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Formulation and Evaluation of Moisturizing Stick Containing a Combination of *Aloe vera* (*Aloe barbadensis*) and Chamomile (*Matricaria recutita*) Dry Extracts

Formulasi dan Evaluasi Stick Pelembab yang Mengandung Kombinasi Ekstrak Lidah Buaya (*Aloe barbadensis*) dan Chamomile (*Matricaria recutita*)

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ABSTRACT

Aloe vera (*Aloe barbadensis* Mill.) and chamomile (*Matricaria recutita* L.) extracts contain aloin and apigenin, compounds known for their moisturizing, soothing, and antioxidant properties that help reduce oxidative stress in the skin. This study aimed to obtain the optimal formulation of a moisturizing stick containing *Aloe vera* and chamomile dry extracts based on physical characteristics, moisturizing effectiveness, and antioxidant activity. Dry extracts were prepared by percolation using 96% ethanol, followed by spray drying and standardization. The optimal formulation was determined using a 2^2 factorial design with *Aloe vera* (10–20%) and chamomile (5–15%) extracts. The stick formulation was prepared by hot-melt extrusion and evaluated for hardness, spreadability, moisturizing effectiveness (AUC) using a sorption–desorption method, and antioxidant activity (IC_{50}) using the DPPH assay. The optimal formulation contained 18.711% *Aloe vera* extract and 8.167% chamomile extract.

ABSTRAK

Ekstrak lidah buaya (*Aloe barbadensis* Mill.) dan kamomil (*Matricaria recutita* L.) mengandung senyawa aktif aloin dan apigenin yang diketahui memiliki sifat pelembap, efek menenangkan (soothing), serta aktivitas antioksidan yang dapat membantu mengurangi stres oksidatif pada kulit. Penelitian ini bertujuan untuk memperoleh formula optimum stik pelembap yang mengandung ekstrak kering lidah buaya dan kamomil berdasarkan karakteristik fisik, efektivitas pelembapan, dan aktivitas antioksidan. Ekstrak kering diperoleh melalui perkolasi menggunakan etanol 96%, kemudian dikeringkan dengan metode *spray drying* dan distandarisasi. Formula optimum ditentukan menggunakan rancangan faktorial 2^2 dengan variasi konsentrasi ekstrak lidah buaya (10–20%) dan kamomil (5–15%). Sediaan stik dibuat dengan metode *hot-melt extrusion* dan dievaluasi meliputi kekerasan, daya oles, efektivitas pelembapan (AUC) menggunakan metode *sorption–desorption*, serta aktivitas antioksidan (IC_{50}) menggunakan metode DPPH. Formula optimum mengandung 18,711% ekstrak lidah buaya dan 8,167% ekstrak kamomil.

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1. INTRODUCTION

Skin is the largest organ and serves as the primary protector against environmental stressors such as wind, pollution, ultraviolet (UV) radiation, and free radicals. Exposure to these stressors may lead to skin problems, including dryness and irritation; therefore, moisturizing agents are required to maintain hydration of the stratum corneum, strengthen the skin barrier, and prevent irritation (Choi et al., 2020). Under extreme environmental conditions, additional soothing ingredients such as antioxidants are needed to provide greater protection against oxidative processes by reducing oxidative stress caused by reactive oxygen species (ROS). This mechanism may consequently delay the skin aging process (Ainurofiq et al., 2023; Shane, 2023).

A combination of moisturizer and antioxidant can be obtained from natural ingredients such as *Aloe vera* extract (*Aloe barbadensis* Mill.) and chamomile extract (*Matricaria recutita*). *Aloe vera* extract is rich in polysaccharides and aloin, which support skin cell regeneration and act as soothing agents while protecting the skin from water loss. Meanwhile, apigenin, the active compound in chamomile, functions as a natural antioxidant that neutralizes free radicals and prevents cellular damage caused by oxidative stress (Yoon et al., 2023). Natural ingredients are generally considered gentler and safer than synthetic counterparts while exhibiting comparable bioactivity (Manful et al., 2024). Previous studies reported that a 10% *Aloe vera* hydrogel formulation effectively maintains skin moisture (Chelu et al., 2023), while chamomile extract demonstrates antioxidant activity with an IC_{50} value of 1.19 µg/mL (Al-Snafi & Hasham, 2023; Catani et al., 2021; Michalak, 2022). In the cosmetics industry, stick-type skincare products have recently gained popularity due to their ease of use, hygiene, portability, and stability. However, studies investigating moisturizing stick formulations containing a combination of *Aloe vera* and chamomile extracts with optimized concentrations and comprehensive evaluation of both moisturizing effectiveness and antioxidant activity remain limited. Therefore, this represents an important research gap in the development of multifunctional stick-based skincare formulations.

Dry extracts were selected because they exhibit higher microbial stability and better preservation of active compounds during storage and processing (Jaiswal et al., 2021). In this study, a moisturizing stick containing a combination of dry *Aloe vera* extract and chamomile extract was developed. This formulation was hypothesized to provide dual benefits, namely enhancing skin hydration and protecting the skin from oxidative stress. A factorial design approach using Design-Expert version 12.0 software was employed to determine the optimal moisturizing stick formulation with two main factors, namely the concentrations of *Aloe vera* extract (10–20%) and chamomile extract (5–15%). The novelty of this study lies in the development and optimization of a multifunctional moisturizing stick combining *Aloe vera* and chamomile dry extracts using factorial design to simultaneously evaluate physical quality, moisturizing effectiveness through the sorption–desorption test (SDT), and antioxidant activity using the DPPH method. Therefore, the objective of this study was to determine the optimal formulation of a moisturizing stick containing *Aloe vera* and chamomile extracts based on physical characteristics, moisturizing effectiveness, and antioxidant activity.

