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Green Innovation in Skincare: Harnessing Cucumber Peel Extract and Gel Base Selection for Enhanced Cleansing Mask Efficacy

Warongporn Rattanabun [a], Atittaya Meenongwa [a], Pranudda Pimsee [a], Nichthima Warinthip [a], Chonticha Jumneansree [a], Bencharat Wannapokhin [a], Panita Phoeiklin [a], Natnicha Phungsara [b], Wongnapa Nakyai [c] and Wannisa Keawbankrud [a*]

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

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

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

Abstract

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This study aimed to develop a cleansing mask incorporating cucumber peel extract by systematically comparing different base gels and surfactant systems. The extraction was performed by ethanol maceration followed by rotary evaporation, yielding a 6.45 ± 0.33% extract rich in phenolic and flavonoid compounds (26.62 ± 0.51 mg GAE g^{-1} dry extract and 14.96 ± 0.42 mg QE g^{-1} dry extract) and exhibiting antioxidant activity (DPPH IC_{50} = 380.67 ± 1.53 µg mL^{-1}; ABTS IC_{50} = 384.04 ± 1.94 µg mL^{-1}). Simple gel formulas were developed with bases of Hydroxyethyl cellulose, Carbomer SF1 and Aristoflex AVC, later combined with surfactant systems (SLS/CAB or MPE) containing different proportions of cucumber peel extract. The formulations were evaluated for physical properties, sensory attributes, stability, foaming power and microstructure. Carbomer SF1 gel with SLS and CB showed the best sensorial properties and foam quality, whereas Aristoflex AVC exhibited higher viscosity (3106.08 ± 105.83 cP) and stable appearance throughout the study period. Notably, the C1 (MPBE system) generated finer microfoam and superior cleansing efficacy, underscoring the impact of base and surfactant selection on cleansing performance, antioxidant delivery and consumer acceptability, and supporting the potential of agro-waste–derived extracts for multifunctional cosmetic masks.

*** Corresponding author** : Wannisa.k@mail.rmutk.ac.th

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1. Introduction

Cucumber extract has been gaining importance in skincare studies for its powerful antioxidant and moisture binding benefits. Cucumber is a natural and safe alternative to synthetic material as it contains abundant vitamin C, flavonoids, and phenolic compounds in accordance with demand for such components by consumers. Valorization of cucumber agro-waste, using peel for example, provides sustainability object in cosmetic science by enabling a renewable approach to bioactive molecule production [1, 2]. In particular, cucumber peel contains higher levels of phenolic acids, flavonoids (such as quercetin and kaempferol), vitamin C and dietary fiber than the inner pulp, and therefore exhibits stronger antioxidant, anti-inflammatory and skin-soothing activities than other parts of the fruit. Several studies have shown that extracts from cucumber peel can protect against oxidative damage, support epidermal hydration and contribute to skin-brightening effects, making this agro-waste fraction promising functional ingredient for topical formulations [3]. Recent research highlights the advantages and untold environmental impacts of cucumber extracts: its fruit and skin provide significant sources of bioactive compounds providing antioxidant, hydrating, and skin-brightening support. For one, high-performance liquid chromatography shows the quercetin and gallic acid content that help in melanin decrease while increasing our skin's hydration

levels. Additionally, biodegradable cosmetics and cucumber peel valorization to produce materials are emerging as a potential solution for the sustainability of the beauty industry in terms of a circular economy. In summary, these findings demonstrate the double value of cucumber extract: it is an efficient active ingredient in skincare products and a sustainable approach toward upcycling agricultural byproducts [4, 5].

However, when it comes to adding the cucumber extract to cleansing mask compositions many technical and sensory difficulties are encountered. The type of gelling agents and surfactant systems including Carbomer SF1, Aristoflex AVC and conventional surfactants including Sodium Lauryl Sulfate (SLS) and Cocamidopropyl Betaine play a significant role in imparting the stability, texture, foaming properties as well as compatibility with bioactive compounds of cucumber. Recent studies have highlighted the importance of a thorough assessment of such bases, and some may improve physical properties while not maintaining skin feel or antioxidant activity [1]. Further study also confirms the effect of base and surfactant choice on stability and activity of cosmetics containing cucumber extract. For example, a study on cucumber-aloe creams found that the formulations were characterized by adequate pH (6.5 ± 0.2) and viscosity stability values (13,200 cP) as well as good sensory characteristics; surfactant selection, however, was crucial to avoid phase separation and microbial contamination caused by their use. Finally, in a study analyzing gel masks formulated using black sea cucumber extracts, authors found an influence of type fig-5 of surfactant and emulsifier on the viscosity index, and homogeneity and long-term stability indices of plant extract gels when different formulations were considered (crude extract vs. solid lipid nanoparticles). This is further supported by a comprehensive work, which showed that in comparison to conventional surfactant-based thickeners, Carbomer could better stabilize emulsions and maintain the clarity and viscosity of gel with or without extracts or oil under study [6].

