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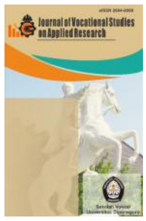

Research Article

Optimization of Natural Lip Tint Formulation Using Red Beet (*Beta vulgaris* L.) and Waru Leaves (*Hibiscus tiliaceus* L.) Extracts with Enhanced Sun Protection Factor

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Abstract

This study aimed to optimize the formulation of a natural lip tint utilizing red beet (*Beta vulgaris* L.) and Waru leaves (*Hibiscus tiliaceus* L.) extracts, with ZnO incorporated to enhance sun protection performance. The optimization was carried out using Response Surface Methodology (RSM), employing three independent variables—extract ratio (1:2, 1:3, 1:4), homogenization speed (5,000–12,000 rpm), and homogenization time (4–10 min)—ultimately generating 16 formulation trials. Key phytochemical responses, including betacyanin, anthocyanin, and SPF, alongside stability parameters (pH, viscosity, and density), were systematically evaluated to assess formulation performance. The optimal formulation containing ZnO (F6) produced 0.0129% betacyanin, 0.0590% anthocyanin, and an SPF value of 18.1, whereas the optimal formulation without ZnO (F15) yielded 0.0140% betacyanin, 0.0428% anthocyanin, and an SPF value of 12.7. The RSM optimization model further predicted betacyanin, anthocyanin, and SPF values of 0.0104%, 0.0593%, and 13.89 for formulations with ZnO, and 0.0109%, 0.0434%, and 11.05 for formulations without ZnO. These outcomes demonstrate that extract ratio and homogenization conditions play a critical role in determining pigment concentration, stability, and UV-protective performance, confirming the feasibility of developing a plant-based lip tint with improved functional properties through ZnO-enhanced formulation optimization.

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1. Introduction

The global cosmetics industry continues to show strong growth, reaching a market value of approximately USD 307 billion in 2023 and projected to surpass USD 415 billion by 2030, driven by increasing consumer awareness of personal care and demand for multifunctional beauty products (Lestari & Wismantoro, 2024). Within this market, lip tint has become one of the most preferred lip cosmetics, not only because of its lightweight texture and long-lasting pigmentation but also due to its favorable physicochemical properties, such as ease of spread ability, rapid absorption, and stable color performance on the lips. However, concerns regarding the safety of synthetic colorants have encouraged consumers to shift toward natural-based cosmetic products (Tampubolon, 2023).

Red beetroot (*Beta vulgaris* L.) is a promising natural pigment source, as it contains betacyanin, betacyanidin, and betaxanthin compounds that provide vivid coloration and exhibit strong antioxidant activity (Lembong & Utama, 2021). Recent research has demonstrated that betalains from red beetroot maintain significant radical-scavenging capacity and correlate strongly with total phenolic content (r = 0.80–0.91) in different beet varieties, highlighting their functional duality as both colorants and bioactive compounds (Sokolova et al., 2024).

The pigment content produces a distinctive purplish red color, so it has great potential to be applied as a natural dye in the food and

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pharmaceutical industries (Pramudika & Paramita, 2023). Meanwhile, Waru leaves contain active compounds saponin, flavonoids, and at least five phenolic compounds that are antioxidants and provide protection against cell damage due to free radicals and UV exposure, these phytochemicals function by scavenging reactive oxygen species, stabilizing free radicals, and reducing oxidative stress, thereby helping to prevent cellular damage induced by UV exposure and flavonoid compounds possess aromatic chromophore structures capable of absorbing UV radiation, which means these compounds contribute to photoprotection through antioxidant radical scavenging and direct UV absorption, thereby reducing UV-induced oxidative damage and enhancing the formulation's effective sun-protection capacity (Rahayu et al., 2022; Yani et al., 2023).