2. METHODS

2.1. Materials and Equipment

Aloe vera extract was obtained from PT Berkah Alam Nusantara (Garut, West Java, Indonesia), while dry chamomile flower extract (*M. recutita*) was obtained from CV Seduh Tisane Nusantara (Bekasi, West Java, Indonesia). Dry extracts of *Aloe vera* and chamomile were produced using a spray-drying method with water as the solvent and maltodextrin as the carrier. The extract-to-maltodextrin ratios were 6:1 and 10:1 (w/w) for *Aloe vera* and chamomile extracts, respectively.

The solvents used were of pharmaceutical grade and included 96% ethanol, methanol (pro analysis), isopropanol, ethyl acetate, formic acid, and toluene (Merck, Darmstadt, Germany), as well as DPPH (Sigma-Aldrich, USA) and distilled water. Other materials used were white petrolatum (Rose Polymer Company, Singapore), cetyl alcohol (Techbo Pharmachem, India), lanolin (Wujiang Pitsch LLC, China), white beeswax (Spectrum Chemical MFS Corp., Singapore), cetyl ester wax (PT BASF, Indonesia), carboxymethyl cellulose (CMC), and isopropyl myristate (PT Brataco Chemica, Indonesia).

The equipment used included an oven and water bath (Memmert, Schwabach, Germany), Sartorius BP110S analytical balance (Sartorius, Göttingen, Germany), UV lamp (254/366 nm; CAMAG, Muttenz, Switzerland), silica gel 60 F254 TLC plates (Merck, Darmstadt, Germany), Multiskan GO spectrophotometer (Thermo Fisher Scientific, Waltham, USA), Centurion 1020 centrifuge (Centurion, Chichester, UK), micropipettes (Socorex, Ecublens, Switzerland), 96-well microplates (Iwaki, Tokyo, Japan), and a Shore A durometer (HUATEC, Beijing, China).

2.2. Standardization of Dry Extracts

Dry extracts of *Aloe vera* and chamomile were selected to ensure improved microbial stability and preservation of active compounds during storage and processing (Ainurofiq et al., 2021). Prior to formulation, both extracts were standardized using specific and non-specific parameters.

Non-specific parameters included water content (oven method, 105°C), total ash content (800 ± 25°C), acid-insoluble ash using dilute HCl, and water-soluble ash. Specific parameters included organoleptic characteristics, physical properties, pH, and the determination of water-soluble and ethanol-soluble extractive values (Dirjen POM, 2000).

2.3. Identification of Aloin and Apigenin by Thin-Layer Chromatography

The presence of aloin and apigenin in the dry extracts of *Aloe vera* and chamomile was confirmed using thin-layer chromatography

(TLC). Silica gel 60 F254 plates were used as the stationary phase. The mobile phase for aloin consisted of ethyl acetate:methanol:water (9:1:0.5, v/v/v), whereas the mobile phase for apigenin consisted of toluene:ethyl acetate:formic acid (7:2.5:0.5, v/v/v). One gram of dry extract and 3 g of moisturizing stick sample were dissolved in ethanol as test solutions. TLC spots were visualized under UV light at 254 nm for aloin and 366 nm for apigenin. The theoretical Rf values were 0.78 for aloin (blue-green fluorescence) and 0.44 for apigenin (bluish-yellow fluorescence) (Kemenkes RI, 2017).

2.4. Factorial Experimental Design

A complete 2^2 factorial design was used to determine the optimal formulation of the moisturizing stick. The independent variables were *Aloe vera* extract concentration (10–20%, XA) and chamomile extract concentration (5–15%, XB). The evaluated responses were hardness (Y_1), spreadability (Y_2), moisturizing effectiveness expressed as AUCtotal (Y_3), and antioxidant activity expressed as IC_{50} (Y_4).

2.5. Preparation of Moisturizing Stick

Four moisturizing stick formulations were prepared using the hot-melt extrusion (HME) method (**Table 1**). Lanolin was prepared by mixing adeps lanae and water at a ratio of 75:25 (v/v). The wax phase consisting of lanolin, white petrolatum, white beeswax, cetyl ester wax, and cetyl alcohol was melted in a water bath at 55–65°C. *Aloe vera* and chamomile extracts were then incorporated into the melted wax phase under continuous stirring. The mixture was poured into stick molds and allowed to solidify at room temperature (20–25°C).