Despite the widespread cosmetic use of cucumber-derived ingredients in face washes and masks, most published work has focused on fruit or juice extracts and on basic product performance, with limited systematic comparison of peel-derived extracts incorporated into different gelling agents and surfactant matrices. Furthermore, there is a lack of data linking the composition and antioxidant activity of cucumber peel extract with the rheology, foam microstructure and sensory properties of cleansing mask formulations based on polymers such as Carbomer SF1 and Aristoflex AVC. The present work addresses this gap by correlating extract characteristics with the stability and user-relevant performance of cleansing masks containing cucumber peel extract [7]. In this study, prototypes of cleansing mask formulations with cucumber peel extract incorporated into different gel bases were systematically designed and compared in terms of their physicochemical, organoleptic and antioxidant properties. Results show that Carbomer SF1 gels in the presence of conventional surfactants deliver superior organoleptic properties and foam characteristics. In contrast, the Aristoflex AVC has much higher viscosity and formulation stability. These findings demonstrate that rational design for fabrication of consumer friendly and sustainable cleansing mask using cucumber extract as a versatile active ingredient is highly significant. Recent published data also confirms that Aristoflex AVC provides better viscosity, greater stability and good skin feel as compared to conventional Carbomer. Furthermore, Carbomer masks display good viscosity, transparent appearance and compatibility with plant-derived antioxidants on the skin-supporting, non-irritative and high-functional products. Studies have also demonstrated both the antioxidant function and hydrating/skin-soothing properties of cucumber extract, supporting its role as a key ingredient in modern multifunctional formulations [8-10]. Therefore, the present study aimed (i) to obtain and characterize an ethanolic extract of cucumber peel with respect to total phenolic and flavonoid contents and in vitro antioxidant activity, and (ii) to systematically develop cleansing mask prototypes incorporating this peel extract into different gel bases and surfactant systems, and to compare their physicochemical stability, foaming characteristics and sensory attributes. Cucumber peel was specifically selected because it represents a phenolic-rich by-product with documented antioxidant and skin-conditioning benefits, while facial cleansing masks were chosen as an appropriate vehicle that can simultaneously deliver antioxidants, remove surface impurities and fit current consumer demand for gentle yet effective skincare products [11].

2. Materials and Methods

Cucumber extraction

Fresh cucumber peel (*Cucumis sativus* L.) was purchased from Suan Plu Market, Thailand. It was washed cleanly, peeled and sliced into equal size of 1x1 cm. These samples were then dried at 50°C in a hot air oven for three days. After drying, the material was powdered and extracted by maceration with ethanol (1:4 w:v) for 7 days. The extract was filtered using Whatman No. 1 filter paper and the solvent was evaporated using a rotary evaporator. The crude extract was recovered and the yield (%) of crude extract was calculated. The extract was analyzed further [12]. The extract was measured in terms percentage yield as per equation (1):

$$\text{yield (\%)} = \frac{\text{weight of dried extract}}{\text{weight of dried cucumber peel powder}} \times 100 \quad (1)$$

Total phenolic content (TPC)

Total phenolic content of the extracts was determined by the Folin-Ciocalteu method. Sample solutions (1 mg mL^{-1}) were added in amounts ranging from 20–50 µL to a 96-well plate, then mixed with 100 µL of Folin-Ciocalteu reagent diluted 10-fold and with 75 µL of a sodium carbonate solution at 7.5%. The reactions were incubated in darkness at room temperature for 2 h and absorbance was measured

at 765 nm with a CLARIOstar® microplate reader (BMG LABTECH, Ortenberg, Germany). Gallic acid was used as the reference (5–100 μg mL^{-1}) to obtain a calibration curve and expressed in milligrams of gallic acid equivalents per gram of extract (mg GAE g^{-1} extract) [13].

Total flavonoid content (TFC)

Total flavonoids in the extracts were quantified by the aluminium chloride colorimetric method. Solutions of samples (1 mg mL^{-1}) were pipetted out (20–50 μL) to a 96-well plate. Then, 10 μL of the aluminium chloride solution (10% w v^{-1}) and 10 μL of 1 M sodium acetate were added, and the volume was made up to be 160–200 μL with ethanol. The mixtures were incubated in the dark at 25°C for 35 min, and then absorbance was determined at 415 nm with a CLARIOstar® microplate reader (BMG LABTECH, Ortenberg, Germany). Quercetin was used as a standard (5–100 μg mL^{-1}) and the results were expressed in milligrams of quercetin equivalent per gram of extract (mg QE g^{-1} extract) [14].

2,2-diphenyl-1-picrylhydrazyl (DPPH) assay

Measurement of antioxidant activity DPPH radical scavenging activity was performed to measure the antioxidant capability. In brief, the different amounts of samples were added in 96 well plate before adding to it 1 mM DPPH solution. The reaction mixture was further incubated at room temperature in the dark for 30 min, then the absorbances were recorded at 515 nm with a microplate reader. The free radical scavenging percentage was determined as;

$$\% \text{ free radical scavenging} = \frac{A_{control} - A_{sample}}{A_{control}} \times 100 \quad (2)$$

A sample = Absorbance of the sample or standard substance + DPPH
A control = Absorbance of methanol + DPPH

The standard was ascorbic acid. IC_{50} values were calculated with GraphPad Prism Version 10 (GraphPad Software, San Diego, US).

2,2'-azinobis-(3-ethylbenzothiazoline-6-sulfonic acid) (ABTS) assay

Antioxidant activity (ABTS assay) was determined. An ABTS solution (7 mM) and a potassium persulfate solution (2.45 mM) were mixed at a ratio of 1:0.5 for 12–16 h in the dark to prepare ABTS•+ radicals. The solution obtained was diluted with distilled water and extinction 0.70 ± 0.02 at 734 nm. In the assay, 20 μL of extract was mixed into the 96-well plate with 180 μL prepared ABTS solution. The absorbance was read at 734 nm after 6 min incubation in the dark at room temperature [15]. Standard for comparison was ascorbic acid. The percentage of inhibition was calculated using the following formula:

$$\%\text{inhibition} = [(A_{control} - A_{sample})/A_{control}] \times 100 \quad (3)$$

A sample = Absorbance of the sample or standard substance + ABTS
A control = Absorbance of methanol + ABTS

The IC_{50} value (the concentration needed to scavenge 50% radicals) was used to determine the antioxidant activity.

