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Formulation development, physical stability, and preliminary safety screening of cosmetic emulsions containing banana peel extract

Pranudda Pimsee [a], Atittaya Meenongwa [a], Warongporn Rattanabun [a], Nichthima Warinthip [a], Pattaraphorn Panomai [a], Wannisa Keawbankrud [a], Duangsuree Sanseera [a], Supaporn Khangkham [b], Pattarawat Kraipiyaset [c], Wongnapa Nakyai [d] and Natnicha Phungsara [e*]

[a] *Division of Health Science and Aesthetic, Department of Science, Faculty of Science and Technology, Rajamangala University of Technology Krungthep, Bangkok, 10120, Thailand*

[b] *Chemistry Program, Faculty of Science and Technology, Bansomdejchaopraya Rajabhat University, Bangkok, 10600, Thailand*

[c] *Division of Digital Media and Mass Communication Technology, Rajamangala University of Technology Krungthep, Bangkok, 10120, Thailand*

[d] *Faculty of Integrative Medicine, Rajamangala University of Technology Thanyaburi, Pathum Thani, 12130, Thailand*

[e] *Mahidol Bumrungrak Nakhonsawan Medical Center, Mahidol University, Nakhonsawan Campus, 60130, Thailand*

Abstract

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The purpose of the present study was to prepare and evaluate a lotion and cream containing banana peel extract for cosmetic application. The developed prototype formulations contained thickeners and emollients, and their physical, chemical, and preliminary sensory characteristics were evaluated. Experimental techniques used particle size analysis, viscosity and pH measurement as well as in vitro irritancy on reconstructed human epidermis (OECD 439). Cytocompatibility was also evaluated using HaCaT cell lines through the MTT assay. Both lotion and cream formulations containing banana peel extract (0.1% w w^{-1}) showed consistent appearance and physical properties under the tested conditions. Skin irritation test results showed that the formulations are classified as non-irritant (viability > 50% relative to the negative control) according to OECD TG 439 criteria. Cytotoxicity studies revealed that all formulations at 1000 µg mL^{-1} (extract-equivalent) were non-cytotoxic, maintaining cell viability above 70% in accordance with ISO 10993-5. These results suggest preliminary feasibility and in vitro safety under the tested conditions, indicating the potential of banana peel extract as a sustainable cosmetic ingredient for further dermatological development.

*** Corresponding author** : Natnicha.phu@mahidol.ac.th

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1. Introduction

Sustainability concerns and the increasing interest towards natural, safe, and effective cosmetic products gained favor for using bioactive ingredients from fruit in dermatological formulations. One of these is banana peel, usually considered as a byproduct in agriculture, but which has gained importance due to the presence of phytochemical substances with antioxidant, anti-inflammatory and antimicrobial effects. Recent studies have found that banana peels extracts are active against a broad spectrum of pathogenic bacterias and fungi, such as Staphylococcus aureus and Bacillus subtilis, even certain skin disease causing bacteria. Its antibacterial effect is related to high tannins, saponins and flavonoids content, more prevalent in unripe peels [1 – 3]. Apart, from its broad-spectrum antimicrobial and antioxidant activity, banana peel extract has been reported to promote wound healing and skin moisturization by increasing the collagen density in epidermis followed by boosting up of recovery from injury upon application to human skin. Its clinical and animal model studies indicate that this extract has no side effects on human volunteers and in model animals except for mild burning sensation felt by some subjects [3 – 5], therefore, offers eco-friendly product enrichment for cosmetic science. Several studies verified that the banana peel was rich in phenolics, flavonoids, vitamins and minerals and had wide spectrum antioxidant and antimicrobial activities. Utilization of bioactive compounds from banana peels conforms to the principles of waste valorization, circular economy and consumer-digit direction towards green

cosmeceuticals. Studies have demonstrated that banana peels contain significant amounts of phenolic acids and flavonoids, which contribute to its potential antioxidant and skin-moisturizing properties [6 – 8]. Owing to its skin-hydrating, wound-healing and antioxidant properties, the topical application of banana peel extracts in the form of creams and lotions have also been useful. Recent studies have also confirmed, the wound healing, antioxidant and hydration potentials of banana peel extracts in a wide range of topical applications. For example, in 2024 a study reported the potent antioxidant activity and wound healing ability of banana peel transfer some gel and indicated that it plays an important role in skin regeneration and protect body against oxidative damage [9]. Another investigation showed that mixed creams including banana peels' extract and pumpkin seed oil exhibited antioxidant potential and acceptable physical characteristics, suggesting its feasibility as a natural cosmetic ingredient [10]. Moreover, a banana peel extract-loaded spray gel demonstrated significant antimicrobial and wound healing benefits, affirming the potential of applying banana-derived actives in topical preparations [11]. Together, these studies further validate the use of banana peel extract in next-gen skin care formulation and underscore the need for additional translatable studies in human-relevant skin models. Notwithstanding these encouraging results, most of the literature has focused on simple antioxidant tests, antimicrobial studies or animal models, with limited translation to evaluate application performance, safety in RHE or scalability for the use in cosmeceutical preparations [12 – 17].

The purpose of this study was to introduce cosmetics containing banana peel extract and systematically investigate the same. This research addresses the limited data regarding the interaction of banana peel extract within structured emulsion systems (lotion and cream). The emphasis is placed on the investigation of their physicochemical stability, in vitro cytocompatibility and irritation potential in reconstructed human skin models. To bridge the gap between simple extract testing and commercial application, this study focuses on the preliminary formulation of lotion and cream bases to assess how the integration of banana peel extract affects the physicochemical nature of standard cosmetic vehicles. This gap in research, the study suggests preliminary feasibility and in vitro safety under the tested conditions, rather than asserting definitive commercial dermatological appropriateness.