Table 1. Composition of moisturizing stick formulations containing *Aloe vera* (*A. barbadensis* Mill.) and chamomile (*M. recutita*) extracts

Ingredients (g)	F-1 (Low–Low)	Fa (High–Low)	Fb (Low–High)	Fab (High–High)	Blank
Aloe vera extract	10	20	10	20	–
Chamomile extract	5	5	15	5	–
Cetyl alcohol	3	3	3	3	3
White beeswax	5.25	5.25	5.25	5.25	5.25
Cetyl ester wax	10.5	10.5	10.5	10.5	10.5
Lanolin (Adeps lanae : water = 75 : 25)	10.5	10.5	10.5	10.5	10.5
White petrolatum	70.75	70.75	70.75	70.75	70.75

Notes: Each formulation had a total weight of 100 g. One experimental run (1R) yielded approximately 6 g of product, and each formulation was prepared in two batches. The formulations represent different combinations of extract concentrations: F-1 (low *Aloe vera*–low chamomile), Fa (high *Aloe vera*–low chamomile), Fb (low *Aloe vera*–high chamomile), Fab (high *Aloe vera*–high chamomile), and Blank (formulation without plant extracts).

2.6. Physical Evaluation of Moisturizing Stick

The prepared sticks were evaluated for organoleptic properties, homogeneity, hardness, melting point, spreadability, and weight uniformity.

Organoleptic characteristics, including texture, color, and odor, were observed visually (Jumriani et al., 2022). Homogeneity was assessed by vertically splitting the stick and observing the presence of coarse particles or uneven color distribution (Lanjewar et al., 2020).

Hardness was measured using a Shore A durometer, with an acceptable range of 30 ± 5 N (Teclock Co. Ltd., n.d.). The melting point was determined using a water bath, and the acceptable range was 35–45°C (Allen & McPherson, 2023).

Spreadability was evaluated by melting approximately 0.50 ± 0.01 g of sample at 40 ± 2°C for 2 min, placing it between two glass plates, and applying a 100 g load for 60 s. The resulting diameter of spread was recorded (Allen & McPherson, 2023).

Weight uniformity was assessed by weighing ten randomly selected sticks individually. The acceptable variation was ±5% of the average weight, with a target weight of 6.50 ± 0.50 g (U.S. Pharmacopeia, 2025).

2.7. Moisturizing Effectiveness Test

Moisturizing effectiveness was evaluated using the sorption–desorption test (SDT). A skin model was prepared using a 3% CMC-based hydrophilic gel and a 0.45 μm Millipore membrane impregnated with isopropyl myristate for 24 h. The stick formulation was applied to the membrane and stored in an oven at 32 ± 0.5°C. Sample weight was recorded at 0, 0.5, 1, 2, and 4 h. The area under the curve (AUC) was calculated to determine moisturizing effectiveness. Lower AUC values indicated higher moisturizing effectiveness (Mawazi et al., 2022; Rodrigues & Pintado, 2024; Susanto et al., 2024).

2.8. Determination of Antioxidant Activity (DPPH Method)

Antioxidant activity was determined using a modified DPPH assay in a 96-well microplate format (Sulistiana & Darijanto, 2022). A 0.5 mM DPPH solution was prepared in methanol, and absorbance was measured at 400–800 nm. Vitamin C was used as a reference antioxidant. Sample solutions were prepared, vortexed, sonicated, filtered, and serially diluted. Two hundred microliters of each sample solution were placed in the microplate wells and mixed with 100 μL of DPPH solution. The plates were incubated in the dark at room temperature for 30 min. Absorbance was measured at 517 nm using a microplate reader. The IC_{50} value was calculated using linear regression between concentration and percentage inhibition. Samples with IC_{50} ≤150 ppm were categorized as having moderate antioxidant activity (Masykuroh & Abna, 2022).

2.9. Stability Testing

The stability of the moisturizing stick formulations was evaluated over 4 weeks under storage at 5°C and 25°C without exposure to sunlight. Observations included color, odor, and physical appearance. A formulation was considered stable if no phase separation or significant physical changes were observed during storage (Allen, 2020; BPOM RI, 2025).

2.10. Data Analysis

Experimental data from physical quality tests, moisturizing effectiveness, and antioxidant activity were analyzed using one-way ANOVA with SPSS statistical software version 17.0. The optimal formulation was determined using Yates' treatment with a significance level of $\alpha = 0.05$ (Antony, 2023).

3. RESULTS AND DISCUSSION

3.1. Standardization of Dry Extracts

The appearance of the dry extracts is presented in **Figure 1**, and the results of non-specific and specific standardization are summarized in **Table 2**. Water-soluble and ethanol-soluble extractive values reflect the proportion of constituents extracted by solvents of different polarity. Both *Aloe vera* and chamomile dry extracts showed higher extractive values in water than in ethanol, indicating predominance of polar constituents. In addition, chamomile showed a higher water-soluble extractive value than *Aloe vera*, suggesting a greater proportion of water-soluble compounds in chamomile extract.

Figure 1. Dry extracts of (a) *Aloe vera* (*A. barbadensis* Mill.) and (b) chamomile (*M. recutita*)

Table 2. Standardization parameters of *Aloe vera* extract and chamomile extract

Standardization parameter	*Aloe vera* extract	Chamomile extract
Specific parameters		
Physical form	Powder	Powder
Color	Fawn	Light brown
Odor	Characteristic	Characteristic
pH (1% w/v aqueous solution)	7.70 ± 0.04[a]	6.40 ± 0.05[a]
Water-soluble extractives (%)	86.89 ± 7.27[a]	95.51 ± 1.75[a]
Ethanol-soluble extractives (%)	1.62 ± 1.13[a]	2.86 ± 1.39[a]
Non-specific parameters		
Moisture content (%)	2.02 ± 0.20[a]	6.58 ± 1.28[a]
Total ash (%)	0.13 ± 0.01[a]	6.48 ± 0.15[a]
Acid-insoluble ash (%)	0.12 ± 0.01[a]	5.15 ± 0.14[a]
Water-soluble ash (%)	0.06 ± 0.01[a]	1.18 ± 0.12[a]

Notes: [a] Values are presented as mean ± SD.