Preparation of Cleansing Mask Base Formulations

The gelling agents used were correctly weighed based on the target amounts as shown in **Table 1**. Hydroxyethyl cellulose was used as the gelling agent in F1. For Formula 2 (F2), Carbomer SF1 was used with 0.2% w/w triethanolamine added. In F3, Aristoflex AVC has been used. Each of the gelling agents was slowly added to the beaker with continuous stirring until it was completely dissolved. The mixture was then warmed through, to dissolve the gel. The resulting gels were then transferred into clean vials for further use.

Table 1 Basic Gel Base Preparation with Different Gelling Agents.

Ingredient	F1 %w w^{-1}	F2 %w w^{-1}	F3 %w w^{-1}	Function
DI water	Qs to 100	Qs to 100	Qs to 100	Solvent
Hydroxyethyl cellulose	0.5	-	-	Gelling agent
Carbomer (SF1)	-	0.5	-	Gelling agent
Aristoflex AVC	-	-	0.5	Gelling agent

Note: F1 = 0.5% w w^{-1} hydroxyethyl cellulose, F2 = 0.5% w w^{-1} Carbomer SF1, and formula F3 = 0.5% w w^{-1} Aristoflex AVC.

Procedure

The gelling agents were accurately weighed in the prescribed quantities. In F1, the gelling agent was hydroxyethyl cellulose. The F2 used Carbomer SF1 with the addition of 0.2% w w^{-1} triethanolamine. As gelling agent, Aristoflex AVC (Formula 3, F3). To the beaker, each gelling agent was slowly added with constant stirring until completely dissolved. The solution was warmed very gently until a clear gel formed. The gels that formed were then poured into clean beakers for further use.

Preparation of Cleansing Mask Extract Formulations

Two surfactant systems were evaluated: (i) 2% w w^{-1} sodium lauryl sulfate plus 4% w w^{-1} cocamidopropyl betaine, and (ii) a fluorosurfactant system in which 6% w w^{-1} of a 1:1 mixture of methyl perfluorobutyl ether and methyl perfluoroisobutyl ether replaced Sodium Lauryl Sulfate (SLS) and Cocamidopropyl Betaine (CB) at an equivalent total surfactant concentration. The cleansing mask formulations employed in the current experiments were prepared in different forms according to their surfactant matrix. Comparative Example Two different formulations were tested, Formula 1 comprising SLS and CB as the cleansers and Formula 2, Methyl Perfluorobutyl Ether and Methyl Perfluoroisobutyl Ether both serving as cleansing agents shown in Table 2.

Table 2 Cleansing mask formulation containing extract.

Ingredient	1 %w w^{-1}	2 %w w^{-1}	3 %w w^{-1}	Ingredient Function
Hydroxyethyl cellulose gel	2	-	-	Emulsifier
Carbomer SF1gel	-	2	-	Surfactant
Aristoflex AVC gel	-	-	2	Gelling agent
DI-Water	Qs to 100	Qs to 100	Qs to 100	Solvent
Sodium Lauryl Sulfate (SLS)	2	2	2	Surfactant
Cocamidopropyl betaine (CB)	4	4	4	Surfactant
Methyl Perfluorobutyl Ether and Methyl Perfluoroisobutyl Ether (MPIE)	6	6	6	Surfactant
Sodium Chloride	1	1	1	Surfactant
Glydant	1	1	1	Preservative

Note: 1 = 0.5% w w^{-1} hydroxyethyl cellulose, F2 = 0.5% w w^{-1} Carbomer SF1, and formula F3 = 0.5% w w^{-1} Aristoflex AVC.

Procedure

All six formulations were prepared: the first three used SLS and CB as surfactants, whereas the following three used MPBE and MPIE.

Gel base preparation

1. Weighed the required gelling agent (0.5% w w^{-1} hydroxyethyl cellulose, Carbomer SF1, or Aristoflex AVC) and slowly dispersed it into deionized water, which was less than the final batch weight.

2. Allowed the polymer to hydrate completely and adjusted the conditions (e.g. pH or mixing rate, as recommended by the supplier) until a uniform, bubble-free gel base was obtained.

Surfactant solution preparation

1. For the SLS/CB system, dissolved sodium lauryl sulfate (2% w w^{-1}) and cocamidopropyl betaine (4% w w^{-1}) in a portion of deionized water with gentle stirring until a clear solution formed.

2. For the MPBE/MPIE system, mixed methyl perfluorobutyl ether and methyl perfluoroisobutyl ether in a 1:1 ratio to give a total concentration of 6% w w^{-1} and dispersed this mixture in a suitable aqueous phase under moderate agitation to obtain a homogeneous fluorosurfactant solution.

Cleansing mask formulation

1. Combined the appropriate surfactant solution (SLS/CB or MPBE/MPIE) with each gel base (HEC, Carbomer SF1, or Aristoflex AVC) under slow to moderate stirring to minimize aeration and ensure uniform mixing.

2. Added sodium chloride (1% w w^{-1}) to adjust viscosity and then incorporated Glydant (1% w w^{-1}) as preservative, mixing until the formulation became homogeneous.

3. Adjusted the weight with deionized water to 100% w w^{-1}, mixed gently to obtain a smooth gel, inspected the appearance, and filled the cleansing mask formulations into suitable airtight containers for further evaluation.

In total, six cleansing mask formulations were prepared: three based on the SLS/CB system and three based on the MPBE/MPIE system, each using a different gel base (HEC, Carbomer SF1 or Aristoflex AVC) as shown in **Fig. 1**.

