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Formulation and Characterization of Herbal Lip Balm Utilizing Red Dragon Fruit (*Hylocereus polyrhizus*) Extract as a Natural Colorant and Active Ingredient

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ABSTRACT: This study formulated an herbal lip balm using dragon fruit extract (*Hylocereus* spp.) as a natural colorant and moisturizer. The extract was integrated with a base of coconut oil, beeswax, cocoa butter, vitamin E, and rose water. The extract was incorporated into a lipid-based matrix composed of coconut oil, beeswax, cocoa butter, vitamin E, and rose water. Physical testing indicated an average pH of 5.08 and a melting point of 63–65 °C, complying with standard safety requirements for lip care products. Organoleptic evaluation by 10 panellists demonstrated high acceptance, with 90% approving the soft texture and aroma, and 85% favouring the natural pink. The product exhibited stability over a 28-day storage period. Material characterization via X-Ray Diffraction (XRD) identified an amorphous crystal structure ($2\theta \approx 25.6^0$), while Scanning Electron Microscopy (SEM) revealed a porous surface with a particle distribution of 8µm. X-Ray Fluorescence (XRF) analysis confirmed the extract is rich in macro-elements, specifically Potassium (67.5%), Calcium (15.5%), Magnesium (8.5%), and Phosphorus (8.4%).
Keywords: herbal lip balm; dragon fruit extract; natural cosmetics; betacyanin; antioxidants

1. Introduction

Cosmetic products continue to grow in demand as public awareness of skin health and appearance increases. Among them, lip balms are widely used due to their role in maintaining lip comfort and preventing dryness caused by environmental exposure. However, many commercial lip balms still rely on synthetic waxes, colorants, fragrances, and preservatives, which may trigger irritation and allergic reactions (Draelos, 2001; Balsam & Sagarin, 2021), as well as contribute to environmental issues associated with the production and degradation of synthetic materials (Li & Sun, 2011). These concerns have encouraged the development of cosmetic formulations that incorporate natural, safer, and more sustainable ingredients.

Dragon fruit (*Hylocereus* spp.) is a promising natural ingredient due to its high content of polyphenols, flavonoids, and betalain pigments—particularly betacyanins—which provide vibrant natural coloration and have been widely reported to possess strong antioxidant potential (Tenore et al., 2011; Akhtar et al., 2017). Betalains are also known for their relative stability in certain cosmetic and food matrices, making them attractive alternatives to synthetic dyes (Azeredo, 2009; Sadowska-Bartosz & Bartosz, 2021). Previous studies, including those by Akhtar et al. (2017), Martínez et al. (2024), and Bom et al. (2021), have highlighted the growing interest in botanical pigments and bioactive compounds for application in natural cosmetic formulations. This trend aligns with global market data indicating increased consumer preference for herbal and organic cosmetic products, driven by concerns regarding product safety and environmental sustainability (Aziz & Azahari, 2021; Sharma et al., 2022).Although dragon fruit pigments have been widely applied as food colorants and investigated for potential cosmetic uses, including lipstick formulations, their specific application in herbal lip balm products remains underexplored. Existing research has primarily focused on pigment extraction and stability (Azeredo, 2009; Gengatharan et al., 2015), antioxidant characterization (Tenore et al., 2011; Akhtar et al., 2017), and the use of betalains as natural colorants in emulsions or pharmaceutical preparations (Korac & Khambholja, 2011; Bujang et al., 2021). However, studies examining the behavior of dragon fruit extracts within semi-solid lip balm matrices—particularly in terms of physical stability, melting behavior, texture, and color stability—are still limited.

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Furthermore, limited information is available regarding the interaction between dried dragon fruit extracts and common lip balm base materials such as beeswax, cocoa butter, and coconut oil. Therefore, this study aims to evaluate the feasibility of using red dragon fruit (Hylocereus polyrhizus) extract as a natural colorant and active botanical ingredient in herbal lip balm formulations. The research focuses on assessing key physical characteristics of the formulated lip balm, including pH, melting point, spreadability, texture, and short-term stability. In addition, the dried dragon fruit extract is characterized using X-ray diffraction (XRD), scanning electron microscopy (SEM), and X-ray fluorescence (XRF) to elucidate its structural and mineral composition. The findings of this study are expected to contribute to the development of natural, locally sourced cosmetic products and support the growing demand for safer and environmentally friendly lip care formulations.

