slight decrease in adhesion was observed in Formulas I, II, and III, whereas Formula IV showed a slight increase. However, these changes were minor and did not indicate a substantial alteration in the adhesive properties of the cream. Statistical analysis showed that there were no significant differences in adhesion values among the formulations before and after stability testing, as indicated by the same superscript letter in all groups ($p > 0.05$). This suggests that differences in Robusta coffee fruit peel extract concentration did not significantly affect the adhesion of the cream formulations. In addition, accelerated stability testing did not significantly alter the adhesion properties of the creams.

The slight variation in adhesion values may be related to minor changes in the internal structure, viscosity, and water content of the emulsion during storage. However, these variations remained statistically insignificant and within an acceptable range for topical cream preparations. These findings indicate that cream formulations containing 1–5% Robusta coffee fruit peel extract were able to maintain adequate adhesion after accelerated stability testing. Adequate adhesion is important for topical preparations because it supports sufficient contact time between the cream and the skin surface, allowing the active compounds to remain on the application site during use and potentially contributing to photoprotective efficacy [53], [54].

3.3.7. Viscosity

Viscosity measurements revealed that the cream formulations exhibited viscosities ranging from 30,000 to 73,000 cP before accelerated storage and from 35,000 to 50,000 cP after storage (Table 4). Formula I showed the highest initial viscosity (73,000 cP), while Formula III had the lowest (30,000 cP). After accelerated storage, the viscosities of the formulations tended to converge, with Formula I showing a reduction in viscosity to 50,000 cP, and Formulas II, III, and IV exhibiting similar viscosity values of 42,000 cP, 35,000 cP, and 35,000 cP, respectively. Statistical analysis using one-way ANOVA followed by Tukey's HSD post-hoc test showed statistically significant differences in viscosity among the formulations both before and after stability testing ($p < 0.05$). Formulas I and IV showed significantly higher viscosities before storage, while Formulas II and III had lower viscosities, reflecting the impact of extract concentration and formulation composition on viscosity. After stability testing, all formulations showed a decrease in viscosity, but the differences were not significant, indicating that the formulations maintained their semi-solid consistency during accelerated stability testing.

These viscosity values are characteristic of semi-solid creams, which are ideal for topical application due to their consistency and ability to form a uniform layer on the skin. The observed decrease in viscosity after accelerated testing is expected and likely arises from minor structural rearrangements in the emulsion system. Such changes are typically seen in systems containing plant extracts and polymeric emulsifiers, where interactions and slight modifications in the internal structure may occur without necessarily compromising the formulation's stability [27], [33]. Moderate changes in viscosity during accelerated testing are not uncommon in cosmetic formulations and do not indicate instability. The formulations maintained acceptable viscosities, which are essential for ease of application and retention on the skin, contributing to the overall performance of the cream, including its potential for effective film formation and skin adhesion.

3.4. SPF Results of Cream Containing Robusta Coffee Fruit Peel Extract

The in vitro SPF values of the cream formulations are summarized in Table 5.

Table 5. SPF Values of Cream Preparations (n=3)

Formula	Extract Concentration (%)	Mean SPF value $\pm$ SD	Sunscreen category
I.	1	6.40 $\pm$ 2.48	Extra protection
II.	3	12.85 $\pm$ 4.83	Maximum protection
III.	5	16.32 $\pm$ 6.23	Ultra protection
IV	Base	5.70 $\pm$ 2.48	Moderate protection

Note : I: 1% extract; II : 3% extract; III : 5% 1% extract; IV : base cream without extract

The base cream (Formula IV) showed an SPF of 5.70, categorized as moderate protection. Incorporation of 1% extract (Formula I) slightly increased the SPF to 6.40, classified as extra protection. A more pronounced enhancement was observed at 3% extract (Formula II), which reached an SPF of 12.85 (maximum protection), and at 5% extract (Formula III), which achieved an SPF of 16.32, corresponding to ultra protection.

These results clearly demonstrate a concentration-dependent increase in photoprotective efficacy, especially between 1% and 5% extract, indicating that the Robusta coffee fruit peel extract effectively contributes to the overall SPF of the cream. The ability of the base cream to provide moderate SPF likely arises from its excipients, some of which may impart limited photoprotective or scattering effects; however, the substantial increment at 3% and 5% extract underscores the functional role of the plant-derived actives [35], [52].

The observed enhancement is in agreement with reports that plant extracts rich in polyphenols and flavonoids can augment the SPF of conventional formulations or even act as primary photoprotective agents [1], [17], [48], [55]. For example, *Calendula officinalis* and *Passiflora cincinnata* extracts have been shown to significantly increase the photoprotective capacity of creams and lotions when incorporated at appropriate concentrations, often through combined UV absorption and antioxidant mechanisms [48], [55]. Similar synergistic behavior has been described for green tea, grape seed, and xanthone-containing extracts, which not only contribute to SPF but also improve the photostability of synthetic UV filters [2], [3], [13], [16], [36].

The presence of polyphenols, flavonoids, and caffeine in *Coffea canephora* peel [19], [20], [21] likely underpins the SPF enhancement observed in the present creams. Polyphenols can act both as direct UV filters and as potent radical scavengers, thereby reducing UV-induced oxidative damage and photoaging [1], [2], [3]. Caffeine may further stabilize chemical filters and contribute anti-inflammatory effects, which are beneficial under UV stress [25].

From a formulation standpoint, the ability of the coffee peel cream to achieve SPF levels up to ultra protection without apparent compromise of stability, spreadability, or pH is notable. It aligns with the current trend toward multifunctional sunscreens that combine classical UV filters (where present) with antioxidant and anti-photoaging agents to enhance efficacy and safety [10], [18], [56]. The integration of a value-added agricultural by-product such as coffee peel also supports sustainability and circular economy concepts in cosmetic development [19], [20].

Although the SPF values reported here are derived from in vitro spectrophotometric methods, which may not fully replicate in vivo performance [10], [11], the clear concentration-dependent improvement suggests that Robusta coffee fruit peel extract is a promising candidate as a natural photoprotective ingredient. Future work employing reconstructed human skin models and, ultimately, controlled in vivo studies would be valuable to confirm broad-spectrum protection (UVA and UVB) and to evaluate long-term benefits on photoaging and oxidative skin damage, in line with recommendations for modern sunscreen development [6], [12], [49], [57].

4. CONCLUSION

This study demonstrated that the ethanolic extract of *Coffea canephora* fruit peel contains flavonoids, polyphenols, and alkaloids, confirming its potential as an active ingredient for topical use in sun protection formulations. The extract exhibited measurable in vitro SPF values, increasing from low to moderate–extra protection with rising concentrations, indicating its intrinsic photoprotective activity. When incorporated into oil-in-water cream formulations at concentrations of 1–5%, the extract significantly enhanced SPF from a moderately protective base cream to maximum and ultra-protection levels at 3% and 5%, respectively, while maintaining acceptable pH, spreadability, adhesion, viscosity, and physical stability under accelerated conditions. These findings suggest that Robusta coffee peel, an agro-industrial by-product, can be valorized as a natural sun protection ingredient in multifunctional sunscreen creams, offering both UV-absorbing benefits and contributing to sustainable formulation practices. This work adds to the growing body of evidence supporting plant-derived materials, including polyphenols and caffeine-containing extracts, as promising alternatives or co-actives to conventional UV filters. Future studies should include in vivo and advanced in vitro evaluations (e.g., reconstructed skin), assessment of UVA protection,

photostability, compatibility with standard filters, and long-term stability and safety profiling to fully establish clinical relevance and product applicability.

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