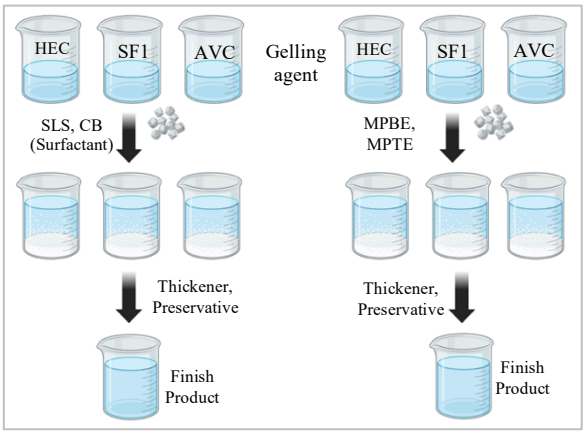


Fig. 1 Shows the steps involved in preparing the cleansing product.

Development of Cleansing Mask Products Containing Cucumber Peel Extract

The development of cucumber peel extract-containing cleansing mask products was performed through the selection of optimum base formulations. Just the sodium lauryl sulfate and cocamidopropyl betaine, and Methyl perfluorobutyl ether and methyl perfluoroisobixel ether formulations were chosen for following addition of cucumber in different concentrations. The first formulation contained 1% w w^{-1} cucumber peel extract, and the second contained 2% w w^{-1} cucumber peel extract, and both were evaluated for their physical properties (color, odour, pH, viscosity, phase separation, spreadability and foam formation). These formulations were systematically characterized and the results recorded.

Stability Test

Sensory Evaluation

Objective Sensory and product exterior attributes evaluation was conducted systematically. Evaluation criteria: appearance, color, odor, creamy soundness of washing mask, phase separation phenomena and spreadability.

Heating Cooling Cycle

Stability studies were conducted by exposing the product to alternate temperature changes for storage at 45°C and 4°C each for a period of 8 hours, repeated for three cycles [16,17].

Viscosity

The viscosity was measured by means of a viscometer and a % torque value near 100% was used for the highest accuracy. Measurements were taken at a speed of 4.0 rpm

using a No. 63 spindle and the tests were performed in triplicate [18].

pH

The pH of the mask product with cucumber extract (*Cucumis sativus* L.) was measured. The product was partitioned and tested at ambient temperature. The pH of the composition as measured should be in the range of about 4.5–5.5, that is generally within an acceptable value or for skin compatibility).

Statistical Analysis Used in Testing

All the experiments were performed three times. Mean ± standard deviation provided results in conjunction with standard error. All statistical analysis was performed using **GraphPad prism 10.**

3. Results and Discussion

Results of Cucumber Extraction

Cucumber peels (*Cucumis sativus* L.) were dried at 50°C for three days, producing a fine green powder (**Fig. 2a**), indicating that the pigments and phytochemicals were stable and maintained in the dehydrated samples. This observation is consistent with reports that hot-air drying at moderate temperatures (50-60°C) can preserve chlorophylls and phenolic compounds in vegetable peels when exposure times are controlled. Several studies on cucumber and other cucurbit peels have shown that shade or low-temperature oven drying maintains antioxidant phytochemicals with minimal degradation [19-21]. To this, maceration in ethanol for one week was conducted and resulted with evaporation to rotary, where a thick extract dark green was obtained with slightly odor (**Fig. 2b**). The physical features of the raw materials (green color and fine powder form) as well as a highly viscous and colored extract was obtained can be attributed to retained chlorophyll, phenolics and other active contents which are characteristic for agro-waste peels upon botanical extraction. The intense green color of the extract can be attributed to retained chlorophylls together with conjugated phenolics and other chromophoric phytochemicals that are characteristic of vegetable peels obtained by ethanolic extraction. Similar correlations between peel extract color, chlorophyll phenolic content and antioxidant capacity have been reported for cucumber and other fruit and vegetable by-products [22, 23].

The crude extract was collected at 6.45 ± 0.33% and a very slightly acidic pH of 5.33 ± 0.47. This yield of approximation coincides well with the literature reporting on similar agro-waste extractions. Ethanol maceration is said to be effective in solubilising a wide range of bioactive molecules like flavonoids and ascorbic acid which affects the colour and viscosity of the extract. It puts forward these advantages as possible reasons why cucumber seeds and peels could be used to produce antioxidant rich extract varieties that have strong antimicrobial activity which can serve in further valorizations as renewable sources of natural active agents in food or cosmetic usages [1, 18].

(a) (b)

Fig. 2 Shows Physical characteristics of cucumber samples; (a) finely ground cucumber peel powder and (b) concentrated cucumber extract.

Total phenolic and flavonoid content

The total phenolic and flavonoid contents in the ethanolic cucumber peel extract were 26.62 ± 0.51 mg GAE g^{-1} dry extract (DE) and 14.96 ± 0.42 mg QE g^{-1} dry extract (DE), respectively (**Fig. 3**). These results are very consistent with previous research. For instance, few studies showed that ethanol extracted cucumber peel had a content of 51.95 ±10.61 mg GAE g^{-1} dry extract which is in agreement with ours given the sample preparation and natural diversity [24]. The analysis of total phenolics by the Folin–Ciocalteu method is based on a redox reaction where under alkaline conditions, phenolic compounds such as gallic acid (calibration standard), donate electrons to reduce a phosphomolybdic–phosphotungstic acid complex that is contained in the reagent. This reduction leads to the production of a blue-colored molybdenum–tungsten complexes whose intensity, measured spectrophotometrically, is proportional to the phenolic content [25].