The combination of the two is expected to produce a liptint that not only provides natural color but also protection for lip health. In addition, avocado (*Persea americana Mill.*) is a source of vegetable oil that is rich in oleic acid and functions as an emollient and color dispersing agent, along with linoleic and palmitic acids, tocopherols, carotenoids, and phytosterols that confer emollient, antioxidant, and skin-barrier supporting functions (Putri et al., 2018). These properties make avocado oil effective not only as a moisturizer but also as a color-dispersing medium, aiding the uniform distribution of hydrophobic pigments in formulations and avocado pulp oil can be formulated into topical emulsions or creams with stable physicochemical parameters (pH, density, viscosity) and acceptable stability under storage, confirming its suitability as oil phase in cosmetic products (Nascimento et al., 2025).

Despite the growing interest in plant-based lip cosmetics, there is still limited research integrating red beetroot and Waru leaf extracts as combined natural colorants with dual antioxidant and photoprotective functions, particularly within a ZnO-enhanced lip tint system. Furthermore, previous studies have not examined how avocado oil functions simultaneously as an emollient and as a physicochemical carrier influencing pigment dispersion and formulation stability. Therefore, this study aims to develop and optimize a natural lip tint formulation incorporating red beetroot and Waru leaf extracts as bioactive pigments, with avocado oil serving as the oil-phase carrier, and to evaluate its phytochemical characteristics, SPF enhancement, and overall physicochemical stability using Response Surface Methodology (RSM).

2. Materials and Methods

2.1 *Materials*

Red beet (*Beta Vulgaris* L.) and Waru leaves (*Hibiscus tiliaceus* L.) powder that used in this research were obtained from Semarang, Central Java, Indonesia, avocado oil (TS bali), soy lecithin (SWANSON), cetyl alcohol (LAUREX), distilled water, tween 80, ZnO, and glycerin., pH 1 and pH 4.5.

2.2 *Preparation of Oil Phase Process*

The oil phase was prepared by mixing avocado seed oil, cetyl alcohol, soy lecithin, and ZnO (for specific formulations) in a beaker. The mixture was heated to 70 °C and homogenized at 300 rpm for 20 min using a hot plate stirrer.

2.3 *Preparation of Air Phase Process*

The water phase was prepared by dissolving beetroot extract and Waru leaf extract in distilled water in a beaker. The mixture was heated to 70 °C and homogenized at 300 rpm for 15 min using a hot plate stirrer. The remaining solids were then filtered, and the resulting filtrate was combined with Tween 80 and homogenized again.

2.4 *Homogenization Process*

After pre-homogenizing the oil and water phases separately, the two phases were combined and subjected to a final homogenization using a high-speed homogenizer. This step was performed under the specified variable conditions of homogenization time

Table 1. Formulation lip tint.

Ingredient	Formulasi (%)																	Function
	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F11	F12	F13	F14	F15	F16	
Avocado seed oil	20	20	20	10	10	10	10	20	20	20	20	20	20	10	20	20	20	Color dispersing agent
Soy lecithin	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	Emulsifier
Cetyl Alcohol	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	Emulsifier
Red beet Extract	7.33	8.8	8.25	8.8	7.33	8.8	7.33	8.8	8.25	8.25	8.25	8.25	8.25	7.33	8.8	8.25	8.25	Active ingredient (color)
Waru leaves Extract	3.67	2.2	2.75	2.2	3.67	2.2	3.67	2.2	2.75	2.75	2.75	2.75	2.75	3.67	2.2	2.75	2.75	Active ingredient (antioxidant)
Aquadest	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	40	Solvent
Glyserin	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	Humectant
Tween 80	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	Surfactant
ZnO	0	0	0	10	10	10	10	0	0	0	0	0	0	10	0	0	0	UV filter

(4, 8, and 10 min) and speed (5000, 10000, and 12000 rpm) for formulations F1 to F16, as presented in Table 1.