2. Materials and Methods

2.1. Materials

The materials used in this study are listed in Table 1. A laboratory experimental design was employed to formulate and evaluate an herbal lip balm incorporating red dragon fruit (*Hylocereus polyrhizus*) extract as a natural colorant and botanical ingredient. This design enabled controlled preparation of raw materials, formulation development, and physical characterization of the final product.

Table 1. Lip Balm Ingredients

No	Ingredient Name	Quantity	Specification
1	Fresh Dragon Fruit (*Hyloceruss* pp.)	150 g (producing ~60 mL extract)	Washed, peeled, blended, and filtered
2	Coconut oil	30 ml	Food-grade, cold pressed
3	Beeswax	5.5 g	Cosmetic grade
4	Cocoa butter	4.0 g	Cosmetic grade
5	Vitamin E (Tocopherol)	3 capsules (600 mg total)	Antioxidant
6	Rose water	5 ml	USP cosmetic grade
7	Cheesecloth	-	For filtration
8	Double boule	1 set	Heating
9	Sterile container (mold)	1 set	Molding

2.2. Production stages

The production process consisted of extract preparation, melting and mixing of lipid components, incorporation of active ingredients, molding, and product evaluation.

2.2.1. Preparation of Dragon Fruit Extract

Fresh dragon fruit was cut into small cubes and blended for 60 seconds. The resulting pulp was filtered using sterile cheesecloth to obtain approximately 60 mL of liquid extract. To slightly reduce water content without degrading betacyanin pigments, the extract was gently heated at 45–50 °C for 10 minutes, followed by cooling to room temperature. No high-temperature processing (e.g., caramelization) was performed, as excessive heat may cause pigment degradation.

2.2.2. Preparation of Dried Extract for XRD, SEM, and XRF

Because instrumental characterization (XRD, SEM, XRF) requires a dry solid sample, a portion of the liquid extract was oven-dried at 60 °C for 12 hours until a fine, dry powder was obtained. This dried powder was used solely for material characterization and not for lip balm formulation.

2.2.3. Lip Balm Formulation Process

Beeswax (5.5 g) and cocoa butter (4.0 g) were melted using a double-boiler system at 70 °C for 10 minutes while stirring at 300 rpm to ensure complete liquefaction. Coconut oil (30 mL) was then added and stirred for another 5 minutes until homogeneous.

The mixture was allowed to cool to 45 °C before adding the active ingredients: 15 mL dragon fruit extract, 600 mg vitamin E and 5 mL rose water. The mixture was manually stirred for 3 minutes to ensure uniform distribution of pigments and lipophilic components. The formulation was then poured into sterile lip balm molds and solidified at 4 °C for 30 minutes.

2.3 Characterization Methods

Physical and material characterizations of the lip balm were performed using several standard analytical techniques. The pH was measured using a digital pH meter, calibrated prior to testing with pH 4 and pH 7 buffer solutions. The lip balm sample was gently melted to 65 °C before measurement, and each test was conducted in triplicate (n = 3). The melting point was determined using a digital thermometer within a controlled heating setup at a temperature increase rate of 2 °C/min, also conducted in three replicates.

Organoleptic evaluation was carried out by 10 panelists using a 1–5 hedonic scale, assessing texture, spreadability, color, and aroma. For XRD, XRF, and SEM analysis, fresh dragon fruit extract could not be tested directly; therefore, the extract was oven-dried at 60 °C for 12 hours to obtain a powdered sample. The dried sample was analyzed by XRD using Cu-Kα radiation within the 10–60° 2θ range. For SEM analysis, the sample was coated with gold (Au) using a sputter coater and vacuum-dried. XRF analysis was carried out using samples pressed into pellet form and analyzed using XRF to quantity mineral elements.

2.4 Storage Stability Test

The original 4-day stability test was extended as recommended. The lip balm was stored at room temperature (25–27 °C) and evaluated at Day 0, 7, 14, and 28 for changes

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in color, texture, phase separation, and odor. This duration aligns with standard cosmetic preliminary stability protocols.

3. Results and Discussion

3.1 Physical Characteristics Tests

The physical characteristics of the herbal lip balm formulated with red dragon fruit (*Hylocereus polyrhizus*) extract are consistent with previously reported natural lip care formulations. The pH values obtained in this study fall within the acceptable range for lip cosmetic products (pH 5.0–6.5), indicating suitability for application on the sensitive lip surface. Similar pH compatibility has been reported in herbal lip balm formulations containing plant extracts (Pavithra et al., 2019; Silva et al., 2019), which is important for maintaining skin barrier integrity (Schmid-Wendtner & Korting, 2006).