2. Materials and Methods

Materials

The banana peel extract was prepared using the peels of *Musa sapientum* L. (Kluai Hom Thong) collected from Phetchaburi Province, Thailand. The preparation of the lotion involved a selection of specialized materials, including butylene glycol; a blend of glyceryl oleate citrate with caprylic/capric triglyceride; glyceryl stearate; ceteareth-25; sorbitan monooleate; and C9-15 alkyl phosphate. Additional emollients used were isononyl isononanoate and various botanical oils such as argan oil, sweet almond oil, and apricot kernel oil. Additional stabilizers and emulsifiers were PEG 100-stearate, glyceryl stearate, a preservative complex of Phenoxyethanol, chlorphenesin, aqua and glycerin as well as citric acid solution 75%w v^{-1}. For cream formulation, the composition comprised sodium polyacryloyldimethyl taurate, hydrogenated polydecene, trideceth-10, and similar botanical oils (argan oil, apricot oil, and almond oil), with isononyl isononanoate and the same preservative system. All raw materials and chemicals used in both cream and lotion preparation were procured from Chemipan (Thailand). In conducting the in vitro skin irritation assessment employing the reconstructed human epidermis model, a range of equipment and reagents was utilized. This included the EpiSkin model (0.38 cm^2, France), twelve-well culture plates (Corning, Germany), and the MTT reagent [3-(4,5-dimethylthiazol-2-yl)-2,5-diphenyltetrazolium bromide, Thiazolyl blue] (AppliChem, Germany). The experimental workflow further required a microplate reader (CLARIOstar, Germany), a CO_2 incubator (Binder CB160, Germany), and a class II laminar airflow cabinet (LAMSYSTEMS CC, Russia). Other consumables were hydrochloric acid (Chem-Lab, Belgium), isopropanol (Scharlau, Spain), phosphate-buffered saline (PBS; Calbiochem, USA) and maintenance/assay media (EpiSkin, France). Sodium lauryl sulfate (SLS; Merck, Germany) was employed as a reference irritant. All procedures were conducted in accordance with standardized laboratory protocols for cell-based assays, including seeding cell lines in 96-well plates, applying MTT reagent at final concentration of 5 mg mL^{-1}, and preparing test solutions at 1000 µg mL^{-1}. Moreover, 100% DMSO and 10% SDS were prepared as additional controls for the cytotoxicity assay.

Methods

Preparation and Standardization of banana peel extract

The peels of *Musa sapientum* L. (Kluai Hom Thong) at the ripe stage were collected from Phetchaburi Province, Thailand. The raw materials were cleaned, sliced, and dried in a hot air oven at 60 °C until a constant weight was achieved. The dried peels were ground into a fine powder using a mechanical grinder. The extraction was performed by macerating the powder in 95% ethanol at a ratio of 1:10 (w v^{-1}) for 72 h at room temperature with occasional stirring. The mixture was filtered through Whatman No. 1 filter paper, and the filtrate was concentrated using a rotary evaporator under reduced pressure at 40 °C. The resulting crude extract was stored in a light-protected container at 4 °C [18]. For functional standardization, the extract was characterized for its bioactive content and antioxidant capacity. The total phenolic content (TPC) was determined using the Folin-Ciocalteu method and expressed as mg GAE g^{-1}. The total flavonoid content (TFC) was measured using the aluminum chloride colorimetric assay and reported as mg QE g^{-1}. Additionally, the antioxidant activity was evaluated using the DPPH radical scavenging assay, yielding an IC_{50} value (µg mL^{-1}). These baseline metrics

were established to ensure batch-to-batch consistency and to mitigate potential interference during subsequent MTT-based viability assays (OECD TG 439 and HaCaT testing).

Preparation of lotion base formulations

Base lotion preparation (Hot process)

Two distinct base lotion formulations were developed, differing primarily in their thickening systems. The first formulation (F1) utilized a single-component thickener, whereas the second formulation (F2) was prepared by incorporating a multi-component thickening system to evaluate its impact on the base's stability and texture. The specific compositions for both F1 and F2 are detailed in Table 1.

Table 1 Lotion base composition.

Phase	Ingredient	F1	F2	Function
A	DI water	Qs.to 100	Qs.to 100	Solvent
A	butylene glycol	2	2	Humectant
B	glyceryl oleate citrate (and) caprylic/capric triglyceride	-	0.5	Emulsifiers and Structuring Agents
B	glyceryl stearate, ceteareth-25, sorbitan monooleate, C9-15 alkyl phosphate	7.5	7	Emulsifiers and Structuring Agents
B	isononyl isononanoate	3	3	Emollient
B	argan oil	1	1	Emollient
B	sweet almond oil	2	2	Emollient
B	apricot kernel oil	2	2	Emollient
B	PEG 100 stearate, glyceryl stearate	8	8	Emulsifier
C	phenoxyethanol, chlorphenesin, aqua and glycerin	1	1	Preservative
C	citric acid solution 75%w v^{-1}	0.01	0.01	Adjust pH

Note: F1 = Formulation 1, F2 = Formulation 2.

Procedure

The lotion base was prepared using a hot process emulsification method. The procedure was standardized as follows: Phase A Preparation: DI water and butylene glycol were added to a 250 mL glass beaker. The mixture was heated to 70 ± 2 °C using a water bath and stirred at 500 rpm using a propeller mixer (Heidolph, Germany) for 10 minutes until the solution was clear. Phase B Preparation: The oil phase ingredients, including C9–15 alkyl phosphate, glyceryl stearate, PEG-100 stearate, and cetyl alcohol, were combined in a separate beaker. The mixture was heated to 70 ± 2 °C and held for 15 minutes until all components were completely melted and a uniform liquid was formed. Emulsification: Phase B was slowly added to Phase A while maintaining the temperature at 70 °C. The mixture was homogenized at 3,000 rpm using a high-shear homogenizer for 10 minutes to ensure a uniform emulsion.