2.5 *Optimization Using Response Surface Methodology (RSM)*

The extraction conditions were optimized using Response Surface Methodology (RSM), which has been widely applied for optimizing multivariable processes in natural product extraction (Bezerra et al., 2008). Experimental design and data analysis were performed using Design-Expert Software version 19.0 (Minitab 19 statistical software), recognized for its flexibility and accuracy in fitting quadratic models (Bas & Boyaci, 2007). The effects of microwave power and extraction time on curcumin yield were statistically analyzed using analysis of variance (ANOVA), including both linear and quadratic interaction terms to account for variable interactions. The application of RSM enabled visualization of three-dimensional response surfaces and identification of the optimal extraction parameters (Nekkaa et al., 2021).

RSM was employed to systematically model the effect of process parameters on curcumin recovery efficiency. The Central Composite Design (CCD) embedded in the software was used to construct the experimental matrix and test the significance of each model coefficient at the 95% confidence level (Mansur et al., 2019).

2.6 *Determination of Phytochemical Analysis (Betacyanin, Anthocyanins, and SPF*

Flavonoid levels were determined by diluting 1 gr of lip tint with 10 mL of ethanol solvent into a beaker, stirring for 10 min and letting it stand for 30 min. Then filtered with Whatman paper no. 2. A total of 5 ml of beetroot extract sample was put into a cuvette, then its absorbance was measured using a UV-Vis spectrophotometer with a wavelength of 538 nm. The calculated concentrations were expressed as Flavonoid levels were determined by diluting 1 gr of lip tint with 10 mL of ethanol solvent into a beaker, stirring for 10 min and letting it stand for 30 min. Then filtered with Whatman paper no. 2. A total of 5 ml of beetroot extract sample was put into a cuvette, then its absorbance was measured using a UV-Vis spectrophotometer with a wavelength of 538 nm. The calculated concentrations were expressed as a percentage of dry weight, allowing comparison with other studies and standardization of betacyanin results (Asra et al., 2020). The betacyanin content is then calculated using equation (1).

$$\%Betacyanin = \frac{A}{\varepsilon \times L} \times MW \times \frac{Vd}{Wd} \times \frac{1}{1000} \times 100\% \quad (1)$$

Where A is the absorbance at 538 nm for Betacyanin, MW is the molecular weight of betacyanin (550g/mol), ε is the molar existence coefficient 60,000 L/ mol cm; L is thickness of cuvette (1 cm); Vd is the Dilution Volume; Wd is the Weight of dry extract (g).

The anthocyanin content in lip tint samples was determined using the pH differential method. A pH 1 buffer solution was made by dissolving approximately 1.490 grams of KCl with distilled water in a 100 ml measuring cylinder to the limit. Then mix 25 ml of KCl solution with 67 ml of 0.2 N HCl, while a pH 5 buffer solution was made by mixing 15 mL of 0.2 M acetic acid solution with 35 mL of 0.2 M sodium acetate solution and then diluting it with 100 mL of distilled water. A total of 1 gram of sample was dissolved in 10 mL of each buffer solution at pH 1 and pH 4.5. The absorbance of the sample was then measured using a UV-Vis spectrophotometer at wavelengths of 536 nm and 700 nm (Adam, 2017). The absorbance of the dissolved sample (A) was determined using equation (2).

$$A' = \left(A_{536} - A_{700}\right)_{pH\ 1.0} - \left(A_{536} - A_{700}\right)_{pH\ 5.0} \quad (2)$$

The anthocyanin concentration content (mg/L) in the sample is then calculated using equation (3).

$$\%Anthocyanin = \frac{A' \times MW \times DF \times 1000}{\varepsilon \times L} \quad (3)$$

Where A' is calculated using equation (2), ε is the molar absorptivity of cyanidin-3 glucoside 26900 L/mol.cc, L is the cuvette width (1 cm), MW is molecular weight of cyanidin-3 glucoside 449.2 g/mol, and DF is the dilution factor.