The uniform reddish coloration observed in the lip balm confirms the effectiveness of betalain pigments from dragon fruit as natural colorants, in agreement with earlier studies on betalain application in food and cosmetic systems (Azeredo, 2009; Rebecca et al., 2006). However, slight color fading during storage was observed, which is consistent with previous findings that betalains are sensitive to environmental factors such as light and temperature (Echeverría et al., 2020; Sora et al., 2015). This behavior further supports reports that betalain stability is strongly influenced by formulation composition and storage conditions (Gandía-Herrero & García-Carmona, 2013).

Table 2. Results of the Evaluation of the Characteristics of Dragon Fruit Extract Lip Balm

Parameters	Average results	Reference standard	Description
pH	5.08 ± 0.05	4.5-6.5	Suitable, safe for lips
Melting point	63±0.5 °C	60-70 °C	Stable
Texture	Soft, Homogeneous	Smooth, not gritty	Acceptable
Color	Light pink natural	Matching color natural pigment	Stable for up to 28 days
Aroma	Mild, characteristic	Neutral-mild	Acceptable
Spread ability	Easy, not sticky	Non-greasy	Good
Storage stability (28 days)	Stable color, no phase separation	Must be stable	Passed

The melting behavior and texture of the formulation were comparable to those reported for herbal lip balms based on natural waxes and butters (Pavithra et al., 2019; Bujang et al., 2021), indicating good compatibility between the dragon fruit extract and lipid base materials. Additionally, the antioxidant potential of the extract aligns with previous studies highlighting the richness of polyphenols and betalains in *Hylocereus* spp. (Tenore et al., 2011; Akhtar et al., 2017). Overall, this study extends existing research by demonstrating the applicability of dried dragon fruit extract in semi-solid herbal lip balm formulations.

Compared with the earlier 4-day test period, the extended 28-day observation showed no visible changes in phase stability, color, odor, or texture, indicating that the formulation exhibits short-term storage stability.

The natural pink color originated from betacyanin pigments present in dragon fruit extract. Color retention for 28 days suggests that the pigment remained stable under storage conditions, although comprehensive stability (e.g., accelerated aging, light stability) is recommended for future studies. While betacyanins are reported in the literature to possess antioxidant potential, this study did not evaluate antioxidant activity directly; therefore, such benefits are discussed only as potential properties based on prior research, not as confirmed experimental outcomes.

Organoleptic evaluation by 10 panelists indicated 90% rated the texture as soft and homogeneous, 88% rated spreadability as good and non-sticky, 85% liked the natural color, and 80% accepted the mild aroma

These findings suggest that the combination of beeswax, cocoa butter, and coconut oil contributed to desirable sensory attributes. Overall, the physical characteristics demonstrate that red dragon fruit extract is suitable as a natural pigment and botanical ingredient for herbal lip balm formulations. However, future studies should include long-term stability (≥3 months), microbial safety, and antioxidant testing to strengthen product validation.

3.2 Material Characteristics Testing

3.2.1 XRD Analysis

The XRD analysis was performed on oven-dried dragon fruit extract powder, as fresh juice cannot be directly analyzed by XRD (clarified as requested by reviewer). The diffraction pattern (Figure 1) shows a broad amorphous halo centered around $2\theta \approx 25.6°$, typical of organic materials and dried polysaccharide-rich matrices. The absence of sharp crystalline peaks indicates that the dried extract is largely amorphous.

This amorphous nature is beneficial for cosmetic formulations because it enhances pigment dispersion in the lipid base, reduces light scattering and grittiness, and contributes to a smoother final texture.

The XRD results correlate with the SEM findings showing non-crystalline morphological features (Section 3.3).