Cooling and Phase C: The emulsion was continuously stirred at 200 rpm using a propeller mixer and allowed to cool naturally. Once the temperature reached 40 °C, the preservative (Phenoxyethanol, chlorphenesin, aqua and glycerin) was added.

The final mixture was stirred until homogeneous, defined as the absence of visible lumps and a smooth texture. The pH of the formulation was adjusted to 5.5–6.5 using a 75% w v^{-1} citric acid solution.

Preparation of facial cream base formulations

The facial cream base was developed using a cold-process emulsification method. Four phase distinct formulations were prepared, utilizing varying concentrations and types of thickening agents and emollients to achieve the desired texture and stability. The detailed composition and concentration of each ingredient for all four facial cream formulations are presented in Table 2.

Table 2 Facial cream base composition.

Phase	Ingredient	F1	F2	Function
A	DI water	Qs. to 100	Qs. to 100	Solvent
A	sodium polyacryloyldimethyl taurate, hydrogenated polydecene, trideceth-10	7	8	Emulsifiers and Structuring Agents
B	argan oil	0.5	0.5	Emollient
B	apricot oil	0.3	0.3	Emollient
B	almond oil	0.4	0.4	Emollient
B	isononyl isononanoate	5	5	Emollient
D	Phenoxyethanol, chlorphenesin, aqua and glycerin	0.5	0.5	Preservative

Note: F1 = Formulation 1, F2 = Formulation.

Procedure

The facial cream base was prepared using a cold process (room temperature, 25 ± 2 °C) to ensure energy efficiency and suitability for heat-sensitive components. The stepwise procedure was as follows: Gel Formation: DI water was added to a glass beaker. Sodium polyacryloyldimethyl taurate, hydrogenated polydecene, trideceth-10 was added under continuous stirring at 1,500 rpm using a propeller mixer for 15 minutes until a smooth, consistent gel base was formed. Oil Phase Addition: The emollient phase (argan oil, apricot oil, almond oil and isononyl isononanoate) was pre-blended and added to the gel base in small portions (approximately 5 mL per addition) to prevent phase separation. The mixture was stirred at 1,500 rpm for 5 minutes after each addition. Phase C Addition: After the oil phase was fully integrated, Phase C ingredients, including phenoxyethanol, chlorphenesin, aqua and glycerin were added to the mixture. The entire formulation was mixed at 1,000 rpm for an additional 10 minutes until homogeneous. The acceptance criteria for homogeneity included a glossy appearance, no visible oil droplets or lumps, and stable viscosity after resting for 24 h.

Development of lotion and cream containing extract

The base formula was supplemented with banana peel extract at a concentration of 0.1% w w^{-1}. The physical and chemical properties of product containing banana peel extract were then evaluated. The concentration of 0.1% (w w^{-1}) banana peel extract was selected based on a balance between bioactive efficacy and formulation aesthetics. Preliminary studies indicated that this concentration provided sufficient antioxidant properties without compromising the physical stability, color, or odor of the cosmetic bases. Higher concentrations were found to significantly alter the natural color of the cream and lotion to a dark brown hue, which may negatively impact consumer organoleptic acceptance.

Evaluation of physical and chemical properties

Evaluation of physical properties

Appearance and Homogeneity Evaluation

Physical properties of the cream and lotion were evaluated by visual and olfactory inspection. Color, texture, and odor were recorded at room temperature. The homogeneity was assessed by spreading a small amount of the formulation on a transparent glass slide to observe the presence of any visible lumps, sedimentation, or phase separation. Changes relative to the baseline were scored using a 4-point scale: 0 (no change), 1 (minor change), 2 (moderate change), and 3 (major change).

Viscosity Measurement

The viscosity of the lotion and cream was measured using a Brookfield viscometer (Model DV-II+, USA). For the lotion, spindle No. 63 was used at a speed of 100 rpm, while spindle No. 64 was utilized for the cream at 50 rpm. All measurements were conducted at 25 ± 2 °C. The samples were allowed to rest for 10 minutes before measurement to ensure stable readings. Each sample was tested in triplicate.

Determination of pH Value

The pH values of all formulations were determined using a digital pH meter (Mettler Toledo, Switzerland). The glass electrode was directly immersed into the sample at 25 ± 2 °C. Measurements were performed in triplicate for each formulation to calculate the mean and standard deviation. The device was calibrated with standard buffer solutions at pH 4.0 and 7.0 prior to use.

Stability Testing (Centrifugation and Thermal Stability)

The physical stability was evaluated using a centrifugation test and accelerated aging. In the centrifugation test, 5 g of each formulation was placed in a centrifuge tube and spun at 3,000 rpm for 30 minutes to observe any phase separation. For thermal stability, the samples were stored at 4 °C, 25 °C (room temperature), and 45 °C for 30 days [19]. After the storage period, all samples were re-evaluated for appearance, pH, and viscosity using the methods described above.

Microscopic Observation of Emulsion Microstructure.

Microscopic Observation of Emulsion Microstructure was measured using a Leica microscope (LED DM 2000 LED) with a magnification of 100x (Scale 20 μm).