The presence of marker compounds was confirmed by thin-layer chromatography (TLC)(**Figure 2**). Aloin was detected in *Aloe vera* extract (Rf = 0.77; blue-green fluorescence under 366 nm) using ethyl acetate:methanol:water (9:1:0.5, v/v/v) as the mobile phase. Apigenin was detected in chamomile extract (Rf = 0.42; bluish-yellow fluorescence under 366 nm) using toluene:ethyl acetate:formic acid (7:2.5:0.5, v/v/v) as the mobile phase. These Rf values were close to the theoretical values reported for aloin (Rf = 0.78) and apigenin (Rf = 0.44) (Kemenkes RI, 2017; Nakiguli et al., 2022). Minor discrepancies between observed and theoretical values may arise from differences in sample matrices, extraction conditions, and solvent composition. The detection of aloin and apigenin supported the presence of bioactive constituents relevant to moisturizing and antioxidant performance in the developed stick formulation.

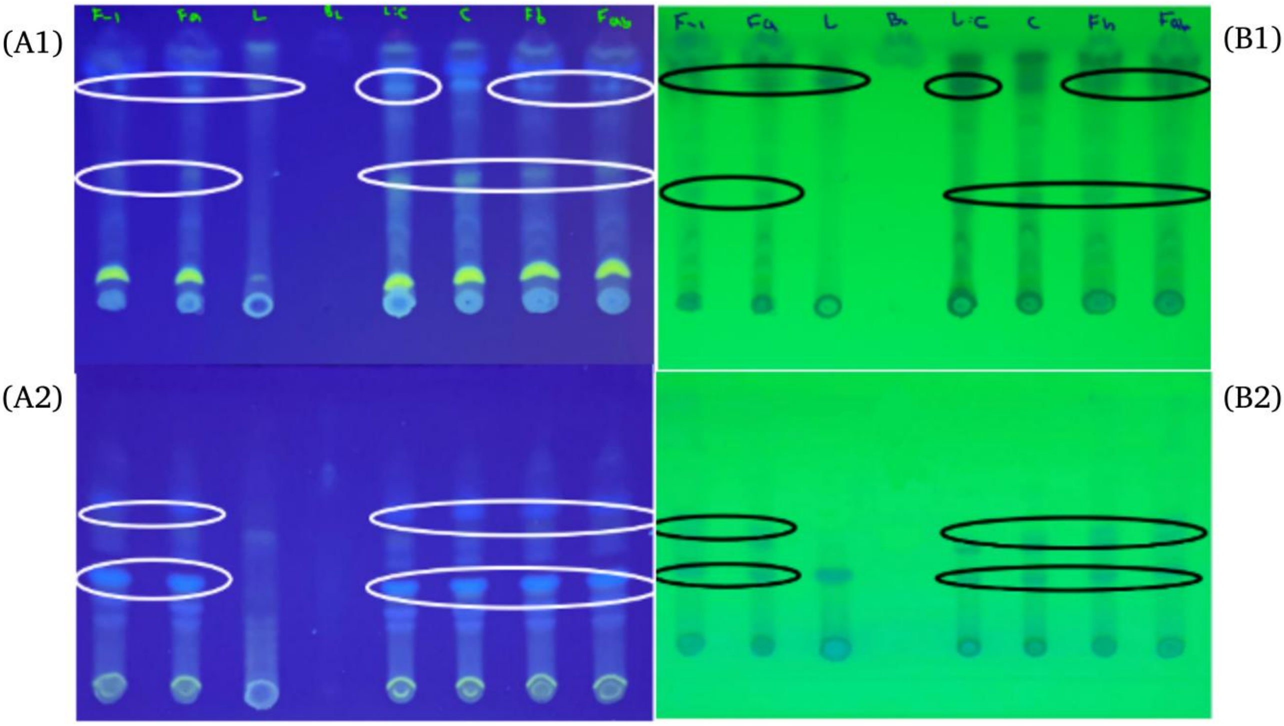

Figure 2. TLC profiles of moisturizing stick formulations F(-1), F(a), F(b), F(ab), and blank (BL). The chromatograms of *Aloe vera* extract were developed using ethyl acetate–methanol–water (9:1:0.5, v/v/v) as the mobile phase (A1–B1), while chamomile extract was developed using toluene–ethyl acetate–formic acid (7:2.5:0.5, v/v/v) (A2–B2). Plates were observed under UV light at 254 nm (A1–A2) and 366 nm (B1–B2).

3.2. Physical Evaluation of Moisturizing Stick

Organoleptic evaluation indicated that the moisturizing sticks had a uniform solid form, homogeneous brownish-yellow color, and a characteristic aroma of *Aloe vera* and chamomile extracts (**Figure 3A**). Homogeneity testing further confirmed uniform dispersion of the dry extracts within the wax matrix, as no visible lumps or coarse particles were observed and all formulations exhibited a consistent texture (**Figure 3B**). These results suggested adequate mixing and compatibility of the extracts with the base.

