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Development of the optimal formulation for a sunscreen spray emulsion containing *Centella asiatica* L. and *Avena sativa* L. kernel flour as soothing ingredients

Optymalizacja składu emulsji przeciwsłonecznej w postaci sprayu z dodatkiem wąkrotki azjatyckiej oraz mączki z ziaren owsa jako składników łagodzących

ABSTRACT

Introduction: Sunscreens are essential for protecting the skin from harmful ultraviolet radiation. Spray emulsions have become popular for their lightweight consistency and ability to provide even coverage.

Aim: The study aimed to optimize the composition of a sprayable sunscreen emulsion containing *Centella asiatica* L. (gotu kola) and oat kernel flour, both known for their skin-soothing and moisturizing properties.

Materials and Methods: The formulations were evaluated for physical properties and stability, and the moisturizing effect of the developed product was assessed in a group of 18 volunteers over a 4-week period. A simplex lattice design was employed to optimize the concentrations of xanthan gum and polyethylene glycol 400 (PEG 400).

Results: Optimization of the composition resulted in a sprayable sunscreen emulsion that remained stable throughout the study period. The formulation containing *Centella asiatica* L. and oat kernel flour (*Avena sativa* L.) showed a statistically significant increase in skin hydration.

Conclusions: The developed formulation is a promising sunscreen product supporting skin protection and hydration. Further research should assess ultraviolet protection efficacy through *in vitro* and *in vivo* testing to more comprehensively establish the preparation's clinical effectiveness.

Keywords: sunscreen spray, filters, soothing agent, *Centella asiatica*, oat kernels.

STRESZCZENIE

Wprowadzenie: Filtry przeciwsłoneczne mają zasadnicze znaczenie dla ochrony skóry przed szkodliwym promieniowaniem ultrafioletowym. Emulsje w sprayu zyskały popularność dzięki lekkiej konsystencji i zdolności do zapewniania równomiernego pokrycia.

Cel: Celem badania była optymalizacja składu emulsji przeciwsłonecznej w sprayu zawierającej wąkrotkę azjatycką oraz mączkę z ziaren owsa, znanych ze swoich właściwości łagodzących i nawilżających skórę.

Materiały i metody: Preparaty oceniono pod kątem właściwości fizycznych i stabilności, a działanie nawilżające zoptymalizowanego preparatu zbadano w grupie 18 ochotników w okresie 4 tygodni. W celu optymalizacji stężeń gumy ksantanowej i glikolu polietylenowego 400 (PEG 400) zastosowano plan siatki simpleksowej.

Wyniki: Optymalizacja składu umożliwiła uzyskanie emulsji przeciwsłonecznej w postaci sprayu, która zachowała stabilność w badanym okresie. Stosowanie preparatu zawierającego wąkrotkę azjatycką (*Centella asiatica* L.) oraz mączkę z ziaren owsa zwyczajnego (*Avena sativa* L.) wiązało się z istotnym statystycznie wzrostem nawilżenia skóry.

Wnioski: Opracowana formulacja stanowi obiecujący preparat przeciwsłoneczny wspomagający ochronę i nawilżenie skóry. Dalsze badania powinny obejmować ocenę skuteczności ochrony poprzez oznaczenie współczynnika ochrony przeciwsłonecznej w badaniach *in vitro* i *in vivo* w celu pełniejszego określenia skuteczności klinicznej preparatu.

Słowa kluczowe: spray przeciwsłoneczny, filtry, środek łagodzący, wąkrotka azjatycka, ziarna owsa.

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INTRODUCTION

UV radiation is a major environmental factor contributing to skin damage [1]. Ultraviolet A (UVA) exposure is primarily associated with photoaging and hyperpigmentation, whereas ultraviolet B (UVB) radiation causes DNA damage and plays a key role in skin cancer development [2]. Although limited sun exposure supports vitamin D synthesis, excessive and repeated UV exposure can cause adverse skin effects, highlighting the importance of photoprotective strategies such as sunscreen use [3]. Sunscreens are available in various forms, including gels, lotions, and sprays. Among these, sunscreen sprays have gained increasing attention because of their ease of application, lightweight feel, non-greasy texture, rapid drying, and ability to provide even coverage, particularly on hard-to-reach areas of the skin [4].

Sunscreen formulations often contain additional active ingredients, such as skin-soothing agents, to calm the skin and reduce signs of irritation, such as redness and blemishes, caused by environmental stressors like pollution and UV radiation [5]. *Centella asiatica* L. contains bioactive compounds, such as triterpenes, phenolic compounds, alkaloids, vitamins, and amino acids. These compounds promote fibroblast proliferation, enhance collagen synthesis, increase the tensile strength of newly formed skin, and suppress inflammatory responses, thereby contributing to skin repair while exerting soothing effects [6]. The soothing effect is closely associated with stratum corneum (SC) hydration. UVB radiation disrupts the epidermal permeability barrier and reduces SC hydration. After exposure to 0.75 minimal erythema dose (MED) of UVB radiation, basal trans epidermal water loss (TEWL) in human skin increases significantly [5]. In addition, *Avena sativa* (oat) kernel flour is widely used as a skin-soothing ingredient in topical formulations because of its high content of saponins, β-glucans, phenolic acids, and flavonoids. These bioactive components have been reported to improve SC hydration, reinforce the skin barrier, and reduce inflammation and irritation, particularly in compromised or sensitive skin [6-8]. Therefore, the combination of *Centella asiatica* L. and *Avena sativa* (oat) kernel flour offers complementary skin-soothing and moisturizing properties, making it a promising approach for sunscreen formulations.

AIM

This study aimed to optimize a sunscreen spray emulsion containing *Centella asiatica* L. and *Avena sativa* (oat) kernel flour with skin-soothing and hydrating properties.

MATERIALS AND METHODS

Materials

Centella asiatica L. was obtained from the Traditional Health Services Unit of Dr. Sardjito Hospital, Tawangmangu, Indonesia, as a dried crude herbal material. *Avena sativa* (oat) kernel flour was purchased from PT Tentrem Artha Nugraha, Indonesia, as a commercially available powder. Butylene glycol, xanthan gum, octocrylene, and butyl methoxydibenzoylmethane were kindly donated by Paragon Technology and Innovation. Dexa Medica kindly donated polyethylene glycol 400 (PEG 400) and potassium sorbate, and Liaoning Oxiranpharm Inc. manufactured PEG 400. Distilled water was used as the solvent. Methylene blue and 96% ethanol were obtained from Sigma-Aldrich (St. Louis, MO, USA). All formulation ingredients and analytical reagents were of pharmaceutical grade. This study used standard laboratory glassware, a rotary evaporator, an analytical balance, and a Corneometer® CM 825 (Courage + Khazaka Electronic GmbH, Cologne, Germany).

Methods

- Extraction of *Centella asiatica* L.

The extraction method was performed by conventional maceration using 96% ethanol as the solvent. Dried raw plant materials (simplicia) were cut into small pieces using a blender and macerated in 96% ethanol for 3x24 h at room temperature under static conditions, with occasional manual stirring. This study used no ultrasound-assisted extraction or other techniques. After maceration, the filtrate was concentrated using a rotary evaporator at 65°C at 60 rpm, then dried in an oven at 40°C for 24 h to obtain a thick extract. Subsequently, the water-soluble and ethanol-soluble contents of the simplicia extract were determined.

- Preparation of the sunscreen emulsion

Xanthan gum was dispersed in water heated to 70°C and stirred until a homogeneous mass was formed. The water (PEG 400 and potassium sorbate) and oil (butylene glycol, octocrylene, and butyl methoxydibenzoylmethane) phases were prepared and heated to 70°C. The water and oil phases were then mixed to form an emulsion. The mixing was continued without heat. After the temperature of the emulsion reached below 40°C, *Avena sativa* (oat) kernel flour in water and diluted ethanol extract of *Centella asiatica* L. were added. Design-Expert® software version 13.0 was used to describe formulation optimization and desirability analysis. Tab. 1 presents the formulation design of the sunscreen emulsion developed in this study. The formulation presented in tab. 1 is the subject of an active patent application (Application No. S00202414180). Therefore, certain proprietary formulation details beyond those presented in tab. 1 are not fully disclosed in this manuscript.