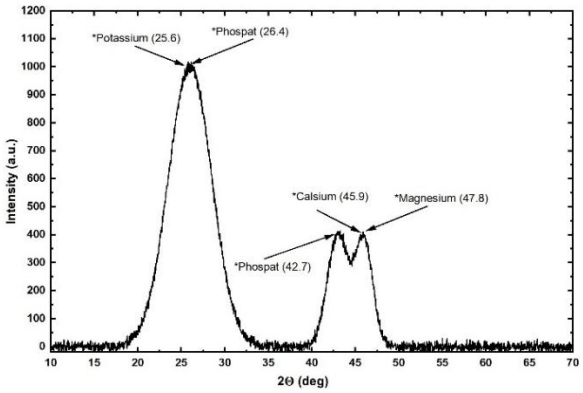

Figure 1. Material Characteristics testing results using XRD

3.2.2 XRF Analysis

XRF analysis was also conducted on the oven-dried extract powder prepared in Section 2.2.2. The elemental composition of the dried red dragon fruit (*Hylocereus polyrhizus*) extract is dominated by potassium (K), accounting for approximately 67.5% of the total detected elements. A high potassium content has been commonly reported in *Hylocereus* spp. and reflects the natural mineral profile of the fruit (Tenore et al., 2011; Akhtar et al., 2017). Potassium plays an important role in maintaining cellular osmotic balance and hydration, which is relevant for cosmetic formulations designed for skin and lip applications. Calcium (Ca) and magnesium (Mg) were present at moderate levels, representing 15.5% and 8.5%, respectively.

Table 3. Elemental Composition of Dried Red Dragon Fruit (*Hylocereus polyrhizus*) Extract

Element	Concentration (mg/kg)	Percentage (%)	Classification
K	2640.04	~67.5	Major element
Ca	608.38	~15.5	Major element
Mg	334.02	~8.5	Major element
P	327.36	~8.4	Major element
Zn	Trace	-	Trace element
Fe	Trace	-	Trace element

These minerals are associated with skin barrier function and enzymatic activity and have been reported in plant-based cosmetic ingredients as supportive elements for skin health (Schmid-Wendtner & Korting, 2006). Phosphorus (P), accounting for 8.4%, is typically related to bioorganic compounds such as phospholipids, indicating the presence of structurally important biomolecules within the extract.

Trace elements, including zinc (Zn) and iron (Fe), were also detected. Although present in low concentrations, these elements are known to contribute to antioxidant activity and skin repair mechanisms (Akhtar et al., 2017). Overall, the mineral composition supports the suitability of dried red dragon fruit extract as a natural cosmetic ingredient, complementing its known pigment and antioxidant properties.

These values represent mineral residues after drying, not the composition of fresh fruit. Such minerals may influence buffering capacity and pigment stability but must be monitored to ensure compliance with cosmetic heavy-metal safety limits. Future work should include ICP-MS for higher-resolution trace metal analysis.

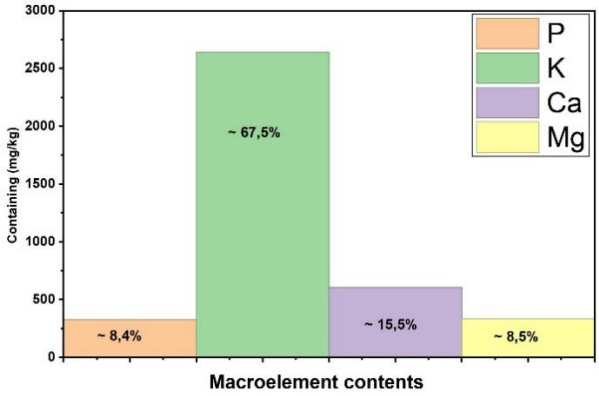

Figure 2. Mineral Content of Dried Dragon Fruit Extract

3.3.3 SEM Analysis

Figures 3(a) and 3(b) show scanning electron microscopy (SEM) micrographs of the oven-dried red dragon fruit (*Hylocereus polyrhizus*) powder at magnifications of ×35 and ×300, respectively. At low magnification (×35), the powder exhibits an irregular, fragmented, and layered morphology, which is typical of dehydrated plant-derived materials. The particles display rough and porous surfaces, indicating a high surface area that may facilitate improved interaction between pigment particles and lipid-based components in cosmetic formulations.

At higher magnification (×300), more detailed structural features become apparent, including lamellar folds, micro-cracks, and micro-pores. These characteristics suggest partial collapse of the plant cell walls resulting from moisture removal during the drying process. Importantly, no evidence of carbonization, melting, or severe thermal degradation was observed, confirming that the low-temperature oven-drying method effectively preserved the microstructural integrity of the material. The absence of thermal damage is crucial for maintaining the stability of heat-sensitive bioactive compounds, such as betalain pigments. From a formulation perspective, this microstructure is advantageous for cosmetic applications. The porous morphology and fine surface features are expected to enhance pigment dispersion and promote better compatibility with lipid matrices such as beeswax and cocoa butter. Consequently, this structure may contribute to

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improved homogeneity, color uniformity, and smoother texture in the final herbal lip balm product.