In vitro skin irritation: reconstructed human epidermis

Analysis to determine of skin irritation on OECD 439 method depended on assessment of the reduction in cell viability) because of exposure human epidermal tissue with a test material. EpiSkin™ model of reconstructed human epidermis is used in these studies and cell survivability is examined by MTT assay. A test substance which provides a % cell viability of less than or equal to 50 is considered an irritation. Firstly, take the EpiSkin out of the Transwell: slowly and gently remove EpiSkin from the agar. Transfer tissue to a 12-well plate with 2 mL of maintenance medium and recover at 37°C, in 5% CO_2, and ~95% humidity for at least 24 h before use. Dispense 10 μL of each test item (e.g., moisturizing cream or lotion) using a positive pipette directly to the EpiSkin. Incubate further at 37°C, 5% CO_2 and 95% humidity for a period ranging 24 h. Use 5% w v^{-1} SLS as positive, PBS as negative control. For powder samples, the EpiSkin is first led to be moistened with 5 μL sterile water before the sample application and a piece of nylon netting, used to provide uniform distribution. After incubation, wash the EpiSkin 2–3 times with 10–15 mL of PBS each time, place the tissue from the insert into a new (12-well) plate containing 2 mL maintenance medium and incubate at 37°C, 5% CO_2 and high humidity for another ± 42 h. Then the tissues are transferred to another 12-well plate with 2 mL of MTT solution (0.3 mg mL^{-1}) and incubated for 3 h at 37°C, in a dark, humidified chamber with 5% CO_2. Finally, release the formazan product by adding 500 μL of acidic isopropanol to the tissue and determine absorbance at 570 nm. Percent cell viability is then determined as:

$$\% \text{ cell viability} = \frac{\text{OD sample}}{\text{OD negative}} \times 100 \quad (1)$$

where OD sample is the optical density of the sample and OD negative is the optical density of the negative control (PBS) [20].

Cytotoxicity testing method (MTT Assay)

Plate the HaCAT cell lines at a density of 1×10^5 cells mL^{-1} in a 96-well plate (100 µL $well^{-1}$) and incubate at 37°C under an atmosphere of 5% CO_2 for 24 h. After incubation, remove the medium from each well, and then add samples (100 µL $well^{-1}$) at a concentration of 1,000 µg mL^{-1}. Incubate the cells at 37°C in a 5% CO_2 environment for another 24 h. Following exposure of samples, 10 µL of MTT solution (5 mg mL^{-1}) were applied to each well and plates were incubated for 4 h at 37°C under a 5% CO_2 atmosphere. The culture medium is then removed, and 100 µL of solubilization solution (9: 1 mixture of 100% p v^{-1} DMSO and 10 % v w^{-1} SDS) is added to each well to solubilize the formazan product. Read the optical density (OD) at 570 nm with a spectrophotometric plate reader, selecting the mixing program for 5 min before performing reading. Convert the absorbance to percentage of cytotoxicity for all the samples according to the formula:

$$\% \text{ cytotoxicity} = \frac{(A-B)}{A} \times 100 \quad (2)$$

where A is the absorbance of control wells (cells in culture medium) and B is the absorbance of wells with sample-treated cells. Absorbance values must first be corrected by subtracting the value of blank wells (containing the solubilization solution only) [21].

Statistical analysis

All experiments were conducted in triplicate. Results are presented as mean ± standard deviation, accompanied by standard error. Statistical analyses were performed using SPSS software.

3. Results and Discussion

Lotion base formulations

The physical properties and consistency of the lotion bases (F1 and F2) shown in Fig. 1 (a) and (b) are mainly related to their compositions, especially the kind and number of thickeners and emollients used. More precisely, F1 has a higher content than F2 of glyceryl stearate and ceteareth-25 (both 7.5% w w^{-1}), sorbitan monooleate and C9–15 alkyl phosphate (all substances each 7% w w^{-1}) but contains no (0% w w^{-1}) glyceryl oleate citrate and caprylic/capric triglyceride. The formulations utilized a combination of emulsifiers and structuring agents to stabilize the oil-in-water system. Ingredients such as Glyceryl Stearate, Ceteareth-25, and C9–15 Alkyl Phosphate functioned primarily as an emulsifying system and consistency factors rather than sole thickeners. The higher concentration of these structuring agents in F1 contributed to its more compact and solid texture compared to F2. This higher thickener amount in F1 brings a more compact, solid and viscous texture (it seems to be firmer as shown in the image). Based on visual and olfactory inspection, F1 and F2 exhibited physical characteristics suitable for cosmetic application. Although F1 appeared qualitatively firmer in texture, with F1 showing a slightly higher viscosity profile compared to F2.

Despite the similarity in humectant, emollient and preservative levels between both formulations, minor differences in phase B lipid blend (and specifically presence of glyceryl oleate citrate as well as caprylic/capric triglyceride) also impact upon emulsion stability and feel. Both compositions contain 8% w w^{-1} of PEG 100 stearate/glyceryl stearate as the emulsifier and, accordingly, are of comparable consistency; however, it is understood that the ratio of the thickeners present in each such base are primarily responsible for determining their respective base textures. As a result, F1 is suitable for applications that desire a more dense, creamy texture versus a lotion base spread inly more freely.

Fig. 1 Lotion base (a) formula 1 (F1) and (b) formula 2 (F2).

These results emphasize the critical optimization of ingredient levels (especially water-solubilized thickeners and oil-phase viscosity modifiers) for desired sensory characteristics and stability. One underlying mechanism is emulsion stability, which depends on the composition of a formulation. A higher continuous phase viscosity, obtained by higher thickener concentrations, immobilizes the oil droplets and counteract separation (creaming or

sedimentation processes). Thickeners (polymers and particulate) play an important role in both creating viscosity and increasing inter-droplet repulsion, with the ratio between thickeners and the oil phase dictating whether a formula swings towards a thick cream versus a lightweight lotion with good spread.

This view is in favor of the emulsion theory that attribute stability to refined structural considerations including droplet size, viscosity of the continuous phase, nature of emulsifier and oil-water ratios. Thus, the controlled distribution of these variables does not only influence stability and skin feel but also allow customization of cosmetic emulsions to desired functional as well as sensory features. Appropriate formulation and accurate adjustment of ingredient levels is challenging to achieve for successful consumer-preferred topical products [22].