The SPF value was determined by making a sample solution by weighing each formula as much as 0.1 grams. Then diluted with 70% ethanol to 100 ml. The UV-vis spectrophotometer was first calibrated using 70% ethanol and 1 ml of 70% ethanol was inserted into the cuvette. The absorption test curve was made in a cuvette with a wavelength between 290-320 nm, 70% ethanol was used as a blank. Then determine the average absorbance (A) with an interval of 5 nm (Auliani et al., 2020). The SPF value is then calculated using equation (4).

$$SPF = CF \times \sum_{290}^{320} \left(EE(\lambda) \times I(\lambda) \times Abs(\lambda)\right) \quad (4)$$

Where CF is correction factor (10), I is light intensity spectrum, EE is erythema effect spectrum, and Abs is absorbance of sunscreen samples.

2.7 *Statistical Analysis*

All data were expressed as mean ± standard deviation and subjected to one way ANOVA using Design-Expert software. Model validation was performed by comparing predicted values to actual experimental results at optimized conditions. Statistical significance was determined at a 95%

confidence level ($p<0.05$).

3. Results and Discussion

The results of the analysis of pH, density, viscosity, betacyanin content, anthocyanin content, and SPF value are presented in Table 2. These parameters were selected to comprehensively evaluate the physicochemical quality, pigment stability, and photoprotective properties of the lip tint formulation. pH, viscosity, and density were measured to assess formulation stability and user safety, while betacyanin and anthocyanin contents were analyzed to determine the effectiveness of pigment incorporation from red beetroot and Waru leaves. SPF value was included to evaluate the contribution of ZnO and antioxidant pigments to UV protection. Following the initial characterization, a response surface methodology (RSM) analysis was performed to examine the interactive effects of extract ratio, homogenization speed, and homogenization time on each response variable, enabling the identification of optimal processing conditions for achieving maximum pigment retention, desirable texture, and enhanced photoprotective performance.

3.1 *Result Physical Analysis (pH, Density, and Viscosity)*

The results of pH analysis are shown in Table 2, where the pH of 16 lip tint samples ranged from 7.6 to 7.9, with an average of 7.8, remaining within the acceptable limits set by SNI 16-4399-1996 (4.5–8). Increased Waru extract ratio raised the pH due to its flavonoid and alkaline compound content. Higher homogenization speed and longer duration also contributed to elevated pH, likely from thermal decomposition of organic compounds, also pH remained in the slightly acidic range, which is favorable for betalain and anthocyanin stability because both pigments undergo protonation at lower pH, reducing degradation rates through suppression of hydrolysis and oxidative cleavage (Lestari, 2021; Saputri et al., 2023).

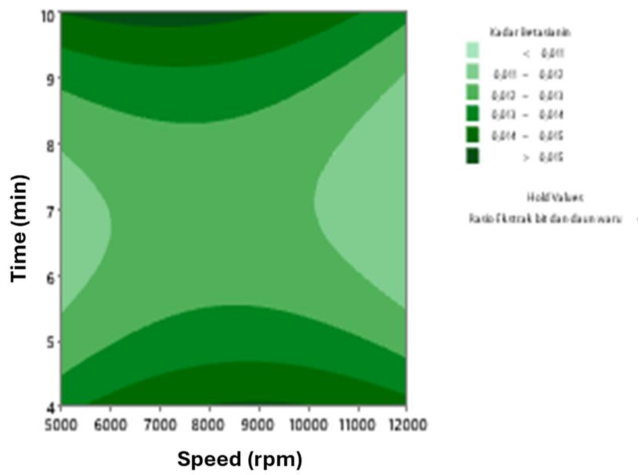
The results of density analysis are shown in Table 2, where lip tint density ranged from 15.5135 to 17.2442 g/mL. Higher extract ratios introduce more dissolved solids, which normally increases density due to greater mass per unit volume. However, at higher homogenization speeds, the density tended to decrease because intense shear forces reduce droplet size and increase air incorporation into the emulsion matrix, both of which lower bulk density. Additionally, the presence of avocado oil, which has a lower intrinsic density than water, contributes to density reduction when dispersed more efficiently at high speeds.