Tab. 1. Formulation design of the sunscreen spray emulsion. **Source:** [9, 10].

Materials	Function	Concentration
Extract of Centella asiatica L.	Soothing agent	5%
Avena sativa (oat) kernel flour	Soothing agent	3%
Butylene glycol	Humectant	10%
Xanthan gum	Emulsifier	1% - 0.1%
PEG 400	Co-emulsifier	8% - 8.9%
Octocrylene	UV Protection (UVA and UVB)	10%
Butyl methoxydibenzoylmethane	UV Protection	5%
Potassium sorbate	Preservative	0,1%
Rose fragrance	Fragrance	0.01%
Aquadest	Solvent	Ad 100%

- Evaluation of sunscreen emulsion spray

Organoleptic evaluation
Organoleptic evaluation was performed by placing a drop of the sunscreen formulation onto a glass slide. The appearance, color, and consistency of the formulation were visually assessed to evaluate its physical characteristics.

Homogeneity test
Homogeneity testing was performed by spraying the sunscreen formulation onto a glass surface from a distance of 10-15 cm. The sprayed sample was then visually examined for unmixed particles or clumps to assess formulation uniformity.

pH measurement
The pH of the sunscreen spray formulation was measured at room temperature using a calibrated digital pH meter (SevenCompact, Mettler Toledo) to ensure it was suitable for topical application.

Spray pattern test
Spray pattern testing was conducted to evaluate the spray applicator performance. The sunscreen spray was applied to a mica plastic sheet at distances of 3, 5, 10, 15, and 20 cm. The diameter of the resulting spray pattern was measured.

Viscosity measurement
The viscosity of the samples was determined using a HAAKE Viscotester D (Thermo Scientific, Spain) equipped with an R2 spindle at 30 rpm. Measurements were performed at room temperature to evaluate the formulation's flow properties.

Determination of the emulsion type
The emulsion type of sunscreen spray was determined using methylene blue staining. A drop of the formulation was placed on a glass slide, stained with methylene blue, and observed under an Olympus CX31 optical microscope to identify the continuous phase. Observations were performed under bright-field illumination using a 10× eyepiece with 10× and 25× objective lenses, corresponding to total magnifications of 100× and 250×, respectively.

Observation of the globule size
Globule size was evaluated by placing a drop of the sunscreen spray onto a glass slide and observing it under an Olympus CX31 optical microscope. Observations were performed under bright-field illumination using a 10× eyepiece with 10× and 25× objective lenses, corresponding to total magnifications of 100× and 250×, respectively.

Evaporation time test
The evaporation time was determined by spraying the sunscreen formulation once onto a mica plastic sheet and allowing it to dry at room temperature. The time required for the formulation to completely dry was recorded.

- Skin hydration level test

The skin hydration level was evaluated to assess the moisturizing effect of the sunscreen spray formulation containing *Centella asiatica* L. ethanol extract and *Avena sativa* (oat) kernel flour. This study included 18 healthy volunteers over 4 weeks. Inclusion criteria were age 10-24 years, no history of dermatitis or allergic reactions on the forearm, and no use of topical or systemic medications affecting skin condition during the study period. Exclusion criteria included known hypersensitivity to any formulation component, pregnancy or breastfeeding, vaccination within 2 weeks before the study, and use of additional skincare products on the test area.

Measurements were performed on the volar forearm, selected for its relatively uniform skin characteristics and its use in dermatological testing. The test area for each formulation was standardized to 3×4 cm. Subjects applied 0.1 mL of the assigned formulation using a syringe twice a day (morning and evening). The left forearm received the placebo sunscreen, sunscreen containing *Centella asiatica* L. and *Avena sativa* (oat) kernel flour, and an untreated control area, while the right forearm received the sunscreen containing *Centella asiatica* L. and *Avena sativa* (oat) kernel flour and an untreated control area.

Skin hydration was measured at three time points: baseline before application (T0), 14 days after application (T14), and 28 days after continuous application (T28). Hydration levels were determined using a Corneometer® CM825 (Courage

+ Khazaka, Germany), a non-invasive device that measures hydration of the SC based on changes in skin capacitance. All measurements were performed in Skinproof (PT Derma Laboratory Asia) Indonesia, with controlled room temperature (22-25°C) and relative humidity maintained at approximately 40-60%. Before the measurement, the participants were acclimatized to the measurement room for at least 15 min and instructed to refrain from washing the test area, applying cosmetic products, or engaging in vigorous physical activity for at least 12 h before assessment.

Skin hydration data were analyzed using repeated-measures analysis of variance (ANOVA), with time (T0, T14, and T28) as the within-subject factor. Prior to analysis, data normality was assessed using Q-Q plots, and no significant deviations from normality were observed. Assumptions for the repeated-measures analysis of variance were evaluated visually using Q-Q plots. Statistical significance was set at $p < 0.05$. RStudio was used to perform statistical analyses and generate data visualizations.

RESULTS

Extraction of *Centella asiatica* L.

Tab. 2 presents the extractive values and extraction yield of *Centella asiatica* L. extract. The water-soluble extractive content was 9.33 ± 0.42%, meeting the Indonesian Herbal Pharmacopoeia requirement of not more than 10%, while the ethanol-soluble extractive content was 9.60 ± 0.20%, exceeding the minimum requirement of 7.2% [11]. The extraction process yielded 60.14% ethanol extract.

Tab. 2. Extractive values and extraction yield of *Centella asiatica* L. extract. **Source:** Own elaboration.

Parameter	Result
Water-soluble extractive content (%)	9.33±0.42
Ethanol-soluble extractive content (%)	9.60±0.20
Extraction yield (%)	60.14

- Preparation and evaluation of the sunscreen emulsion spray

Tab. 3 presents the evaluation results of all sunscreen emulsion spray formulations. To determine their physicochemical characteristics and compliance with the specified quality requirements, the formulations (F1-F5) were assessed for organoleptic properties, homogeneity, pH, viscosity, spray pattern, emulsion type, globule size, and evaporation time.

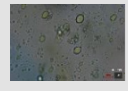
Spray pattern test

The spray patterns of the five formulations are presented in fig. 1, and the corresponding spray diameters are summarized in tab. 3. The spray pattern response generated from the simplex lattice design (SLD) is described by equation (1):

$$y = 9.44A + 12.04B + 2.86AB \quad (1)$$

where y = spray pattern (cm); A = concentration of xanthan gum; B = concentration of PEG 400; and AB = the interaction between xanthan gum and PEG 400.

Tab. 3. Physicochemical evaluation of the sunscreen emulsion spray. **Source:** Own elaboration.