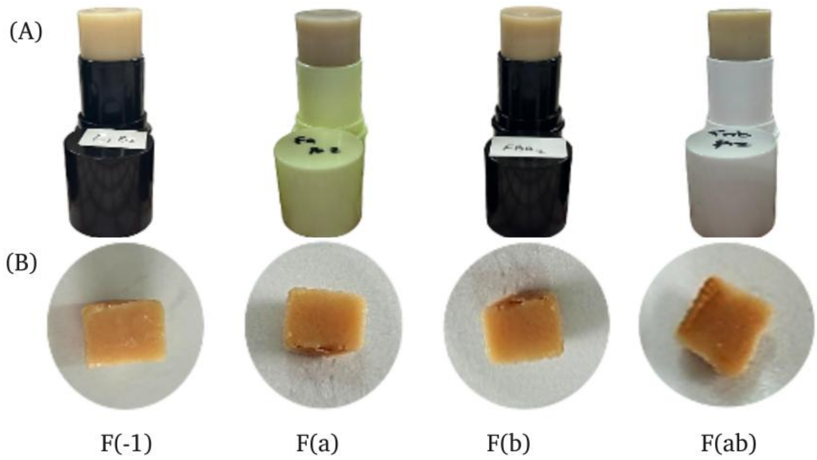

Figure 3. Physical characteristics of moisturizing stick formulations containing *Aloe vera* and chamomile extracts. (A) Organoleptic appearance of formulations F(-1), F(a), F(b), and F(ab). (B) Homogeneity test of the corresponding formulations.

All formulations met the hardness specification (30 ± 5 N) (**Figure 4a**), indicating sufficient mechanical integrity for handling and application while minimizing the risk of discomfort during use. The melting points were within the acceptable range (35–45°C) (**Figure 4b**), indicating stability at room temperature and softening during application. Similarly, spreadability met the target range (6–10 spreads per layer) (**Figure 4c**), supporting practical application performance. The blank formula F(BL) showed comparable hardness (30.05 ± 0.25 N), melting point (36.5 ± 0.50°C), and spreadability (6.17 ± 0.17 spreads per layer), indicating that incorporation of the extracts did not compromise baseline physical performance. Weight uniformity was acceptable across formulas, with no significant difference between two batches for each formulation ($p > 0.44$), indicating consistent fill and molding performance (**Figure 4d**).