The results of viscosity analysis are shown in Table 2, where viscosity values ranged from 5.3755 to 10.4815 cP and showed a direct correlation with density. The use of glycerin, a high-viscosity humectant, contributed to the overall thickness. The increase in viscosity at higher extract ratios can be attributed to the elevation of solute concentration in the aqueous phase. A higher concentration of hydrophilic pigments and phenolic compounds increases intermolecular interactions particularly hydrogen bonding leading to restricted molecular mobility and a more structured continuous phase. This phenomenon is consistent with classical solute solvent interaction principles in colloidal systems. Extract ratio, speed, and homogenization time significantly affected the final viscosity.

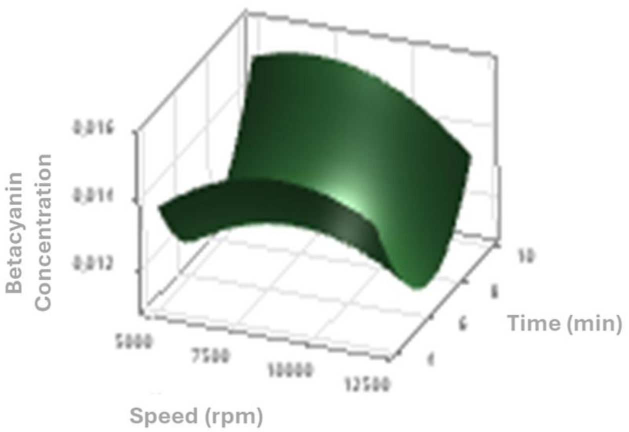
Table 2. Liptint analysis result.

Run	Time (min)	Homogenization Speed (rpm)	Ratio of Beet Extract and Waru Leaf Extract (-)	Betacyanin Content (%)	Anthocyanin Content (%)	SPF Value (-)	pH	Density (gr/ml)	Viscosity (cP)
1	4	5000	3	0.0102	0.0208	8.7	7.7	0.4731	5.8664
2	4	5000	5	0.0121	0.0098	7.6	7.6	0.4519	5.3755
3	4	12000	3	0.0120	0.0196	8.5	7.8	0.5621	8.8711
4	4	12000	5	0.0118	0.0531	17.9	7.6	0.5422	7.9948
5	10	5000	3	0.0118	0.0450	16.1	7.8	0.4919	6.2459
6	10	5000	5	0.0129	0.0590	18.1	7.7	0.4979	6.6768
7	10	12000	3	0.0094	0.0456	16.9	7.8	0.5149	7.4699
8	10	12000	5	0.0111	0.0217	9	7.6	0.6019	10.4815
9	4	10000	4	0.0136	0.0272	10.4	7.8	0.5601	8.7734
10	10	10000	4	0.0145	0.0321	11.5	7.7	0.6249	9.6591
11	8	5000	4	0.0111	0.0096	7.2	7.8	0.5062	7.0285
12	8	12000	4	0.0105	0.0038	6.7	7.9	0.5123	7.1883
13	8	10000	3	0.0072	0.0018	6	7.8	0.5520	82368
14	8	10000	5	0.0100	0.0257	10	7.7	0.5213	7.5927
15	8	10000	4	0.0140	0.0428	12.7	7.6	0.5999	10.3580
16	8	10000	4	0.0138	0.0418	11.8	7.9	0.6062	10.3587

Variations in pH, density, and viscosity observed in this study have direct implications for the performance and stability of the lip tint formulation. The pH values that remain within the safe physiological range indicate that the product is unlikely to cause irritation upon application and also contribute to pigment stability, as betalain- and anthocyanin-based colorants are more stable in slightly acidic environments. Differences in density influence the distribution and uniformity of the dispersion system; formulations with appropriate density values tend to maintain better phase homogeneity, reducing the likelihood of sedimentation or phase separation during storage. Meanwhile, viscosity plays a crucial role in determining the sensory attributes and application behavior of the lip tint. Higher viscosity produces a thicker and more adherent film on the lips, which may enhance color retention and reduce runoff, whereas lower viscosity supports smoother application and more even spreading. Overall, the combined effects of pH, density, and viscosity demonstrate their importance in ensuring physical stability, user comfort, and consistent visual performance of the natural lip tint formulation.