Parameter	Specification	F1	F2	F3	F4	F5
Organoleptic	Green brownish, liquid, and rose fragrance	Conform 	Conform 	Conform 	Conform 	Conform 
Homogeneity	No coarse particles	Conform	Conform	Conform	Conform	Conform
pH	4.5-7.0	5.41	5.41	5.48	5.47	5.47
Viscosity	40-400 cP	118.6 ± 0.25	81.55 ± 0.99	72.07 ± 3.12	92.30 ± 2.72	63.52 ±1.60
Spray pattern	Spread evenly	Spray evenly with diameter 9.5 ± 0.3 cm	Spray evenly with diameter 12 ± 0.12 cm	Spray evenly with diameter 11.5 ± 0.36 cm	Spray evenly with diameter 11.5 ± 0.66 cm	Spray evenly with diameter 12 ± 0.12 cm
Emulsion type	O/W	O/W 	O/W 	O/W 	O/W 	O/W 
Globule size	0.1-100 µm	25.25 ± 5.32 µm	49.38 ± 0.81 µm	47.24 ± 0.64 µm	42.24 ± 0.34 µm	45.74 ± 1.48 µm
Evaporation time	Not more than 5 minutes	2.59 ± 0.08 minutes	2.60 ± 0.33 minutes	2.85 ± 0.02 minutes	2.80 ± 0.02 minutes	2.84 ± 0.03 minutes

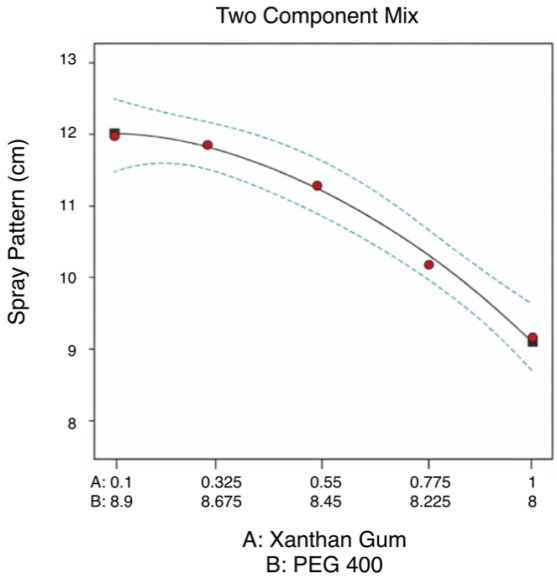


Fig. 1. Graphical plot of the spray pattern to concentrate xanthan gum and PEG 400. **Source:** Own elaboration.

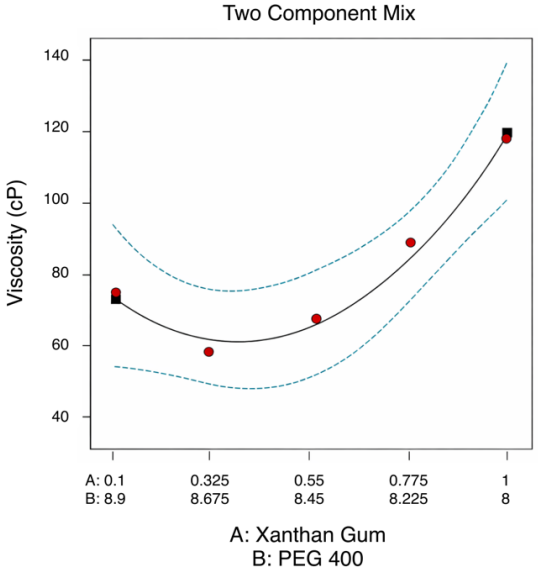


Fig. 2. Graphical plot of viscosity versus concentrations of xanthan gum and PEG 400. **Source:** Own elaboration.

Viscosity measurement

The viscosity response generated from the SLD is described by equation (2):

$$y = 120.52A + 79.37B - 114.69AB \quad (2)$$

where y = viscosity (cP); A = xanthan gum concentration; B = PEG 400 concentration; and AB = the interaction between xanthan gum and PEG 400. Fig. 2 shows the graphical relationship between xanthan gum concentration, PEG 400 concentration, and viscosity.

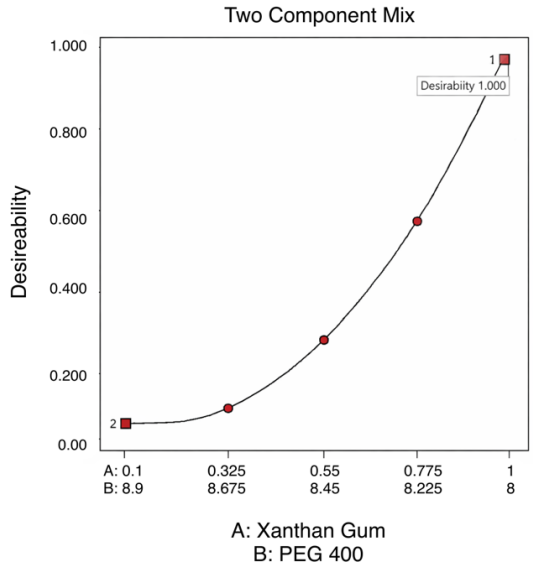


Fig. 3. Desirability values of formulas 1-5. **Source:** Own elaboration.

Tab. 4 presents the analysis of variance (ANOVA) results for the SLD models. The viscosity model showed a statistically significant effect of xanthan gum and PEG 400 concentrations ($p = 0.0238$). Similarly, the spray pattern model was statistically significant ($p = 0.0061$). Both models showed good fit, with R^2 values of 0.9762 and 0.9939 for viscosity and spray pattern, respectively.

Tab. 4. SLD of variables of viscosity and spray pattern. **Source:** Own elaboration.

Response Variable	Sum of squares	Degrees of Freedom (df)	Mean square	p-value	R^2
Viscosity	1777.52	2	888.76	0.0238	0.9762
Spray pattern	4.67	2	2.34	0.0061	0.9939

The optimization results obtained using Design-Expert® 13.0 software are presented in fig. 3. F1, containing 1% xanthan gum, showed the highest desirability value (1.000) among the five formulations and was selected as the optimal formulation. The remaining formulations exhibited lower desirability values.

- Stability of the sunscreen spray formulation

The results of the stability evaluation of the sunscreen spray formulations during storage at room temperature are presented in fig. 4. Throughout the 28-day storage period, all formulations complied with the specified evaluation criteria. No substantial changes in pH, spray pattern, viscosity, globule size, or evaporation time were observed.