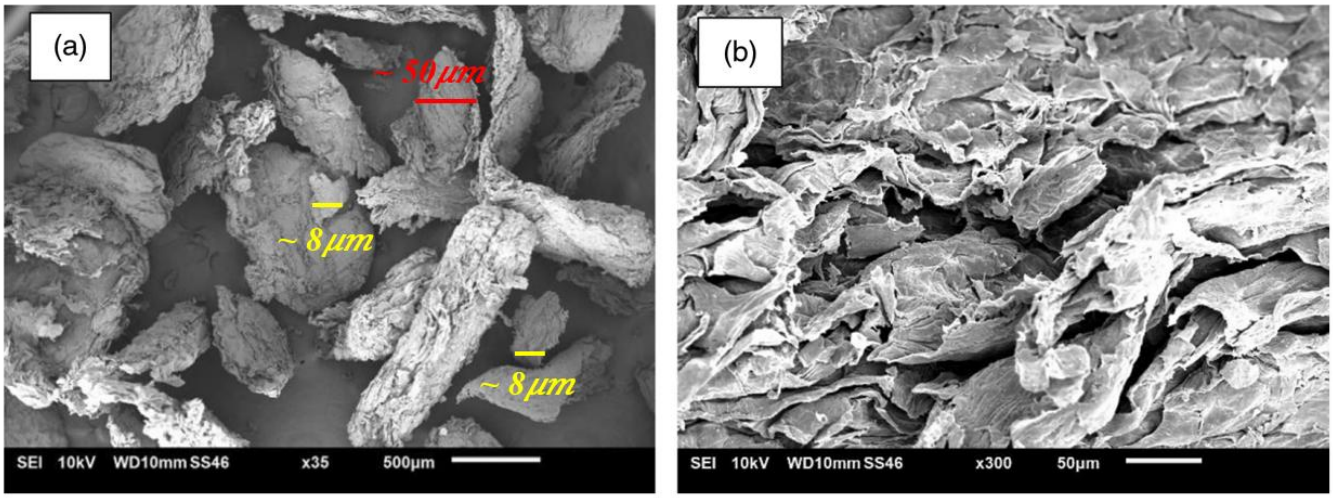

Figure 3. (a) SEM for X35 magnification and (b) for X300 magnification

4. Conclusions

The results of this study demonstrate that dragon fruit extract is a promising natural colorant and botanical ingredient for herbal lip balm formulations based on its physical and aesthetic performance. The formulated product exhibited a pH of 5.08 ± 0.05, which lies within the safe range for lip skin, and a melting point of 63–65 °C, indicating suitable consistency and stability under tropical conditions. The lip balm's natural pink color, derived from betacyanin-containing dragon fruit extract, remained visually stable over the short-term storage period evaluated, and organoleptic testing with 10 panelists indicated high acceptance for texture, spreadability, and aroma. XRD analysis of the oven-dried dragon fruit extract confirmed an amorphous structure with a broad halo at $2\theta \approx 25.6°$, while SEM images revealed porous and layered morphologies; together, these features are favorable for pigment dispersion and interaction with the lipid matrix. XRF analysis of the dried extract showed a predominance of K (2640 mg/kg), Ca (608 mg/kg), Mg (334 mg/kg), and P (327 mg/kg), reflecting the mineral residue of the dried material, which may influence structural and color stability, although trace metals should be further evaluated against cosmetic safety limits. While dragon fruit is known from the literature to contain compounds with antioxidant potential, this study did not directly measure antioxidant activity; therefore, any antioxidant-related effects are considered potential benefits rather than confirmed outcomes. Overall, the findings support the use of red dragon fruit extract as a natural pigment source in lip balm formulations and align with the broader trend toward safer, plant-based, and environmentally friendly cosmetic products. Further work is recommended to investigate long-term stability, antioxidant capacity, and comprehensive safety profiles of the final product.

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Statement
The authors declare that artificial intelligence (AI) tools were used solely to assist with language editing, grammar correction, and improvement of clarity and academic style during manuscript preparation. The AI tools did not contribute to the research design, data collection, data analysis, interpretation of results, or generation of scientific conclusions. All content was reviewed, revised, and approved by the authors, who take full responsibility for the integrity and originality of the work.

Credit authorship contribution statement
Harrys Samosir: Conceptualization, Methodology, Investigation, Data curation, Formal analysis, Writing – original draft.
Tina Sarmila: Investigation, Validation, Visualization, Writing – review & editing.
Loza Asmi Nahara Maharani: Investigation, Data curation, Writing – review & editing.
Devina Sanchia Samosir: Resources, Supervision, Project administration, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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