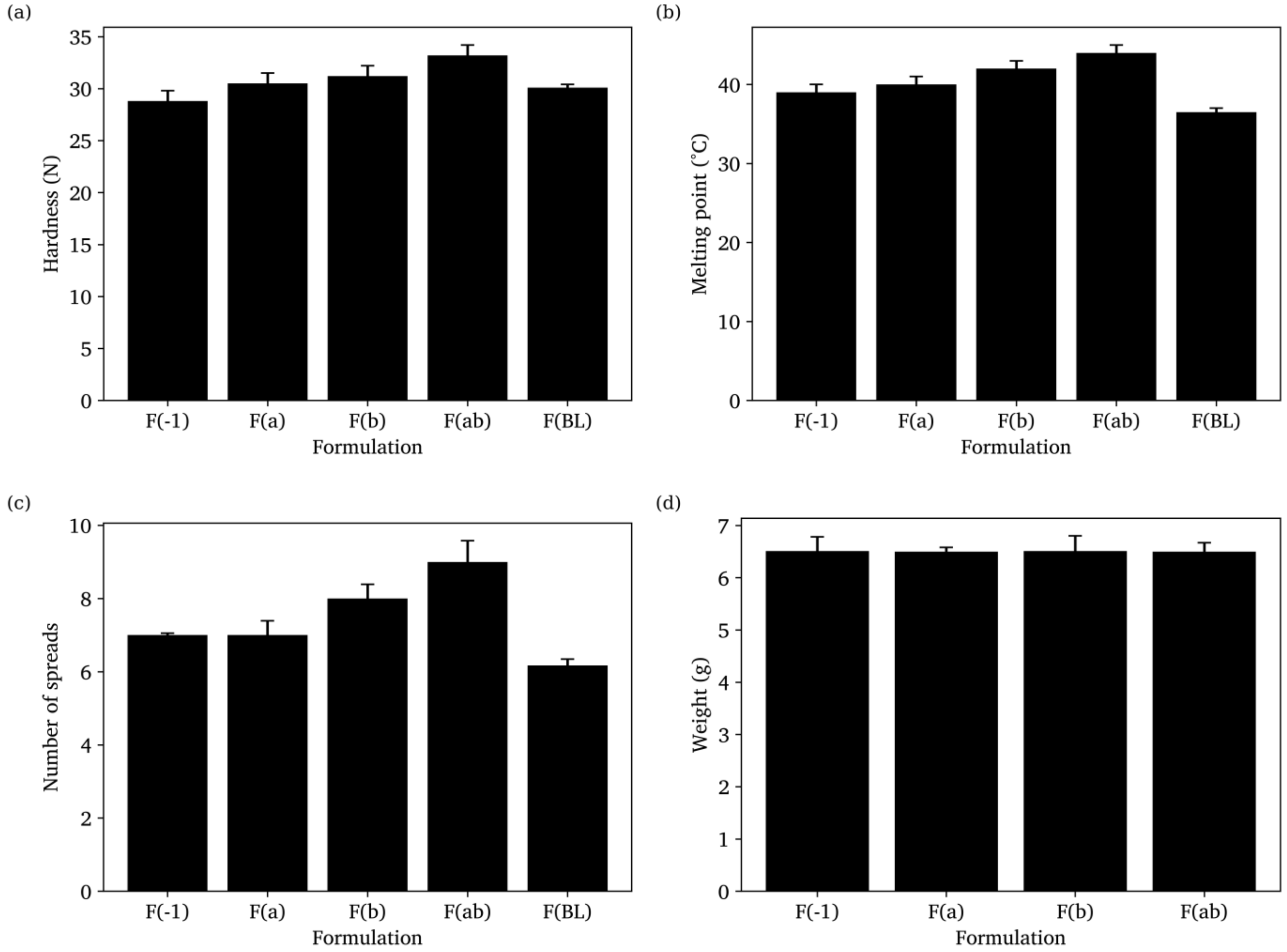

Figure 4. Mechanical and physical evaluation of moisturizing stick formulations containing *Aloe vera* and chamomile extracts: (a) hardness, (b) melting point, (c) spreadability, and (d) weight uniformity. Values are expressed as mean ± SD.

3.3. Effectiveness and Stability of Moisturizing Stick

a. Moisturizing Effectiveness

Moisturizing effectiveness was evaluated using AUC_total derived from the weight gain of the treated membrane during 4 h of testing. Lower AUC_total values indicate reduced water evaporation from the model surface and therefore higher moisturizing effectiveness. The AUC_total values for F(-1), F(a), F(b), and F(ab) were 1.79 ± 0.43, 1.53 ± 0.38, 1.12 ± 0.29, and 1.43 ± 0.40 mg/4 h, respectively (**Figure 5**). All formulations showed lower AUC_total values than the blank F(BL) (2.17 ± 0.58 mg/4 h), indicating improved barrier/moisturizing performance relative to the base. Differences among formulations were statistically significant ($p < 0.019$), suggesting that extract concentrations influenced moisturizing performance.

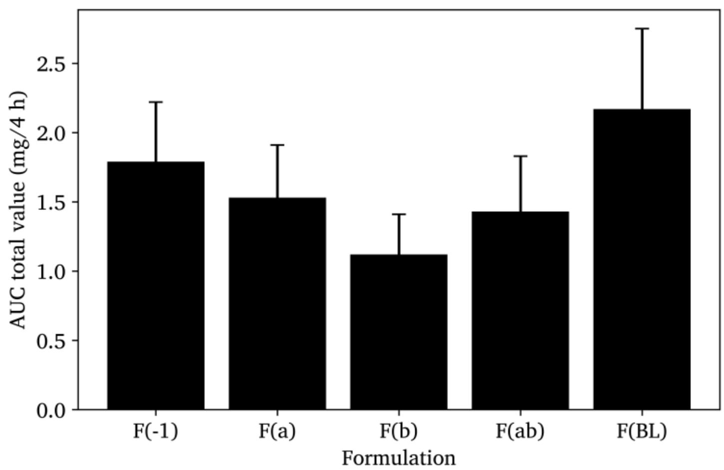

Figure 5. Total AUC values of moisturizing stick formulations containing *Aloe vera* and chamomile extracts. Values are expressed as mean ± SD.

b. Antioxidant Activity

Antioxidant activity was expressed as IC_{50}, reflecting the concentration required to inhibit 50% of DPPH radicals at 517 nm. The IC_{50} values for F(-1), F(a), F(b), and F(ab) were 149.86 ± 0.98, 148.14 ± 0.66, 132.73 ± 0.98, and 132.73 ± 0.98, respectively (**Figure 6**). All formulations met the moderate antioxidant criterion ($IC_{50} \leq 150$ ppm) (Masykuroh & Abna, 2022). The mixture of *Aloe vera* and chamomile extracts and vitamin C showed IC_{50} values of 100.27 ± 0.47 mg/L and 7.02 ± 1.48 mg/L, respectively, confirming the expected ranking of antioxidant potency. Differences among stick formulations were significant ($p < 0.05$), consistent with concentration-dependent contributions of extract constituents.

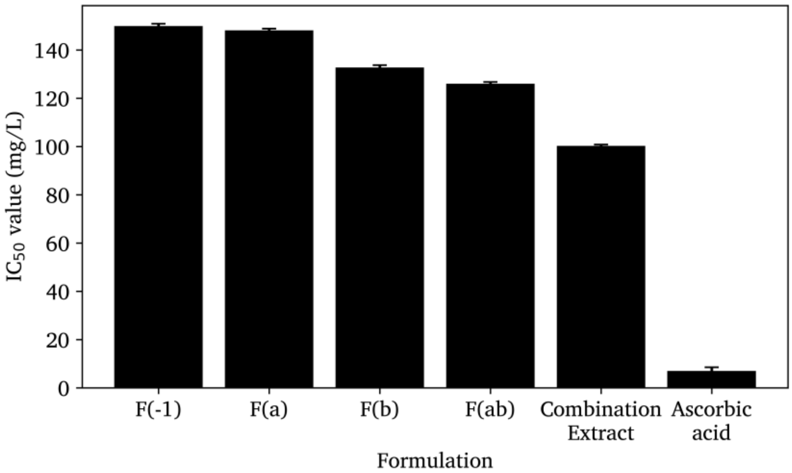

Figure 6. IC_{50} values of moisturizing stick formulations containing *Aloe vera* and chamomile extracts compared with the combination extract and ascorbic acid. Values are expressed as mean ± SD.

c. Stability

Stability was assessed over 4 weeks under cyclic storage at 25 ± 2°C and 5 ± 2°C (RH 60 ± 15%). All formulations maintained their color, odor, and stick form, with no phase separation or observable physical degradation. The samples remained homogeneous throughout storage, indicating that the wax matrix adequately stabilized the incorporated dry extracts under the tested conditions. These observations supported short-term physical stability and suggested potential for acceptable shelf-life under similar storage environments.