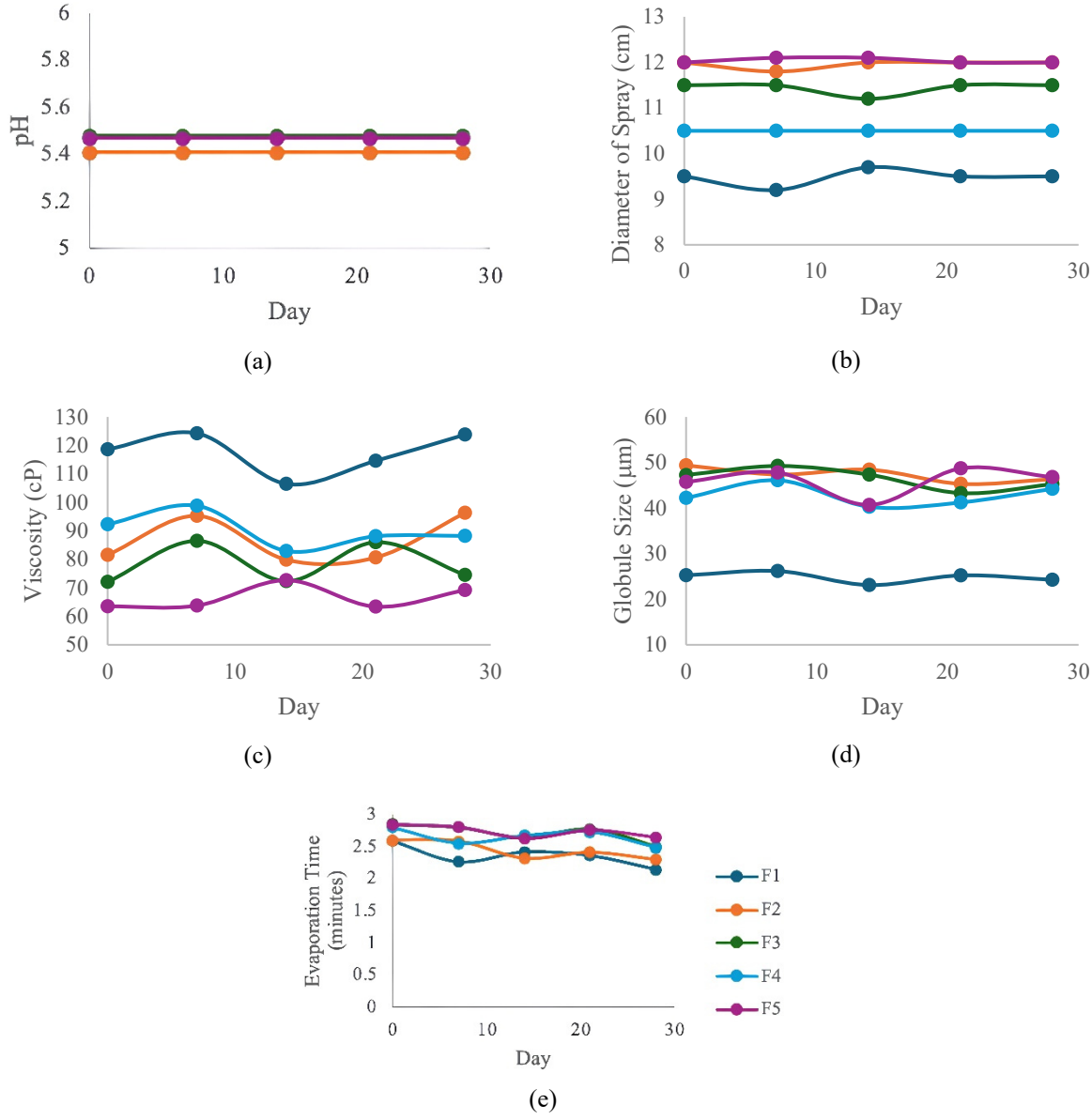


Fig. 4. Results of the stability evaluation of sunscreen spray formulations (F1-F5) during 28-day storage at room temperature: (a) pH, (b) spray pattern, (c) viscosity, (d) globule size, and (e) evaporation time. **Source:** Own elaboration.

The results of the stability evaluation following three freeze-thaw cycles are presented in fig. 5. All formulations remained stable after the test and continued to comply with the evaluation criteria specified. No marked changes in pH, spray pattern, viscosity, globule size, or evaporation time were observed following the freeze-thaw cycles.

Fig. 6 shows the physical appearance of the sunscreen spray formulations after centrifugation at 3000 rpm for 30 min. All formulations remained homogeneous, retained their greenish-brown color and liquid consistency, and showed no evidence of phase separation following centrifugation.

- Skin hydration level test results

Fig. 7 shows the distribution of skin hydration values measured at baseline (T0), after 14 days of application (T14), and after 28 days of application (T28).

The normality of the skin hydration data at T0, T14, and T28 was assessed using normal Q-Q plots (Fig. 8). The data showed an approximately normal distribution, with no outliers among the 18 participants.

The skin hydration values measured at T0, T14, and T28 were compared using one-way analysis of variance. A statistically

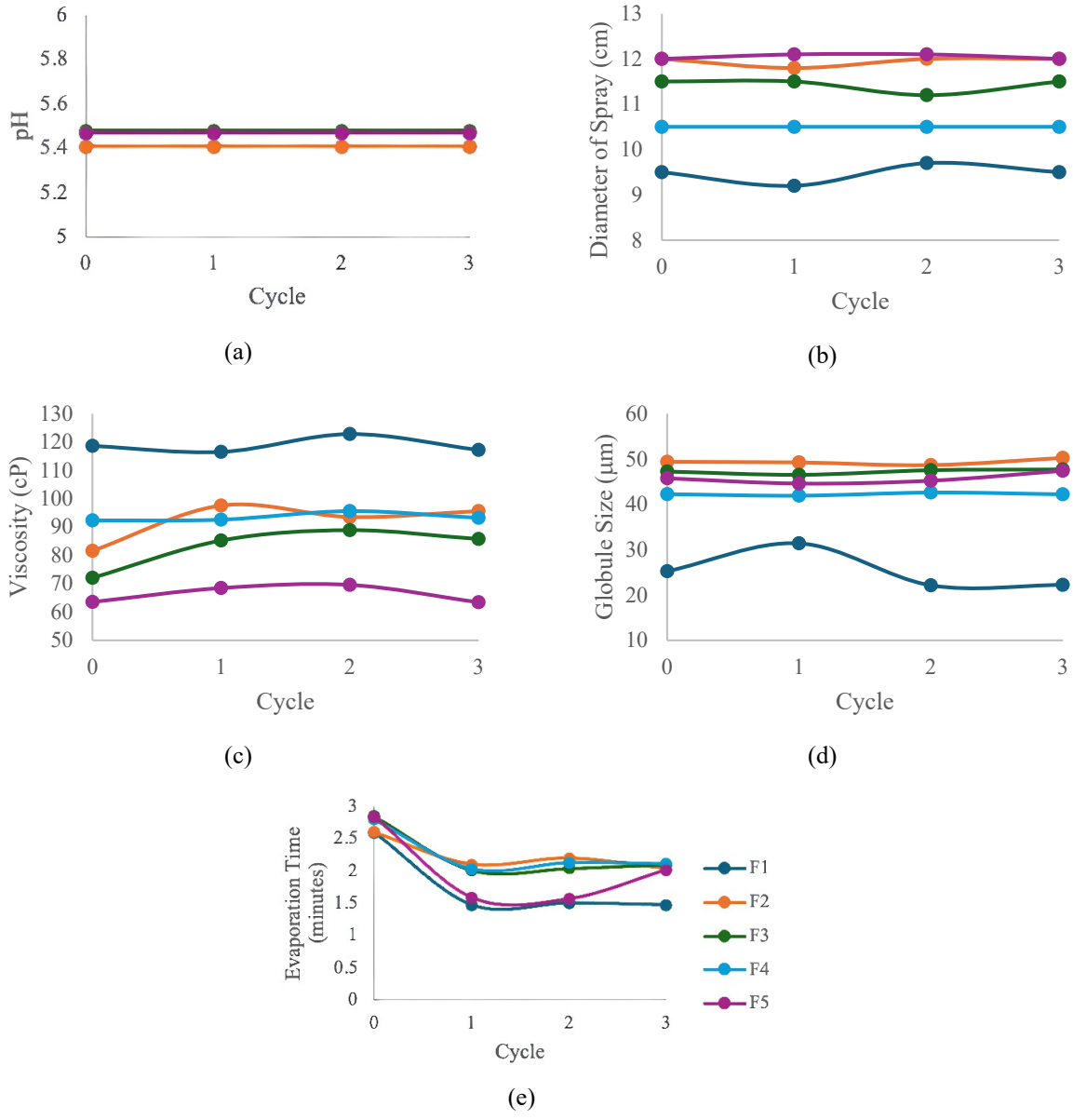


Fig. 5. Stability evaluation results of sunscreen spray formulations (F1-F5) after three freeze–thaw cycles: (a) pH, (b) spray pattern, (c) viscosity stability, (d) globule size, and (e) evaporation time. **Source:** Own elaboration.

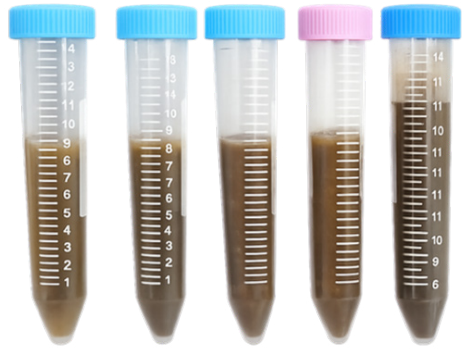


Fig. 6. Physical appearance of sunscreen spray formulations (F1-F5) after centrifugation. **Source:** The authors' own experimental data.

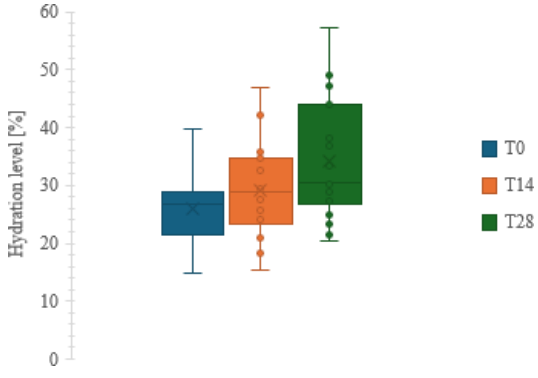


Fig. 7. Distribution of skin hydration values at baseline (T0), 14 days after application (T14), and 28 days after application (T28). **Source:** The authors' own experimental data.