Also, the total flavonoid content obtained from ethanolic cucumber peel extract (14.96 ± 0.42 mg QE g^{-1} dry extract) is closely related to that of 14.02 mg QE g^{-} of dry weight [26]. In particular, their findings further highlighted superior quantities of phenolic and flavonoid content in peel extracts than other cucumber parts [26]. The commonly used colorimetric method of assaying flavanoids with aluminium chloride ($AlCl_3$) entails an acidic stable complexation between $AlCl_3$ and the C-4 keto and C-3 or C-5 hydroxyl groups of flavonoids. When quercetin (representative of the calibration standard) reacts with $AlCl_3$, a complex is formed that is yellow in color whose absorbance depends directly upon flavonoid content [27, 28] and read between 415 and 430 nm.

Antioxidant activity

The DPPH assay yielded an IC_{50} of 380.67 ± 1.53 µg mL^{-1} for cucumber peel extract, which is in the same order of magnitude as values reported for cucumber and other vegetable peel extracts obtained with hydroalcoholic solvents [29] as shown in **Fig. 3**; this is relatively good agreement with the present result. The DPPH method is a

commonly used technique to assess the antioxidant potential of plant extracts by determining their ability to reduce stable purple-coloured DPPH radical (1, 1-diphenyl-2-picrylhydrazyl) which is either bleached or become pale yellow upon acceptance of hydrogen atoms or electrons donated on the part of an antioxidant molecules present in the test sample. The discoloration degree is direct evidence of the radical scavenging capacity of the sample; hence, providing a basis for quantifying the IC_{50} value—concentration required to reduce DPPH radicals by 50% in vitro [30, 31].

Likewise, the 2,2′-azinobis-(3-ethylbenzothiazoline-6-sulfonic acid) (ABTS) system used to evaluate antioxidant activity gave an IC_{50} value of 384.04 ± 1.94 µg mL^{-1} for cucumber peel extract as shown in **Fig. 3**. This result is consistent with previous findings. For example, ABTS IC_{50} of 1.0 ± 0.1 mg mL^{-1} (1000 ± 100 µg mL^{-1}) for methanol extracts from fruit and vegetable peels such as that of cucumber [32]. The lower IC_{50} value in this study suggests the higher ABTS radical scavenging ability of ethanolic extract than that of the methanolic extract and may be due to differences in plant source or pretreatment method, however, both are within same order of magnitude [33]. The ABTS assay assesses radical scavenging activity based on measurements of the reduction in absorbance of the ABTS radical cation (dark blue green) at 734 nm because of treatment with antioxidants in a sample. The resulting decrease—together with electron or hydrogen donation—converts the ABTS radical to a stable, colorless state and the decrease in absorbance is directly proportional to antioxidant content [34, 35].

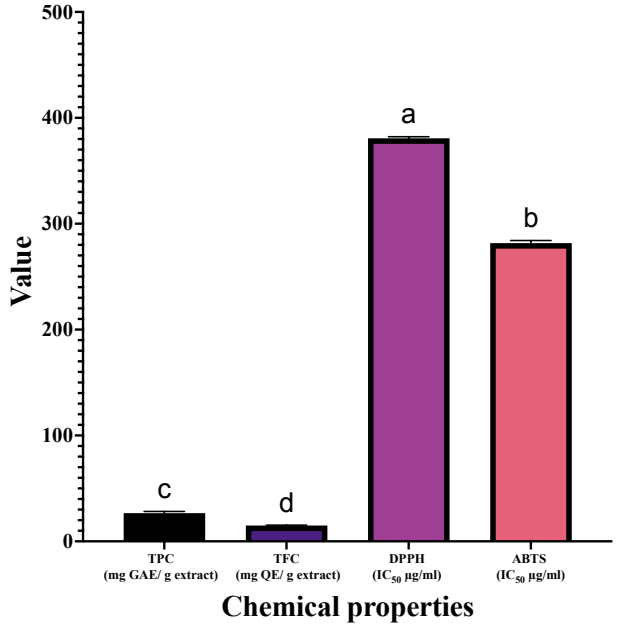


Fig. 3 Shows chemical properties of cucumber extract.

Formulation of Mask bases

Generation of bases for masks using different gelling agents led to sizeable variations in physical attributes and user feel. The three compositions involved gelling agents into the hydrogel-Hydroxyethyl cellulose (HEC), Carbomer SF1 and Aristroflex AVC. Notably, the formulation Carbomer SF1 resulted in a clear gel appearance with a thin luster showing an excellent touch perception relative to other formulations. This is an indication of improved user reception and the feasibility of marketing. The HEC gel was clearer but less viscous, which might affect the stability of its application. Both Carbomer and Aristroflex AVC vehicles were frosted with air bubbles: The Aristroflex vehicle, however, gave the gel a more finished character than did the Carbomer vehicle for proteins, suggesting that a choice between optical transparency and smoothness of feel was required. These results underscore the importance of choosing proper gelling agents to improve not only the aesthetic but also the mechanical properties in cosmetic products, as shown in **Fig. 4**.

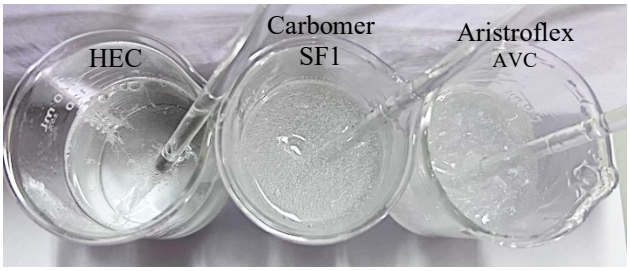


Fig. 4 Shows the physical characteristics of the base formulation.