Facial cream base formulations

Physical appearance and texture properties of the facial cream bases are shown in Fig. 2 (a) for formula 1 (F1) and (b) formula 2 (F2) are mainly dependent on the thickener concentration used in both formulae. More specifically, F1 includes 7 %w w^{-1} of sodium polyacryloyldimethyl taurate, hydrogenated polydecene and trideceth-10, while F2 has a slightly higher thickening agent concentration of about 8%. Interestingly, in both formulations, the emollients and preservatives remain in the same proportions. The higher thickener load in F2 generates a cream that is denser, firmer and more robust structured as could be seen from relatively high peaks presented at sample. Conversely, the lower thickener level in F1 forms a lighter texture with lower textural stability. Therefore, at the time of application, F1 has better spread ability while F2 less tenacity. These data help explain why an addition of thickener gives rise to a heavier, more luxurious texture while a decrease results in lighter, more emollient creams. Thus, it is important for the ingredients to be selected and optimized strategically to customize the characteristics of cream as per the requirement of consumer along with a particular cosmetic application.

From a theoretical perspective, thickener concentration is an established determinant of cream texture and mechanical integrity. The thickening polymer, sodium polyacryloyldimethyl taurate (SPDT), forms a gel network that increases viscosity, binds water or oil within emulsions, and produces a cohesive, structured texture [22, 23]. Enhanced thickener content promotes a firmer consistency, while lower levels generate creams that are softer and more suited to lightweight products [22].

With respect to cold-process emulsions and creams, product stability is dictated by several interrelated mechanisms: first, achieving small droplet size and a resilient interfacial film through the synergy of emulsifiers, surfactants, or polymers is essential for preventing coalescence and maintaining stability. Second, a robust three-dimensional polymer network formed by gel agents and thickeners immobilizes droplets, thereby hindering creaming, sedimentation, or flocculation. Unlike hot-emulsification, cold-process methods depend entirely on mechanical energy and the efficacy of chosen stabilizers, making the chemical properties and arrangement of emulsifiers even more critical. Furthermore, long-term chemical stability is best ensured by controlling pH, water activity, and incorporating antioxidants or chelators to avert oxidation and degradation, especially when heat-sensitive ingredients are used [24]. Collectively, these strategies allow the formulation of creams with desirable sensory, functional, and rheological properties by systematically adjusting thickener type and concentration [22, 25].

Fig. 2 Facial cream base (a) formula 1 (F1) and (b) formula 2 (F2).

Development of lotion and facial cream containing extract

The incorporation of 0.1% w w^{-1} banana peel extract into the lotion and facial cream bases was qualitatively assessed. The resulting formulations appeared to maintain a smooth texture and consistent color without immediate phase separation. From a preliminary organoleptic observation, the products exhibited a non-greasy feel and were easy to spread on the skin. However, since a structured sensory panel was not employed, these observations represent qualitative characteristics rather than definitive consumer acceptability. Regarding physical integrity, the formulations remained visually stable under the observed storage conditions. Future studies involving long-term accelerated stability testing (e.g., freeze-thaw cycles) and a standardized sensory evaluation protocol are recommended to further substantiate these preliminary findings. Lotion F1 had no representative feeling, being neither too heavy nor light in weight and was comfortable to use (non-tacky)

when applied on the skin, so that lotion F1 suit for external application. In the same way, facial cream F1 showed a soft light non greasy touch that satisfied major cosmetic requirements. Both products remained uniform, pale in color and fluid after the incorporation of an extract from banana peel when viewed with the naked eye (Fig. 3) demonstrating their attractive soft and shiny looks which increase consumer acceptability. Both the lotion and cream remain physically intact and spreadable as it shows that extract is successfully incorporated into both systems without deterioration of the core base. Remarkably, the presence of 0.1% w w^{-1} banana peel extract did not negatively influence the appearance and physical stability, and these formulations could be considered for a potential cosmetic use.

This result was consistent with recent reports. For instance, [26] reported respectively that the herbal cream was non-irritant to human skin and patient acceptance of the cream with a pH value that is skin-friendly, it had smoothness, excellent spread ability, and stability due to degummed banana peel (DBP) extract. The beneficial effects had been attributed to bioactive substances such as polyphenols, flavonoids, tannins etc. which proved the efficacy and safety of banana peel extract in dermatological application. Moreover, [12] reported that the addition of banana peel extract to herbal antioxidant creams markedly increased the rheological and sensory properties as well as the stability of its anticancer activity with good skin compatibility. These properties make it an appropriate material for personal care product applications. Consistently, skin performance assessments of the banana peel moisturizing cream indicated effective dryness inhibition and potential for consumer acceptability implying prospects of upcycling agro-waste such as banana peels in value-added cosmetic ingredients [8].

Fig. 3 Lotion (a) and facial cream containing banana peel extract 0.1 % w w^{-1} (b).

Physicochemical Properties and Stability Analysis
Evaluation of Physical and Chemical Properties

Enhancing the determination of Table 3 physical and chemical properties, data from the literature shows that both pH and viscosity are crucial factors affecting emulsion stability, cosmetic elegance and skin tolerability. For skin care emulsions, ideal pH values are usually from 5 to 7 (the typically naturally acid pH of the skin is about pH 5.5). When the pH is in this slightly acidic to neutral range, it not only serves to preserve skin barrier integrity and user comfort but also assists in maintaining chemical stability of an emulsion and thereby prevents hydrolytic degradation and decomposition ingredient effects. In particular, pH below 4 can destabilize emulsifiers (including those containing an ester moiety) leading to product instability and higher than optimal alkalinity of pH may cause skin irritation as well as alter the viscosity and feel of the emulsion. Therefore, effective pH control requires testing at critical steps of the process and along the shelf life of the product, with trials for approval and quality [27].

The physicochemical properties of the developed lotion and facial cream formulations, including pH and viscosity, were monitored over a 1-month storage period as detailed in Table 3. The pH values remained remarkably stable within the range of 5.45–5.62 for all formulations. This consistency aligns with the physiological pH of human skin (typically 4.7–5.75), suggesting that the formulations are skin-friendly and unlikely to cause irritation due to pH imbalance.