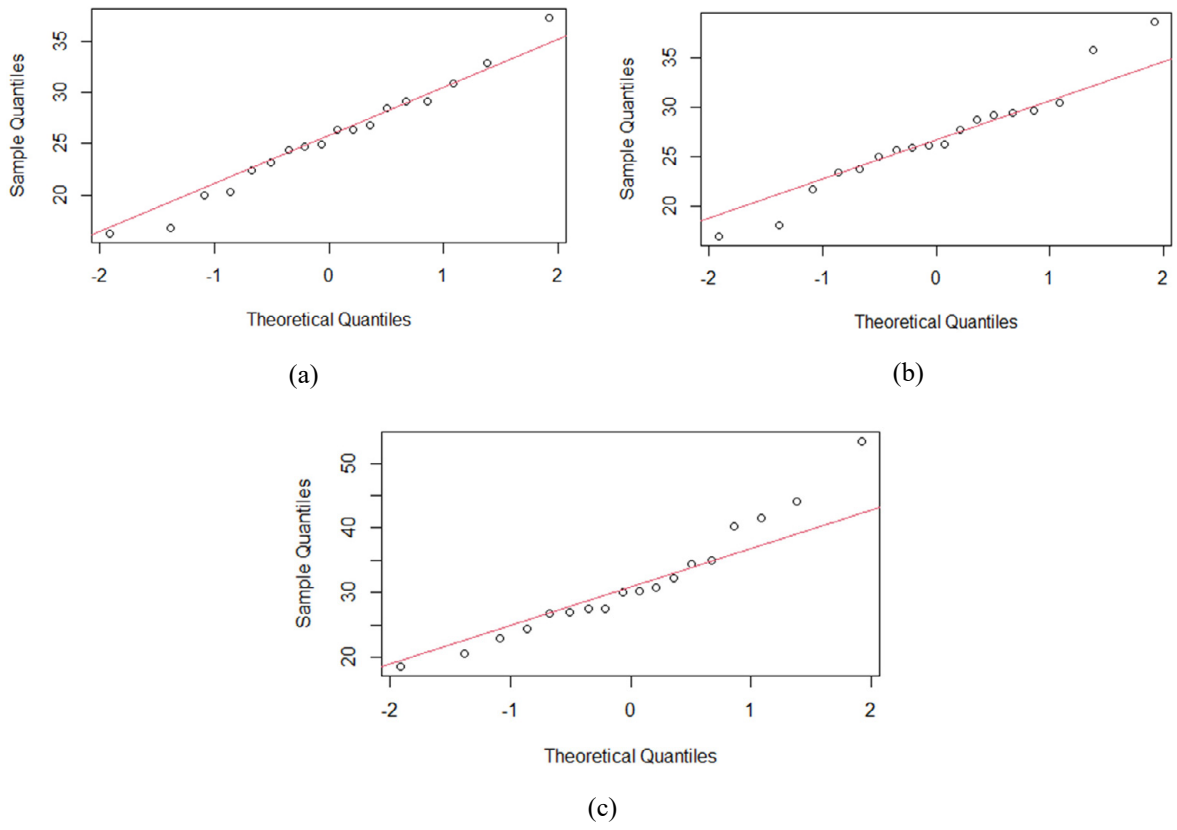


Fig. 8. Normal Q-Q plots of skin hydration data measured at (a) baseline (T0), (b) 14 days after application (T14), and (c) 28 days after application (T28). **Source:** Own elaboration.

significant difference was observed among the three measurement time points (p = 0.0249). A comparison of the skin hydration values is presented in fig. 9.

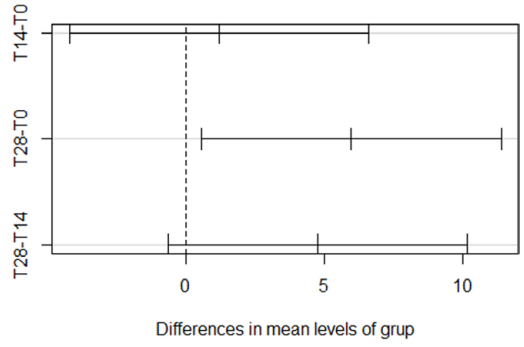


Fig. 9. Skin hydration values at baseline (T0), after 14 days of application (T14), and after 28 days of application (T28). **Source:** Own elaboration.

DISCUSSION

Extraction of *Centella asiatica* L.

Maceration was selected as the extraction method to minimize the degradation or loss of heat-sensitive constituents because the process is carried out without heating [12]. Ethanol (96%) was used as the extraction solvent because it effectively extracts semipolar compounds from *Centella asiatica* L., which contains triterpenes, phenolic compounds, alkaloids, vitamins, and amino acids [13]. The water-soluble extract complied with the requirements of the Indonesian Herbal Pharmacopoeia (≤10%), indicating that the extract quality was acceptable. The extraction yield was 60.14%, which was considerably higher than the 36.37% reported by Djoko et al [14]. This difference may reflect variations in the extraction procedure. In this study, maceration was performed for 3 × 24 h, whereas Djoko et al. employed repeated maceration cycles. Differences in extraction duration, solvent-to-material ratio, particle size, and extraction conditions affect extraction efficiency and yield. According to the Indonesian Herbal Pharmacopoeia (2017), the minimum acceptable extraction yield of *Centella asiatica* L. ethanol extract is 7.2%; therefore, the yield obtained in this study fulfilled the pharmacopoeia requirement. The semipolar constituents, particularly triterpenoids and flavonoids, extracted with 96% ethanol are recognized for their antioxidant, anti-inflammatory, wound-healing, and skin-protective properties, making them relevant for sunscreen formulations [15].

- Preparation and evaluation of the sunscreen emulsion spray

Organoleptic and homogeneity tests

Organoleptic evaluation showed that all formulations exhibited a similar brownish-green color, liquid consistency, and a characteristic rose fragrance due to the added fragrance component. The brownish-green color originated from the incorporation of ethanol extract of *Centella asiatica* L. As the extract concentration increased, its characteristic color and herbal odor became more pronounced. Although the natural color of the extract could not be eliminated, it did not leave noticeable staining on the skin after application. A rose fragrance was incorporated to improve the sensory acceptability of the formulation to mask the characteristic herbal odor. Fragrance is an important sensory attribute of cosmetic products because it enhances user acceptance and contributes to a pleasant application experience, even though it does not directly influence product efficacy [16]. In addition, all formulations were homogeneous and free of coarse particles, indicating uniform ingredient dispersion. Good homogeneity is an important quality attribute because it contributes to the physical stability and enhances user comfort during topical application by providing a smooth texture, uniform spreading, and minimizing the perception of grittiness on the skin [17].

pH measurement

All formulations exhibited pH values that complied with the specified requirements (Tab. 3). The formulations were designed to have pH values close to the skin's physiological pH. The skin surface, particularly the SC, normally exhibits a slightly acidic pH ranging from approximately 4.1 to 5.8, whereas the pH gradually increases with epidermal depth until it approaches the physiological pH of approximately 7.4 [18]. Developing topical products within this pH range helps maintain the skin barrier, minimizes the risk of irritation, and supports product compatibility with the natural skin environment [19].