Evaluation of Product Efficacy

The results indicate that all three base formulations—HEC, Carbomer, and Aristoflex AVC—exhibited stable pH and viscosity within the tested period, as there were no significant changes after the stability assessment. Aristoflex AVC had the greatest apparent viscosity followed by Carbomer, and HEC. There were significant differences between the samples with varying pH and viscosity values (a-e) [36]. Aristoflex AVC maintains viscosity better and more consistently than traditional thickeners e.g. HEC and Carbomer providing improved base polymer stability and rheology for topical or cosmetic formulations. These results are consistent with the recent research findings that Aristoflex AVC is a next-generation gelling agent which is capable of forming highly stable emulsions and cream gels without the introduction of additional emulsifying agents. When in the form of a cross-linked polymer, it effectively captures oil droplets and pigments resulting in stabilization and improved texture of the formulation [37]. Though Carbomer gels are reported to provide moderate-to-high viscosity and adequate pH stability, however, Aristoflex AVC performed better in each aspect as established here.

The pH ranges investigated in this case (5.5–6.0; **Table 3**) are the best and make good sense for skin compatibility, low irritancy potential and intended use in a topically-applied dosage form or cosmetic [38]. Containing Carbopol (Carbomer), Natrosol (HEC analog), and Aristoflex AVC in bleaching gels, confirming that Aristoflex AVC maintains gel performance while preserving surface properties and stability more effectively than Carbopol or Natrosol. This study reinforces the finding that Aristoflex AVC contributes to higher performance in maintaining desired physical properties and formulation stability [10]. Literature also describes the superior stabilizing effects of Aristoflex AVC in oil-in-water emulsions and its ability to impart non-sticky, creamy textures—attributes beneficial for consumer acceptance in personal care products [39].

Table 3 Stability Test of Base Formulations.

Parameter	pH (Mean ±SD)	Viscosity (Mean ± SD)	Centrifuge	Heating - Cooling
F1 (HEC)	5.53 ± 0.02^{a}	1282.67 ± 63.26^{a}	-	-
F2 (Carbomer)	5.90 ± 0.01^{b}	2307.33 ± 94.88^{b}	-	-
F3 (Aristoflex AVC)	5.78 ± 0.03^{c}	3106.08 ± 105.83^{c}	-	-

Notes: – = no significant change observed. Viscosity measured using Spindle No. 61 at 10 rpm with % torque = 95. Superscript letters a, b, c indicates statistically significant differences ($p < 0.05$) between means in each column. Values with different letters are significantly different.

Cleansing Mask bases

The results indicate that the surfactant base compositions—Hydroxyethyl cellulose (HEC), Carbomer, and Aristoflex AVC—demonstrate varied effects when combined with cleaning agents such as Sodium Lauryl Sulfate (2%) and Cocamidopropyl Betaine (4%) as shown in **Fig. 5**. Notably, the type of gel base influences the properties of the foam, tactile sensation, and skin compatibility. Gels with Carbomer as the base exhibit the most favorable skin feel and foam fineness when paired with Methyl Perfluorobutyl Ether surfactant, while bases with added sodium lauryl sulfate and cocamidopropyl betaine enhanced cleansing performance and skin compatibility, as shown in **Fig. 6**. enhance cleansing performance and skin compatibility. Altogether, Carbomer gels (SF1) perform better in terms of consumer sensory attributes. Recent studies have confirmed that Carbomer gels exhibit superior sensory and texture attributes, with users preferring their thickening profile, absorbency and feel upon use. Texture and sensory characterization results are additional support for the extended use of Carbomer gels in personal care applications due to their stability, robustness, and minor changes in foam structure during repeated treatments. Surfactant blends with Sodium Lauryl Sulfate and Cocamidopropyl Betaine are well documented for producing gentle, non-irritating cleansing formulations; these blends retain skin moisture and optimize cleansing performance. Moreover, shower gel formulations containing 2-50% Sodium Lauryl Sulfoacetate and 1-30% Cocamidopropyl Betaine show excellent mildness and moisture retention when tested on human skin, confirming their suitability for sensitive skin applications.

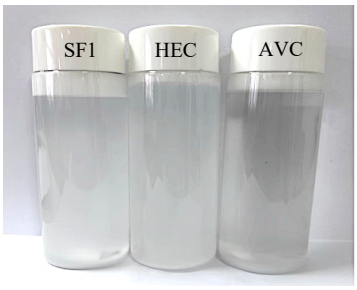


Fig. 5 Shows the appearance characteristics of the base formulation containing 2% Sodium Lauryl Sulfate and 4% Cocamidopropyl betaine.

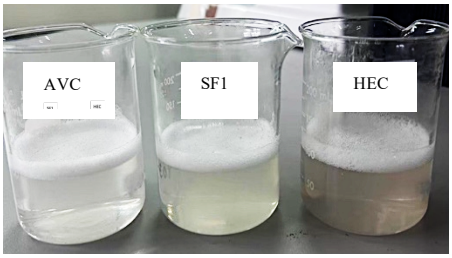


Fig. 6 Shows the appearance characteristics of the base formulation containing 6% Methyl Perfluorobutyl Ether (and) Methyl Perfluoroisobutyl Ether.