Regarding rheological behavior, a noticeable increase in viscosity was observed in both the lotion and cream formulations after 30 days of storage. This "post-thickening" effect is likely attributed to the gradual maturation of the polymer network and the completion of the hydration process of the thickening agents (e.g., Sodium Polyacryloyldimethyl Taurate). Despite this increase, the formulations maintained their structural integrity without evidence of phase separation or sedimentation under visual inspection. While the 1-month storage data indicates short-term physical stability, it should be noted that the assessment was limited to ambient conditions; therefore, the observed viscosity drift is considered acceptable within the development phase of stable cosmetic emulsions. The viscosity of lotions is typically 10,000 to 30,000 cP and for creams is usually between 30,000 to 70,000 cP but these can be varied depending on the application one desires. A diligent attention to viscosity, before and after storage testing, as well as careful use of texture modifiers must be maintained since over thickening can dampen the user appeal [22, 28]. The observed increase in viscosity for both lotion and cream formulations after one month of storage can be attributed to the continuous structural rearrangement of the polymer network and the completion of the hydration process of the thickening agents. As the internal structure of

the emulsion reaches a more ordered state over time, the resistance to flow increases, leading to higher viscosity. This phenomenon is commonly observed in emulsions stabilized by synthetic polymers and fatty alcohols, where the 'post-thickening' effect occurs as the system reaches its final equilibrium.

The physical stability of the emulsions was supported by the absence of phase separation during the centrifugation test and 30-day storage at various temperatures (Table 3). Theoretically, the stability is enhanced by the immobilization of oil droplets within the polymer-surfactant network, preventing common instability phenomena such as creaming or coalescence.

Table 3 Evaluation of physical and chemical properties.

Characterization	Lotion (Time)		Cream (Time)	
	initial	1 month	initial	1 month
Appearance	Characteristic: yellow-white color Smell: Characteristic Sediment: None Separation: None	Characteristics: (0 - no change) Color: White color (1 - yellowish white) Smell: Characteristic (0 - no change) Sediment: None (0 - no change) Separation: None (0 - no change)	Characteristic: yellow-white color Smell: Characteristic Sediment: None Separation: None	Characteristics: (0 - no change) Color: White color (1 - yellowish white) Smell: Characteristic (0 - no change) Sediment: None (0 - no change) Separation: None (0 - no change)
Viscosity	23,626 ± 501.86 cP	30,286 ± 213.13 cP	37,730 ± 355.11cP	53,110 ± 113.58 cP
pH	5.59 ± 0.32	5.51 ± 0.36	5.38 ± 0.28	5.61 ± 0.31

Note: Appearance: 0 - no change, 1 - minor change, 2 - moderate change, 3 - major change; Viscosity: Brookfield Viscometer (DV2T), Probe type: 94, Speed: 10 rpm, 60 seconds; pH: pH meter (pH meter S220, Mettler Toledo)

Microscopic Observation of Emulsion Microstructure.

The microstructure and droplet dispersion of the lotion and facial cream containing 0.1% w w^{-1} banana peel extract were qualitatively assessed using optical microscopy at 100 × magnification (Fig. 4). The micrographs suggested a well-dispersed and uniform distribution of oil droplets within the aqueous phase for both formulations at the observed timepoint. The importance of finely dispersed droplets for emulsion stability, this qualitative assessment provides preliminary evidence of effective emulsification. However, it should be noted that droplet size values or distributions were not quantitatively determined in this study, which represents a limitation for predicting long-term stability. It is well known that particle dispersion influences the stability of cosmetic emulsions. Studies by [22] insist that small and homogeneously distributed droplets-result from a suitable choice of emulsifiers, the performance during processing- are necessary for achieving high physical stability. Homogeneous smaller droplets reduce the chances of agglomeration and phase separation which in turn contributes to uniform texture, appearance during entire shelf life.

Furthermore, [29] give theoretical insides by showing that the energy barrier preventing droplet coalescence results from not only size and packing of droplets but also structure provided by emulsifier. These contribute to the synergistic stability and texture of the emulsion.

In conclusion, stable cosmetic emulsions are obtained by careful mechanical mixing and the proper choice of emulsifiers or stabilizers as well as small uniform particle sizes. These principles are necessary for long-term stability and texture control in quality cosmetic products.

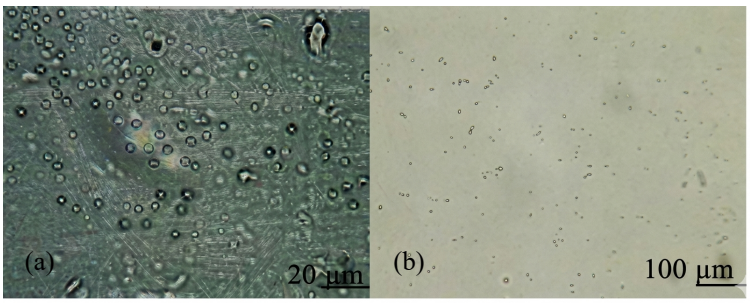

Fig. 4 Microscopic observation of (a) lotion and (b) facial cream containing 0.1% w w^{-1} banana peel extract.

In vitro skin irritation (OECD TG 439)

The skin irritation potential of the lotion and facial cream containing 0.1% w w^{-1} banana peel extract was evaluated using the Reconstructed Human Epidermis (RhE) test according to OECD TG 439. To ensure the reliability of the results, the assay validity criteria were strictly monitored. The negative control (DPBS) exhibited a mean optical density (OD), which is within the required range, and the tissue variability was acceptable (RSD ≤ 18%). The positive control (5% SDS) significantly reduced tissue viability, which is well below the 40% threshold defined by the guideline.