Spray measurement

Based on the regression equation, both xanthan gum and PEG 400 showed positive coefficients, indicating that the spray pattern diameter increased with increasing concentration of either component. PEG 400 exhibited a greater positive effect (+12.04) than xanthan gum (+9.44), suggesting that PEG 400 played a more dominant role in improving spray performance. Xanthan gum is a high-molecular-weight polysaccharide that forms a three-dimensional network within the aqueous phase, increasing viscosity and providing structural resistance to flow [20]. Conversely, PEG 400 acts as a low-molecular-weight polyol that interacts with xanthan gum chains through hydrogen bonding, thereby reducing polymer chain entanglement and improving chain mobility. Consequently, the viscosity of the emulsion decreases, facilitating liquid atomization during spraying and producing a wider spray pattern [21]. Therefore, optimizing the ratio of xanthan gum to PEG 400 is essential for achieving rheological properties that promote efficient atomization [22].

Viscosity measurement

The regression equation (Equation 2) showed that both xanthan gum and PEG 400 positively affected the viscosity of the emulsion. Xanthan gum exhibited a greater effect (+120.52) than PEG 400 (+79.37), indicating that xanthan gum was the primary contributor to viscosity enhancement. This finding is consistent with the well-established rheological behaviour of xanthan gum as a high-molecular-weight polysaccharide that forms an entangled three-dimensional network in the aqueous phase, thereby increasing flow resistance and improving the emulsion's structural integrity [23, 24].

The interaction term between xanthan gum and PEG 400 showed a negative coefficient (–114.69), indicating that their combination reduced viscosity compared with the individual effects of each component. PEG 400 acts as a low-molecular-weight polyol that interacts with xanthan gum chains through hydrogen bonding, thereby reducing polymer chain entanglement and increasing chain mobility. Consequently, the polymer network becomes less rigid, decreasing the formulation's overall viscosity [25].

The ANOVA results confirmed that the quadratic model was statistically significant ($p = 0.0238$), indicating that variations in xanthan gum and PEG 400 concentrations significantly affected the viscosity response. The high coefficient of determination ($R^2 = 0.9762$) demonstrated that the model adequately described the relationship between the formulation variables and viscosity. Consistent with the regression model, the contour plot (Fig. 2) showed that increasing the xanthan gum concentration progressively increased viscosity, whereas increasing the proportion of PEG 400 reduced the formulation viscosity through its interaction with the xanthan gum polymer network. Therefore, optimizing the xanthan gum-to-PEG 400 ratio is essential for achieving rheological properties that promote efficient atomization. The greater coefficient of PEG 400 indicates that this component contributed more substantially to increasing the diameter of the spray pattern than xanthan gum. This effect is likely attributable to the formulation's lower viscosity, which facilitates droplet breakup during atomization and produces a wider spray pattern [26].

Determination of the emulsion type

The emulsion type was evaluated to confirm that the intended emulsion system was successfully produced by

the manufacturing process. All formulations were oil-in-water (O/W) emulsions, which are preferred for topical spray preparations because they are easily spread, readily washed off with water, and provide a non-greasy skin feel [27]. The formation of an O/W emulsion can be attributed to the composition of the formulation, in which the oil phase, consisting mainly of octocrylene (10%) and butyl methoxydibenzoylmethane (5%), accounted for only approximately 15% of the total formulation, while the remaining components were predominantly hydrophilic and constituted the continuous aqueous phase [28]. PEG 400, a highly hydrophilic polyol, acts as a co-emulsifier and co-solvent that improves the compatibility between the oil and aqueous phases. By forming a three-dimensional polymer network, xanthan gum increases the viscosity of the aqueous phase and stabilizes dispersed oil droplets [29]. Consequently, the oil phase remained dispersed within the aqueous continuous phase, forming an O/W emulsion. This finding is consistent with the emulsion theory, which states that O/W emulsions are favoured when the aqueous phase predominates and the stabilizing agents exhibit greater affinity for water than for oil.

Observation of the globule size

The globule size test evaluated whether the emulsion droplets were within the acceptable size range for conventional emulsions (0.15-100 μm) [30]. The measurement results showed that all formulations had globule sizes within this range, indicating successful emulsion formation and good physical characteristics. Globule size is an important parameter that influences the stability, appearance, and skin delivery behaviour of topical emulsions. Excessively small droplets are generally undesirable in sunscreen formulations, as several studies have reported that smaller emulsion droplets may enhance skin penetration by increasing the contact area between the formulation and the skin [31]. Since sunscreens are intended to remain primarily on the skin surface to provide effective UV protection, maintaining an appropriate globule size may help minimize excessive skin penetration while ensuring adequate film formation and product performance [32].

Evaporation time test

The evaporation time test evaluated the time required for the sprayed formulation to dry and form a film on the skin surface. All formulations exhibited evaporation times of 5 min (2.59–2.85 min), indicating rapid drying after application while remaining within the acceptable specification for topical spray preparations. A short evaporation time is desirable because it improves user convenience and enables a protective film to form shortly after application [33].

The slight differences in evaporation time among the formulations can be attributed to the varying concentrations of xanthan gum and PEG 400. Formulations with higher xanthan gum levels tended to exhibit slightly longer drying times because increased aqueous-phase viscosity reduces water mobility and slows solvent evaporation. Xanthan gum forms a 3D polymer network that retains water molecules through hydrogen bonding, thereby delaying moisture loss from the formulation [23]. PEG 400 also affects evaporation behaviour. As a hydrophilic polyol with hygroscopic properties, PEG 400 strongly interacts with water molecules and reduces their evaporation rate [34]. In addition, butylene glycol (10%), another hygroscopic humectant in the formulation, further retains moisture and supports a more gradual drying process. These findings are consistent with Sawatdee et al., who reported evaporation times of approximately 3.4-4.8 min for topical spray formulations, showing that hydrophilic polymers and humectants can moderately prolong evaporation while maintaining acceptable drying characteristics for topical application [35].

The optimization performed using Design-Expert® 13.0 identified F1, containing 1% xanthan gum, as the optimal formulation with a desirability value of 1.000. In the desirability function approach, values closer to 1 indicate that the predicted responses simultaneously satisfy the predefined optimization criteria to a greater extent [36]. The selection of F1 suggests that this formulation provided the most favourable balance among the evaluated responses, including viscosity, spray pattern, pH, evaporation time, globule size, and physical stability.

- Stability of the sunscreen spray formulation

Stability testing evaluated the physicochemical properties of the sunscreen spray formulations under normal storage conditions, temperature fluctuations, and accelerated mechanical stress. All formulations remained physically stable and complied with the specified acceptance criteria throughout 28 days of storage at room temperature. Similarly, after three freeze–thaw cycles and centrifugation at 3000 rpm for 30 min, no significant changes in pH, viscosity, spray pattern, globule size, evaporation time, or physical appearance were observed. No phase separation, creaming, or changes in color or consistency were detected, indicating that the emulsion system maintained its structural integrity under the tested conditions.

The excellent physical stability observed in all formulations can be attributed primarily to the stabilizing effect of xanthan gum. As a high-molecular-weight polysaccharide, xanthan gum forms a hydrated polymer network within the continuous aqueous phase and can establish a protective multilayer around dispersed oil droplets [37]. This hydrated layer provides steric stabilization by preventing close contact between droplets, thereby reducing flocculation and coalescence.

Furthermore, xanthan gum substantially increases the continuous-phase viscosity, limiting droplet mobility and slowing gravitational separation [38, 39].

PEG 400 acts as a hydrophilic co-emulsifier. PEG molecules preferentially partition into the aqueous phase and accumulate at the oil–water interface, reducing interfacial tension [40]. These mechanisms increase the kinetic stability of the emulsion by minimizing droplet aggregation and phase separation. Furthermore, the predominance of the aqueous phase and the relatively small, uniformly distributed globules contributed to emulsion stability [41].

The freeze–thaw test is an accelerated stability study designed to evaluate emulsions' resistance to repeated temperature changes, which may induce droplet coalescence or phase separation due to ice crystal formation and interfacial tension changes. The absence of significant changes after three freeze–thaw cycles suggests that despite repeated thermal stress, the interfacial film surrounding the dispersed oil droplets remained intact. Similarly, the centrifugation test applies accelerated gravitational force to predict long-term physical instability. The absence of phase separation after centrifugation indicates that the emulsion possessed sufficient kinetic stability to resist creaming and coalescence under mechanical stress. Overall, the optimized combination of xanthan gum and PEG 400 provided adequate stabilization of the sunscreen spray formulation, enabling the product to maintain its physicochemical characteristics under both normal and accelerated storage conditions.