3.4. Formula Optimization

Hardness. All formulations satisfied the hardness requirement (25–35 N). The fitted polynomial model for hardness was:

$$Y_1 = 30.87 + 0.9137X\_A + 1.38X\_B + 0.0550X\_AX\_B$$

Yates' analysis indicated significant effects of *Aloe vera* (F = 74.75), chamomile (F = 170.18), and their interaction (F = 16.98) on hardness (F_table = 6.59). Chamomile contributed more strongly to increased hardness than *Aloe vera*. This pattern is consistent with the presence of astringent phenolic constituents in chamomile that may increase structural rigidity within semi-solid matrices (Akram et al., 2024), whereas *Aloe vera* constituents with higher water-associated fractions may contribute to softening (Allen & McPherson, 2023). The interaction term contributed less than the main effects (**Figure 7a**).

Spreadability. All formulations met spreadability requirements (6–10 spreads per layer). The fitted model was:

$$Y_2 = 7.74 + 0.4625X\_A + 0.9375X\_B - 0.0375X\_AX\_B$$

Both *Aloe vera* and chamomile significantly affected spreadability (F = 105.31 and 432.69, respectively; F_table = 6.59), while the interaction was not significant (F = 0.011). Chamomile showed a larger positive contribution, which may be linked to lipophilic constituents that enhance glide and reduce drag during application (Zengin et al., 2023). *Aloe vera* contains hydrophilic polysaccharides (e.g., acemannan and glucomannan) that may reduce friction and improve application feel (Babu & Noor, 2020; Massoud et al., 2022). The negative interaction coefficient suggested a slight synergistic effect in reducing the number of smears needed. At higher concentrations of both extracts, the predicted optimum spreadability was approximately 8 spreads (**Figure 7b**).

*Moisturizing Effectiveness***.** All formulations exhibited improved moisturizing performance relative to the blank, as reflected by lower AUC_total values. The fitted model was:

$$Y_3 = 1.56 + 0.0109X\_A + 0.1520X\_B - 0.0510X\_AX\_B$$

Both extracts significantly affected moisturizing effectiveness (F = 362.17 for *Aloe vera*; F = 39.88 for chamomile; F_table = 6.59), and the interaction was also significant (F = 51.45). *Aloe vera* contributed more strongly than chamomile, consistent with humectant-like effects of polysaccharides and glycoproteins that can support water retention (Babu & Noor, 2020; Massoud et al., 2022). Chamomile likely provided complementary benefits, including soothing and antioxidant support via bisabolol and apigenin (Dai et al., 2023)(Dai et al., 2023). The negative interaction coefficient indicated synergy in reducing AUC_total, and contour analysis suggested that lower *Aloe vera* with higher chamomile yielded the strongest moisturizing effectiveness in the tested design space (**Figure 8a**).

Antioxidant Activity. All formulations met the IC_{50} specification (≤150 ppm). The fitted model was:

$$Y_4 = 138.93 - 10.12X_A - 1.86X_B - 1.22X_AX_B$$

Yates' analysis showed significant effects of *Aloe vera* ($F = 62.41$), chamomile ($F = 1856.45$), and their interaction ($F = 27.13$) on antioxidant activity ($F_{table} = 6.59$). Increasing extract concentrations decreased IC_{50} values, indicating higher antioxidant activity. Chamomile contributed more strongly than *Aloe vera*, which is consistent with its phenolic/flavonoid profile (e.g., apigenin and related compounds) (Akram et al., 2024; Wypych, 2020). The negative interaction coefficient suggested synergistic radical scavenging. *Aloe vera* has been reported to show comparatively lower antioxidant activity and may be prone to degradation depending on processing and storage conditions (Saeed et al., 2022). Contour and overlay plots (**Figure 8b**) supported stronger predicted antioxidant performance at higher extract concentrations.

*Optimal Formula***.** The suggested optimal formulation contained *Aloe vera* extract (18.711%) and chamomile extract (8.167%). Predicted responses were 31.069 N (hardness), 8 spreads per layer (spreadability), 1.455 g/4 h (AUC_total), and 141.60 mg/L (IC_{50}). Experimental verification produced 32.5 N, 8 spreads per layer, 1.422 g/4 h, and 142.60 mg/L, respectively, confirming that the observed responses were close to predicted values and met the defined performance targets.