Regarding the test samples, the percent cell viability for the lotion and facial cream was observed that the initial absorbance values exceeded 100% compared to the negative control (Fig. 5). This phenomenon was identified as non-specific MTT reduction/optical interference caused by the formulation components rather than a biological increase in cell viability. Consequently, as per OECD TG 439 requirements, additional interference controls (killed tissue controls and non-specific color controls) were employed to correct the final viability data. Following these corrections, both formulations showed viability significantly higher than the 50% irritation cutoff, leading to their classification as "non-irritants" (UN GHS Category 3 or No Category) (Fig. 6).

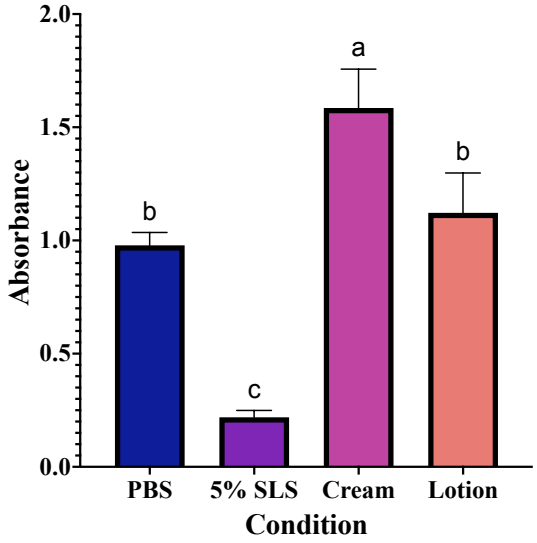

Fig. 5 Absorbance values under different conditions for in vitro skin irritation: Reconstructed Human Epidermis Test. Distinct letters (a,b,c) above the bars indicate statistically significant differences between groups ($p < 0.05$).

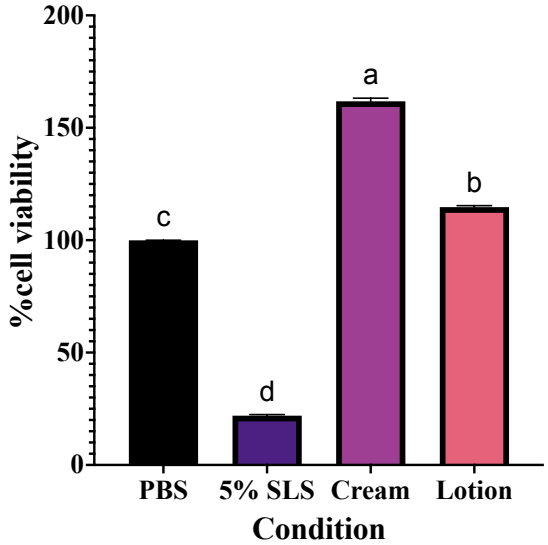

Fig. 6 Shows %cell viability of reconstructed human epidermis after 24 h of exposure to the test samples. Distinct letters (a,b,c,d) above the bars indicate statistically significant differences between groups ($p < 0.05$).

In the OECD TG 439 skin irritation test, the % cell viability exceeding 100% (e.g., in F1 and F2) is a known technical occurrence in MTT assays. This can result from the hormetic effect, where low levels of certain bioactive compounds in the extract slightly stimulate metabolic activity or mitochondrial dehydrogenase enzymes in the keratinocytes. Furthermore, it indicates that the formulations are exceptionally mild and non-cytotoxic to the reconstructed human epidermis (RHE), as they do not hinder cell metabolism compared to the negative control (DPBS)

Cytotoxicity Assay (HaCaT Cells)

The cytotoxicity of the banana peel extract was evaluated using the MTT assay on HaCaT keratinocytes. The extract was dissolved in dimethyl sulfoxide (DMSO) and further diluted with culture medium to a final concentration of 1,000 µg mL^{-1}, ensuring the final DMSO concentration remained below 0.5% (v v^{-1}) to avoid vehicle-induced toxicity. The solution was filtered through a 0.22-µm sterile membrane filter before application. Cells were treated with the extract for 24 hours, after which the MTT reagent was added. The resulting formazan crystals were dissolved in DMSO, and the absorbance was measured at 570 nm. The cell viability was interpreted according to ISO 10993-5:2009, where a reduction in viability of more than 30% (i.e., viability < 70% of the negative control) is considered a cytotoxic effect.

The MTT reduction assay is a well-accepted in vitro cytotoxicity test used to assess the safety of cosmetic products and their ingredients by measuring cell viability after exposure to a test substance. The assay relies on the enzymatic reduction of a yellow tetrazolium salt (MTT) to formazan by mitochondrial succinate dehydrogenase activity in metabolically active cells, and thus the amount of formazan formed is directly proportional to the number of viable cells [30]. Non-cytotoxic was defined based on the recommendation of ISO 10993-5 as well as from quoted references, where cell viability was >80%. The values of the cell viability between 60% and 80% indicate low toxicity, between 40 and 80 moderate cytotoxicity, while below 40 this cytotoxic effect is strong. Such passing criteria are common in cosmetic and topical product studies. In the HaCaT keratinocyte test systems, results with cell viability of over 70-80% at 24 h should be considered nontoxic [30 – 32].

Cytotoxicity was also determined for three cream preparations (cream base, lotion (0.1% w w^{-1} extract) and cream (0.1% w w^{-1} extract)) containing banana peel extracts at a concentration of 1000 µg mL^{-1} in HaCaT cells. The process involved dissolving the samples in DMEM 5% FBS and filtering and viability measurement of triplicates. In all the creams, results showed low cytotoxicity. The base with sample had the lowest cytotoxicity (average 1.29%) and the lotion (0.1% w w^{-1} extract) and cream (0.1% w w^{-1} extract) showed a higher activity (5.47% and 8.38%, respectively), all of them below the threshold value of 20% for cytotoxicity. This result indicates a lower toxicity to the skin cells at the tested concentrations, indicating that there is excellent formulation safety and biocompatibility.