- Skin hydration level test

Skin hydration was evaluated to determine the moisturizing effect of the sunscreen after repeated application. The results demonstrated a progressive increase in skin hydration from T0 to T14 and T28, with a statistically significant difference among the three time points ($p = 0.0249$). This finding indicates that continuous application of the formulation effectively improved skin hydration over the 28-day study period. The moisturizing effect is likely attributable to the combined actions of the ingredients in the formulation. Butylene glycol and PEG 400 function as humectants that attract and retain water within the SC, thereby increasing skin hydration [42]. In addition, xanthan gum forms a thin hydrophilic film on the skin surface, which helps reduce TEWL and prolongs moisture retention after application [43].

The active botanical ingredients also contributed to the observed improvement in skin hydration. *Centella asiatica* L. extract contains triterpenoids, including asiaticoside, madecassoside, asiatic acid, and madecassic acid, which support skin barrier repair and enhance moisture retention [44]. Meanwhile, *Avena sativa* (oat) kernel flour contains β-glucans, polysaccharides, and lipids that form a protective moisturizing film on the skin surface while improving barrier function and reducing water loss [45]. The combined moisturizing effects of these botanical ingredients and the humectants present in the formulation likely contributed to the sustained increase in skin hydration observed after 28 days of application.

These findings suggest that the sunscreen spray possesses moisturizing properties that may improve skin comfort during regular use in addition to providing ultraviolet protection. This is particularly advantageous because prolonged sun exposure impairs the skin barrier and increases TEWL, resulting in skin dryness. Therefore, a sunscreen formulation that simultaneously protects against UV radiation and maintains skin hydration may provide additional benefits for long-term skin health.

CONCLUSIONS

A sunscreen spray emulsion containing *Centella asiatica* L. ethanol extract and *Avena sativa* (oat) kernel flour was successfully optimized using a SLD. The combination of xanthan gum and PEG 400 played an important role in determining the formulation's physicochemical characteristics and spray performance, enabling the development of a stable O/W sunscreen spray with suitable properties for topical application. The optimized formulation remained physically stable under both room-temperature storage and accelerated stability conditions and demonstrated a significant improvement in skin hydration following repeated application, indicating its potential to provide both photoprotective support and moisturizing benefits. These findings suggest that the developed formulation is a promising topical sunscreen spray incorporating natural ingredients for skin protection and hydration. Future studies should evaluate its UV protection efficacy through *in vitro* and *in vivo* testing of the sun protection factor (SPF) to further establish its clinical performance.

CONFLICTS OF INTEREST

The authors have no conflicts of interest to declare.

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AUTHORS' CONTRIBUTIONS

Author Contributions: P.R.: Conceptualization, methodology, formal analysis, investigation, original draft writing, review and editing, funding acquisition, resources, supervision. C.B.: Methodology, investigation, experimentation, formal analysis, and original draft writing. S.S.: Writing the original draft, reviewing, and editing. Y.E.C.: Writing the original draft, reviewing, and editing. All authors have read and approved the published version of the manuscript.

USE OF AI TOOLS

The authors declare that AI tools were used only for typographic checking during the writing process. All content, interpretation, and final proofreading were performed by the authors. No AI tools were used for data analysis or image generation, and no AI tools are listed as authors.

ETHICS STATEMENT

The study was conducted in accordance with the Declaration of Helsinki and was approved by the Research Ethics Committee of the Faculty of Medicine and Health Sciences, Atma Jaya Catholic University of Indonesia, Jakarta, Indonesia (Ethical Clearance No. 03/05/KEP-FKIKUAJ/2024; approval date: May 7, 2024). Written informed consent was obtained from all participants. Written informed consent was not required for the publication of identifiable data/images because no identifiable personal data or images of participants were included in this manuscript.