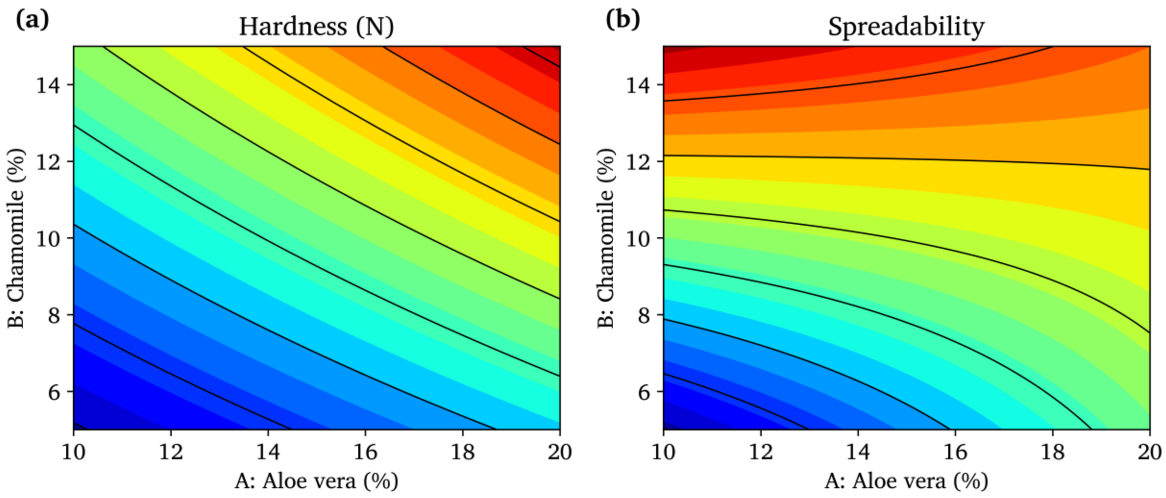

Figure 7. Contour plots illustrating the effects of *Aloe vera* concentration (A) and chamomile concentration (B) on (a) hardness and (b) spreadability of the moisturizing stick formulations based on the fitted polynomial models.

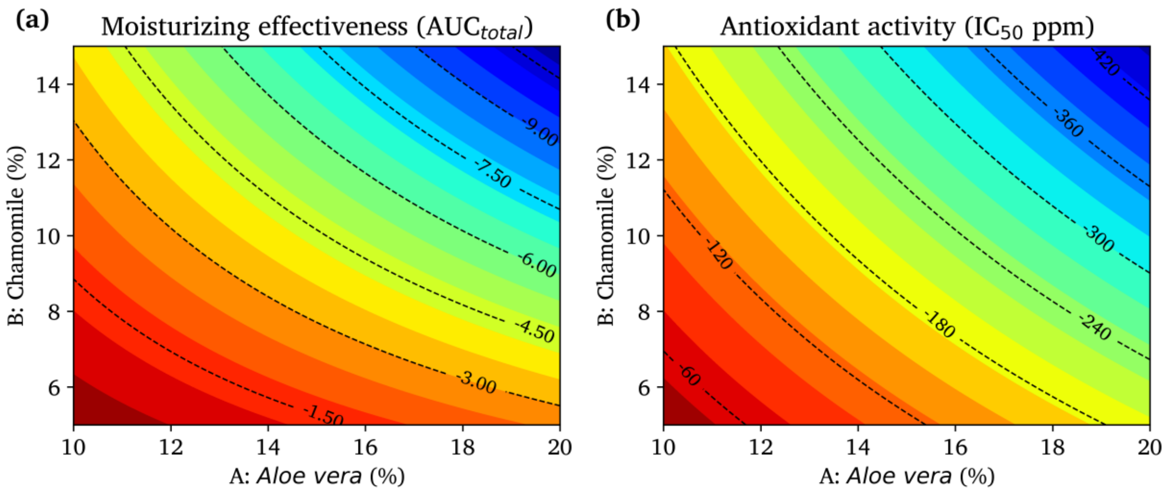

Figure 8. Contour plots showing the effects of *Aloe vera* concentration (A) and chamomile concentration (B) on (a) moisturizing effectiveness expressed as AUC total and (b) antioxidant activity expressed as IC_{50}. The plots were generated from the fitted polynomial models.

4. CONCLUSION

A combination of *Aloe vera* extract and chamomile extract was successfully formulated as a moisturizing stick using the hot-melt extrusion method. The optimal moisturizing stick formulation contained *Aloe vera* extract (18.711%) and chamomile extract (8.167%) and met the predefined quality requirements, as indicated by the following observed parameters: hardness value of

32.5 N, spreadability of 8 spreads per layer, AUC_total of 1.422 g/4 h, and IC_{50} of 142.60 mg/L. These findings indicate that the combination of *Aloe vera* and chamomile extracts provides complementary moisturizing and antioxidant properties in a solid stick formulation, suggesting its potential for development as a multifunctional skincare product that enhances skin hydration while providing protection against oxidative stress.

AUTHOR CONTRIBUTIONS

Conceptualization, methodology: M.K.T., F.L.D., S.M.; software, validation, formal analysis, investigation: M.K.T.; resources, data curation, writing—original draft preparation: F.L.D., M.K.T.; writing—review and editing, supervision: M.K.T., F.L.D., S.M. All authors read and approved the final version of the manuscript.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest.

DECLARATION OF GENERATIVE ARTIFICIAL INTELLIGENCE (AI) USE

During the preparation of this manuscript, the authors used ChatGPT (OpenAI) to assist in improving the clarity, structure, and readability of the text. All outputs were carefully reviewed, edited, and verified by the authors to ensure accuracy and consistency with their interpretations. The authors take full responsibility for the integrity and originality of the published work.

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