Cleansing Mask containing cucumber extract

A cleansing mask was developed by incorporating 1% and 2% w w^{-1} cucumber peel extract into the selected base formulations. The containing 2% Sodium Lauryl Sulfate and 4% Cocamidopropyl Betaine, and another containing 6% Methyl Perfluorobutyl Ether (and) Methyl Perfluoroisobutyl Ether. After evaluating all formulations, the optimal base and cucumber peel extract concentration were selected. The results show that a Carbomer gel base (SF1) with Sodium Lauryl Sulfate and Cocamidopropyl Betaine provided better hand feel and frothiness compared to formulations containing the Methyl Perfluorobutyl Ether analogues. Two optimized cleansing mask formulations were selected: C1, containing 6% MPBE/MPIE and cucumber peel extract, and C2, containing 2% SLS and 4% cocamidopropyl betaine with the same level of cucumber peel extract. Although the two structures have harshly difference in physical properties C1 with smaller bubbles, low viscosity and little odour (as described as mild aroma), and C2 with similar sized particles to C1 but a much higher volume like dense foam C2 are preferentially used for more cleansing applications as shown in **Fig. 7**. Carbomer gels containing sodium lauryl sulfate (SLS) and cocamidopropyl betaine are well known in the art due to their good hand feel and foaming, improved stability, as well as cleansing performance. Cocamidopropyl

Betaine acts as a synergistic foam enhancing agent with anionic surfactants such as Sodium Lauryl Sulfate by increasing foaming efficiency without compromising mildness for sensitive skin [36, 37]. Rather, Methyl Perfluorobutyl Ether provides a silky, smooth texture and may help to build on the skin a protective film which reaches over-water repellence together with refinement of texture and good after feeling. The foaming ability of this system is less than that Classical. These results are consistent with previous studies in properties of foam, surfactant-boosting effects as well as the safety of cosmetics by Cocamidopropyl Betaine and Methyl Perfluorobutyl Ether. Cumulatively, these findings highlight the unique functions contributed by each surfactant system in innovative consumer personal care products allowing for those wherein foaming and cleansing or sensory feel attributes are most relevant to be optimized according to formulation needs.

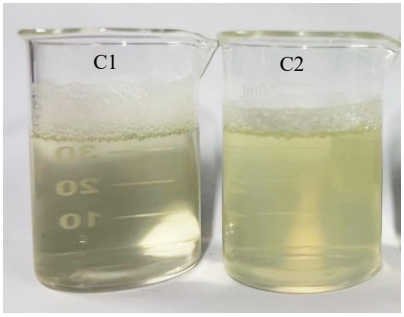


Fig. 7 Shows the cleansing formulations containing cucumber extract. C1 refers to the formulation containing Methyl Perfluorobutyl Ether (and) Methyl Perfluoroisobutyl Ether, while C2 refers to the formulation containing Sodium Lauryl Sulfate and Cocamidopropyl betaine.

Efficacy Testing of the Cleaning Gel Product Physical Property Testing Results of the Cleaning Gel Product

Table 4 Physical property testing of the cleaning gel product.

Formula	pH		Viscosity		Centrifuge		Heating-Cooling
Time	W_0	W_4	W_0	W_4	W_0	W_4	
C1	5.81 ± 0.04[a]	5.80 ± 0.05[a]	77.4 ± 1.09[a]	76.7 ± 0.5[a]	-	-	-
C2	5.98 ± 0.05[b]	5.98 ± 0.05[b]	110. ± 0.62[b]	111. ± 1.08[b]	-	-	-

Notes: C1 = the formulation of Methyl Perfluorobutyl Ether (and) Methyl Perfluoroisobutyl Ether, C2 = the formulation of Sodium Lauryl Sulfate and Cocamidopropyl Betaine. W0 = after fresh preparation, W4 = after 4 weeks. Superscript letters ([a], [b]) that differ indicate statistically significant differences ($p < 0.05$). No changes observed: Viscosity (Spindle No.6, 10 rpm, %Torque = 95). - = No changes observed.

The physical property testing results for the cleaning gel products demonstrate notable differences in pH and viscosity between formulas containing Methyl Perfluorobutyl Ether (C1) and those containing Sodium Lauryl Sulfate combined with Cocamidopropyl Betaine (C2). After both fresh preparation and 4 weeks of storage, C2 exhibited slightly higher pH and significantly higher viscosity compared to C1, with these differences statistically significant ($p < 0.05$). This is consistent with the known synergistic interactions of Sodium Lauryl Sulfate and Cocamidopropyl Betaine on foaming and viscosity by themselves. This dually results in a more viscous gel matrix and improved stability of the formed gels over time [40, 41].

The findings also show that for both formulations, no considerable variations were observed in their physical properties as determined by centrifugation and heating-cooling cycles; hence physical stability of the two products was maintained under accelerated storage conditions. Centrifugation and temperature cycling as stability tests are routine for the testing of cosmetic gels to demonstrate constant viscosity and phasic homogeneity, both of which are important concerning safety and quality for consumer protection. It is for these reasons (resistance to both phase separation and viscosity loss) that they are well suited for practical applications [41,42].

Additionally, Methyl Perfluorobutyl Ether is recognized for its ability to impart smoothness and a non-greasy texture to cosmetic formulas, making C1 ideal for skincare applications. However, as a highly synthetic fluorinated compound, its environmental and long-term safety profile requires careful consideration.

Structural characteristics of cleansing mask products

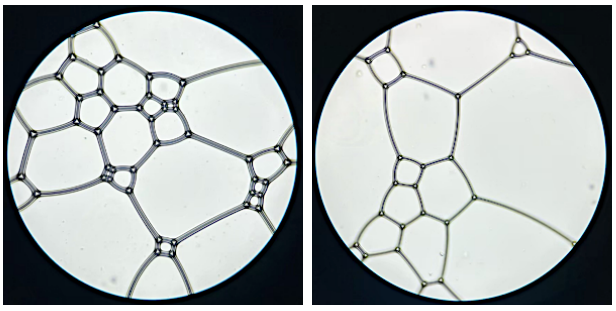
The microscopic examination compared the foam structure of cleansing gel bases made with Methyl Perfluorobutyl Ether (C1) and with Sodium Lauryl Sulfate plus Cocamidopropyl Betaine (C2) at 10x magnification as shown in **Fig.8**. It was obvious from the results that the foam produced by C1 had much denser and finer bubbles, indicating more uniform and stable structure of foam. This compact microbubble composition is believed to strengthen washing power through improved contact with dirt on a work piece and enable the cleaning of more sensitive skin.