REFERENCES / LITERATURA

1. Merin K, Shaji M, Kameswaran R. A Review on sun exposure and skin diseases. *Indian J Dermatol*. 2022;67(5):625-633. https://doi.org/10.4103/ijd.ijd_1092_20
2. Amaro-Ortiz A, Yan B, D'Orazio J. Ultraviolet radiation, aging and the skin: prevention of damage by topical camp manipulation. *Molecules*. 2014;19(5):6202-6219. https://doi.org/10.3390/molecules19056202
3. Teplitz RW, Glazer AM, Svoboda RM, Rigel DS. Trends in US sunscreen formulations: impact of increasing spray usage. *J Am Acad Dermatol*. 2018;78(1):187-199. https://doi.org/10.1016/j.jaad.2017.07.040
4. Bernstein EF, Sarkas HW, Boland P, Bouche D. Beyond sun protection factor: an approach to environmental protection with novel mineral coatings in a vehicle containing a blend of skincare ingredients. *J Cosmet Dermatol*. 2020;19(2):407-415. https://doi.org/10.1111/jocd.13007
5. Ratz-lyko A, Arct J, Pytkowska K. Moisturizing and antiinflammatory properties of cosmetic formulations containing Centella asiatica extract. *Indian J Pharm Sci*. 2016;78(1):27-33. https://doi.org/10.4103/0250-474X.180247
6. Nobile V, Zanoletti V, Manzoni V, et al. Soothing effect of a cosmetic product on skin discomforts induced by a chemical irritant (capsaicin) and UV-radiation, and after mosquito bites and sunburn in a real-world setting. *Cosmetics*. 2022;9(6):130-144. https://doi.org/10.3390/cosmetics9060130
7. Park KS. Pharmacological effects of Centella asiatica on skin diseases: evidence and possible mechanisms. *Evid Based Complement Alternat Med*. 2021;11(1):1-8. https://doi.org/10.1155/2021/5462633
8. He Z, Hu Y, Niu Z, et al. A review of pharmacokinetic and pharmacological properties of asiaticoside, a major active constituent of Centella asiatica (L.) *Urb J Ethnopharmacol*. 2023;302:115865-115870. https://doi.org/10.1016/j.jep.2022.115865
9. Rowe RC, Sheskey PJ, Cook WG, Fenton ME. *Handbook of Pharmaceutical Excipients*. 7th ed. London: Pharmaceutical Press; 2012
10. Firmenich. Sunscreen Optimizer. Published 2021. Accessed July 24, 2025. https://www.sunscreen-optimizer.com/index.html
11. Kementerian Kesehatan Republik Indonesia. *Farmakope Herbal Indonesia*. Ed ke-2. Jakarta: Kementerian Kesehatan Republik Indonesia; 2017.
12. Đurović S, Domínguez R, Pateiro M, et al. *Industrial Hemp: Food and Nutraceutical Applications*. Academic Press; 2022.
13. Lee JE, Jayakody J, Kim JI, et al. The influence of solvent choice on the extraction of bioactive compounds from asteraceae: a comparative review. *Foods*. 2024;13(19):3151-3172. https://doi.org/10.3390/foods13193151
14. Djoko W, Taurhesia S, Djamil R, Simanjuntak P. Standardisasi ekstrak etanol herba pegagan (Centella asiatica). *Jurnal Institut Sains dan Teknologi Nasional*. 2020;13(2):118-123. https://doi.org/10.37277/sfj.v13i2.765
15. Omidian H, Akhzarmehr A, Bertol CD. Natural-based antioxidants in cosmeceuticals: extraction, bioavailability and skin ageing applications. *Int J Cosmet Sci*. 2026;48(2):394-427. https://doi.org/10.1111/ics.70039.
16. Barkat S, Thomas-Danguin T, Bensafi M, et al. Odor and color of cosmetic products: correlations between subjective judgement and autonomous nervous system response. *Intern J of Cosmetic Sci*. 2003;25(6):273-283. https://doi.org/10.1111/j.1467-2494.2003.00196.x
17. Johnson W, Bergfeld WF, Belsito DV, et al. Safety assessment of Centella asiatica-derived ingredients as used in cosmetics. *Int J Toxicol*. 2023;42(1):5-22. https://doi.org/10.1177/10915818231158272
18. Brooks SG, Mahmoud RH, Lin RR, et al. The skin acid mantle: an update on skin pH. *J Invest Dermatol*. 2025;145(3):509-521. https://doi.org/10.1016/j.jid.2024.07.009
19. Lukić M, Pantelić I, Savić SD. Towards optimal pH of the skin and topical formulations: from the current state of the art to tailored products. *Cosmetics*. 2021;8(3):69-79. https://doi.org/10.3390/cosmetics8030069
20. Gao X, Huang L, Xiu J, et al. Evaluation of viscosity changes and rheological properties of diutan gum, xanthan gum, and scleroglucan in extreme reservoirs. *Polymers*. 2023;15(21):4338-4356. https://doi.org/10.3390/polym15214338
21. Berninger T, Dietz N, González López Ó. Water-soluble polymers in agriculture: xanthan gum as eco-friendly alternative to synthetics. *Microb Biotechnol*. 2021;14(5):1881-1896. https://doi.org/10.1111/1751-7915.13867
22. Lefebvre AH, McDonell VG. *Atomization and Sprays*. 2nd ed. Boca Raton, FL: CRC Press; 2017.
23. Patel J, Maji B, Moorthy NSHN, Maiti S. Xanthan gum derivatives: review of synthesis, properties and diverse applications. *RSC Adv*. 2020;10(45):27103-27136. https://doi.org/10.1039/D0RA04366D
24. Wu Y, Wang W, Zhang Y, et al. Study on the effect of structural modification of xanthan gum on its synergistic gelation performance with locust bean gum. *Molecules*. 2026;31(10):1597-1622. https://doi.org/10.3390/molecules31101597
25. Sutar RS, Wu X, Latthe SS, et al. Efficient separation of oil-water emulsions: competent design of superwetting materials for practical applications. *J Environ Chem Eng*. 2023;11(6):111299-111312. https://doi.org/10.1016/j.jece.2023.111299
26. Gong C, Chen F, Kang C. Theoretical and experimental studies on the oil-based emulsion spray. *Front Plant Sci*. 2023;14:1164200-11164209. https://doi.org/10.3389/fpls.2023.1164200
27. Pavlović N, Žabić K, Zaklan D, et al. Phytocosmetic water-in-oil emulsions with plant oils: physicochemical, rheological and photoprotective evaluation. *Cosmetics*. 2026;13(1):23-43. https://doi.org/10.3390/cosmetics13010023
28. Ponphaiboon J, Limmatvapirat S, Limmatvapirat C. Development and evaluation of a stable oil-in-water emulsion with high ostrich oil concentration for skincare applications. Molecules. 2024;29(5):982-1006. https://doi.org/10.3390/molecules29050982
29. Chen YS, Chiu YH, Li YS, et al. Integration of PEG 400 into a self-nanoemulsifying drug delivery system improves drug loading capacity and nasal mucosa permeability and prolongs the survival of rats with malignant brain tumors. *Int J Nanomedicine*. 2019;14(5):3601-3613. https://doi.org/10.2147/IJN.S193617
30. Otto A, Du Plessis J, Wiechers JW. Formulation effects of topical emulsions on transdermal and dermal delivery. *Intern J of Cosmetic Sci*. 2009;31(1):1-19. https://doi.org/10.1111/j.1468-2494.2008.00467.x
31. Chavda VP, Acharya D, Hala V, et al. Sunscreens: a comprehensive review with the application of nanotechnology. *J Drug Deliv Sci Techno*. 2023;86(6):104720-104748. https://doi.org/10.1016/j.jddst.2023.104720
32. Sotler R, Adamič M, Jarni K, et al. Analyzing the photoprotection efficiency of sunscreens containing antioxidants under disinfection conditions. *Antioxidants*. 2021;10(11):1720-1733. https://doi.org/10.3390/antiox10111720
33. Umar AbdK, Butarbutar MET, Sriwidodo S, Wathoni N. Film-forming sprays for topical drug delivery. *Drug Des Devel Ther*. 2020;14(6):2909-2925. https://doi.org/10.2147/DDDT.S256666
34. Mech D, Sangwai JS. Effect of molecular weight of polyethylene glycol (PEG), a hydrate inhibitive water-based drilling fluid additive, on the formation and dissociation kinetics of methane hydrate. *J Nat Gas Sci Eng*. 2016;35(9):1441-1452. https://doi.org/10.1016/j.jngse.2016.06.020
35. Sawatdee S, Choochuay K, Chanthorn W, Srichana T. Evaluation of the topical spray containing Centella asiatica extract and its effica-

cy on excision wounds in rats. *Acta Pharmaceutica*. 2016;66(2):233-244. https://doi.org/10.1515/acph-2016-0018
36. Amdoun R, Khelifi L, Khelifi-Slaoui M, et al. The desirability optimization methodology; a tool to predict two antagonist responses in biotechnological systems: case of biomass growth and hyoscyamine content in elicited Datura Starmonium hairy roots. *Iran J Biotechnol.* 2018;16(1):11-19. https://doi.org/10.21859/ijb.1339
37. Lotos ED, Danila A, Vasiliu AL, et al. The potential emulsions of xanthan gum and daucus carota macerated oil in functional textiles for skincare applications: formulation, characterization, and performance evaluation. *Colloids Surf A Physicochem Eng Asp*. 2024;682(2):132960-132972. https://doi.org/10.1016/j.colsurfa.2023.132960
38. Bouziane H, Seddari S, Moulai-Mostefa N. Investigation of the effects of sodium caseinate/xanthan gum complexes on the stability and sustained release of acid double emulsions using box–behnken design. *Chem Engineering*. 2025;9(6):141-157. https://doi.org/10.3390/chemengineering9060141
39. Hemar Y, Tamehana M, Munro PA, Singh H. Influence of xanthan gum on the formation and stability of sodium caseinate oil-in-water emulsions. *Food Hydrocolloids*. 2001;15(6):513-519. https://doi.org/10.1016/S0268-005X(01)00075-3
40. Suk JS, Xu Q, Kim N, et al. PEGylation as a strategy for improving nanoparticle-based drug and gene delivery. *Advanced Drug Delivery Reviews*. 2016;99(4):28-51. https://doi.org/10.1016/j.addr.2015.09.012
41. Kiromah NZW, Sugihartini N, Nurani LH. Development and characterization of clove oil microemulsion. *Pharmacia*. 2023;70(1):233-241. https://doi.org/10.3897/pharmacia.70.e98096
42. Pinto JR, Monteiro e Silva SA, Leonardi GR. Effects of 1,3-propanediol associated, or not, with butylene glycol and/or glycerol on skin hydration and skin barrier function. *Intern J of Cosmetic Sci*. 2024;46(1):85-95. https://doi.org/10.1111/ics.12911
43. Sparr E, Millecamps D, Isoir M, et al. Controlling the hydration of the skin though the application of occluding barrier creams. *J R Soc Interface*. 2013;10(80):20120788-20120798. https://doi.org/10.1098/rsif.2012.0788
44. Sun B, Wu L, Wu Y, et al. Therapeutic potential of Centella asiatica and its triterpenes: a review. *Front Pharmacol*. 2020;11(9):568032-568056. https://doi.org/10.3389/fphar.2020.568032
45. Kim HS, Hwang HJ, Seo WD, Do SH. Oat (Avena sativa L.) sprouts restore skin barrier function by modulating the expression of the epidermal differentiation complex in models of skin irritation. *Int J Mol Sci*. 2023;24(24):17274-17289. https://doi.org/10.3390/ijms242417274

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