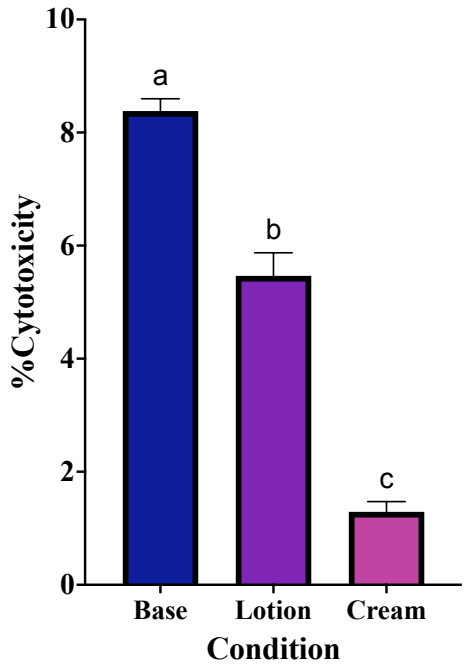

Fig. 7 Cytotoxicity of HaCaT cells after treatment with different formulations (Base, Lotion (containing 0.1% w w^{-1} extract), Cream (containing 0.1% w w^{-1} extract)) at a concentration of 1,000 µg mL^{-1}. Statistical significance was observed ($p < 0.05$).

As shown in Fig. 7, the cell viability after treatment with 1,000 μg mL^{-1} of banana peel extract, following the ISO 10993-5 standard, the extract is classified as non-cytotoxic, as the viability remained well above the 70% threshold. These results suggest preliminary cytocompatibility of the extract under the tested conditions. While these findings support the safety of the ingredient for topical application, further multi-concentration studies and long-term safety assessments would be required to fully substantiate extensive dermatological safety. The differences could be due to difference in formulation or the concentration of extract but, all were still fit for further development. Accordingly, these products meet international safety requirements for topical use and highlight the importance of broad cytotoxicity profiling to develop efficacious and safe dermatological treatments [30 - 32]. The cytotoxicity study on HaCaT cells was specifically conducted at 1,000 μg mL^{-1} as a 'limit test' to demonstrate the safety margin of the extract. Since no significant cytotoxicity was observed at this high concentration (the highest commonly used in standard screening for cosmetic ingredients), it can be inferred that the extract is safe for topical application at the much lower working concentration used in the final formulations (0.1% w w^{-1}). Testing at this peak concentration provides a robust assurance of biocompatibility without the necessity for a full dose-response curve in this preliminary safety screening.

4. Conclusion

This study successfully developed preliminary lotion and facial cream formulations containing 0.1% w w^{-1} banana peel extract (*Musa sapientum* L.). The formulations appeared to maintain their physical integrity without visible phase separation under the tested 30-day storage conditions. Microscopic observation suggested a qualitatively uniform dispersion of the emulsion microstructure, although further quantitative droplet size distribution analysis is required. Regarding dermatological safety, the in vitro skin irritation test according to OECD TG 439 classified both formulations as non-irritants, following necessary corrections for potential MTT interference. Furthermore, the extract showed no cytotoxicity toward HaCaT cells under the specific tested condition (24 h at 1,000 μg mL^{-1}). These results provide preliminary evidence of the cytocompatibility and physical stability of the developed green cosmetic products, serving as a baseline for future comprehensive dose-response and long-term stability assessments.

5. Suggestions

To advance the development and utilization of cosmetic formulations containing banana peel extract, future research should focus on optimizing active ingredient concentrations and evaluating long-term physical stability under various storage conditions. Expanding safety assessments to encompass additional skin models and broader in vivo investigations will provide more robust confirmation of low irritation and cytotoxicity. It is also important to study the antioxidant, anti-inflammatory, and other bioactive effects of banana peel extract to substantiate efficacy claims and support innovative functional cosmetic applications. Collaborations with dermatological experts and consumer panels will offer practical insights into real-world product performance and user acceptance. Finally, scaling up production and ensuring regulatory compliance are essential steps to enable successful market introduction and sustainable commercialization.

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7. Declaration of Generative AI in Scientific Writing

The authors maintain that during preparation of the manuscript all generative AI tools including language models were used only to enhance the overall coherence and readability of the English text. The manuscript was developed and analyzed by the authors, ensuring that the content is authentic and original.

8. CRediT Author Statement

Pranudda Pimsee contributed to conceptualization, methodology, investigation, data curation, formal analysis, visualization, and writing of the original draft. **Atittaya Meenongwa** contributed to methodology, investigation, data curation, formal analysis, and writing-review & editing. **Warongporn Rattanabun** contributed to investigation, data curation, visualization, and writing-review & editing. **Nichthima Warinthip** contributed to investigation, data curation, and writing-review & editing. **Pattaraphorn Panomai** contributed to investigation, resources, and data curation. **Wannisa Keawbankrud** contributed to supervision, project administration, and writing-review & editing. **Duangsuree Sanseera** contributed to investigation, validation, and data curation. **Supaporn Khangkham** contributed to methodology, validation, and writing-review & editing. **Pattarawat Kraipiyaset** contributed to conceptualization, supervision, resources, project administration, and writing-review & editing. **Wongnapa Nakyai** contributed to supervision, validation, and writing-review & editing. **Natnicha Phungsara** contributed to conceptualization, supervision, project administration and writing-review & editing.

9. Research Involving Human and Animals Rights

This research does not involve experiments on animals or humans.

10. Ethics Approval and Consent to Participate

Ethics approval was not required for this study because no experiments involving human subjects were conducted

11. Declaration of Competing Interest

The authors declare that they have no competing interests

12. References

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