These observations are supported by previous research and ingredient data. Methyl Perfluorobutyl Ether, a fluorocarbon compound is well known for its use in providing lubrication and smoothness and stability to cosmetic foams. Microbubble generation low surface tension greatly increases cleaning power and enhances feel. This ingredient is often found in higher quality cosmetics because it creates a lasting, micro-bubble foam that allows for smooth product spread.

C2, however produces bigger but less dense bubbles, thanks to the combination for Sodium Lauryl Sulfate and Cocamidopropyl Betaine. Although these surfactants are gentle and promote substantial foaming and cleaning, they may not accomplish the smoothness and microfoam aesthetic appearance similar to that of C1. These properties become important when dealing with cosmetic cleansers meant for gentle usage or high cleaning action [42].

In summary, using Methyl Perfluorobutyl Ether in cleansing gels can produce microfoam with a more robust and smaller bubbles that could offer milder feeling of usage and strong adsorption power to dirt and impurities than

traditional SLS-betaine systems. This aligns with current cosmetic innovation trends prioritizing both skin feel and high-level cleansing.



(a) (b)

Fig. 8 Structural characteristics of cleansing mask foams: (a) formulation C1 (MPBE/MPIE system) and (b) formulation C2 (SLS/CB system) observed under 10× magnification.

4. Conclusion

Ethanol extraction of cucumber peel yielded 6.45 ± 0.33% extract with preserved pigment and phytochemical content. Specifically, the total phenolic and flavonoid contents were 26.62 ± 0.51 mg GAE g^{-1} dry extract and 14.96 ± 0.42 mg QE g^{-1} dry extract, respectively, thereby confirming strong antioxidant (DPPH IC_{50} = 380.67 ± 1.53 μg mL^{-1}; ABTS IC_{50} = 384.04 ± 1.94 μg mL^{-1}) and bioactive properties. Among mask base gels, it was found that Carbomer SF1 produced a translucent, superior-feeling gel, whereas Aristoflex AVC achieved the highest viscosity (3106.08 ± 105.83 cP), and Carbomer offered greater clarity compared to Aristoflex AVC and HEC. Furthermore, stability testing of base formulations showed no significant change in pH (5.53 – 5.90) or viscosity across 4 weeks for Aristoflex AVC, Carbomer, and HEC, with Aristoflex AVC maintaining the greatest stability and optimal rheological properties for cosmetics. In addition, experiments of cleansing mask prototypes with 2% Sodium Lauryl Sulfate and 4% Cocamidopropyl Betaine (C2) or 6% methyl perfluorobutyl ether (C1), both 1–3% cucumber extract included, showed C2 produced richer foam with a lower spread volume and could make more delicate bubbles than those produced from C1 but had good stability. It was also observed that C2 formulations had higher viscosity (77.49–76.7 cP for C1 vs. 110.16–111.49 cP for C2), and both formulations were stable under centrifuge treatment and thermal cycling stress for four weeks. Crucially, cleansing efficacy studies showed that C1 lab-scale prototypes had a better cleaning performance on artificial staining compared with commercial product C2 while the C2 gel formulation offered milder skin cleansing and uniform foam properties in the context of consumer preference. Also, as observed under the microscope at 10× magnification, C1 generated microbubbles whose density and fineness were higher than those generated by C2; thus, their cleaning capability was enhanced with more delicate tactile sensation than those obtained from larger and less dense bubbles of C2. In conclusion, cucumber peel ethanol extract possesses very good antioxidant activity and can be incorporated into optimized cleansing mask formulations without compromising aesthetic stability. The optimized formulations containing cucumber peel ethanol extract in Carbomer and Aristoflex AVC bases combine antioxidant delivery with desirable rheological and sensory characteristics. Surfactant base C2 in foam formation and viscosity, while C1 achieves finer microfoam and strong cleansing. Thus, these properties provide versatile options for the development of effective, consumer-friendly cleansing masks.

5. Suggestions

Based on these findings, further development and optimization of cleansing mask formulations containing cucumber extract and advanced surfactants, such as Methyl Perfluorobutyl Ether or synergistic blends of Sodium Lauryl Sulfate and Cocamidopropyl Betaine, are strongly encouraged. Harnessing the antioxidant and antimicrobial benefits of cucumber extract, together with innovative gel bases that enhance cleansing efficacy, tactile sensation, and microfoam stability, will support the creation of next-generation cosmetic products. Such formulations have great potential to meet consumer expectations for both gentle skin care and superior cleansing performance, while also promoting market competitiveness through improved sensory profiles and proven stability under various storage conditions.

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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

Warongporn Rattanabun and Atittaya Meenongwa had a substantial contribution to the conception and design, supervision of research. Nichthima Warinthip, Pattaraphorn Panomai, Chonticha Jumneansree, Bencharat Wannapokhin, Panita Phoeiklin and Natnicha Phungsara investigated and curated the data and wrote the first draft of the manuscript. Wannisa Keawbankrud organized the project administration and contributed substantially to the review and editing of the manuscript. All co-authors have read and approved the final manuscript.

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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