(A)



(B)

Figure 1. Effect of Homogenization Time and Speed on Betacyanin Concentration. X-axis: Homogenization Time (min), Y-axis: Homogenization Speed (rpm), Z-axis: Betacyanin Concentration (%). Contour plot (a) and 3D surface plot (b) generated from the RSM model showing the interaction effects of homogenization time and homogenization speed on betacyanin concentration. Increased speed and moderate processing time improved pigment extraction and dispersion.

3.2 *Result Phytochemical Analysis (Betacyanin, Anthocyanin, and SPF) Using Response Surface Methodology*

3.2.1 *Result of Betacyanin Content Analysis with response surface contour plot*

Figure 1 presents three-dimensional contour and surface plots illustrating the effects of homogenization time and speed on betacyanin levels. Different gradations of green represent betacyanin concentration, with dark green indicating the highest level (>0.015%). The results suggest that increasing both homogenization time and speed enhances the release and stabilization of betacyanin pigments within the emulsion system. Peak betacyanin levels were observed at homogenization times of 9–10 min and speeds of 8000–10,000 rpm, as shown at the apex of the three-dimensional surface plot. These findings are consistent with previous studies reporting that more intense agitation and longer processing times improve pigment extraction efficiency and stability (Lestari, 2021; Oktaviani et al., 2023). High-speed homogenization increases shear forces and particle dispersion, which in turn influence the solubility and stability of phytopigments in the aqueous phase. Furthermore, the heat generated during mechanical homogenization may facilitate the release of pigments from the plant cell matrix (Pratiwi et al., 2021).

Result of Betacyanin Content Analysis with response surface contour plot Figure 2 shows the contour plot and response surface of the effect of homogenization time and the ratio of beet extract to Waru leaves on anthocyanin levels.

The results indicate that increasing the homogenization time within the range of 7–9 min and using an extract ratio of 5 leads to higher anthocyanin levels. This trend is reflected by the progressively darker contour colors and the peak of the curve on the three-dimensional surface plot. The increase in anthocyanin levels corresponds with the higher proportion of beet extract in the formulation, considering that betacyanin and anthocyanin are the primary pigments soluble in the aqueous phase (Lembong & Utama, 2021; Adam, 2017). Longer homogenization allows for a more uniform distribution of phenolic compounds and facilitates the release of active constituents from the extract matrix (Saputri et al., 2023). Although the effect was not statistically significant, the combination of a 9-min homogenization time and an extract ratio of 5 produced the highest anthocyanin concentration. These findings support the notion that homogenization conditions can be optimized to maximize the content of active compounds in natural cosmetic formulations (Yani et al., 2023; Rahayu et al., 2022).

3.2.2 *Result of Betacyanin Content Analysis with response surface contour plot*

Figure 3 shows the contour plot and response surface plot of the interaction effect between homogenization time (min) and speed (rpm) on SPF levels. The dark green areas on the contour plot represent the highest SPF values, observed at homogenization times of 9–10 min and speeds between 9500 and 10,000 rpm. This suggests that both variables contribute to increasing SPF, although the effect was not yet statistically significant. The three-dimensional surface plot further illustrates a peak (optimal) point within the time range of 7–10 min and speeds of 9000–10,000 rpm. This observation aligns with the principle that longer homogenization duration and higher speed improve the dispersion of active particles, thereby enhancing UV absorption and SPF efficacy (Ermawati et al., 2020). High-speed homogenization promotes more uniform emulsification, allowing active compounds such as betacyanin, anthocyanin, and ZnO to be evenly distributed within the lip tint matrix, ultimately contributing to increased SPF values (Yani et al., 2023; Auliani et al., 2020).

3.2.3 *Pareto Diagram*

Figure 4 presents a Pareto diagram showing which variables are most influential in the experiment. The independent variables exerting the greatest influence

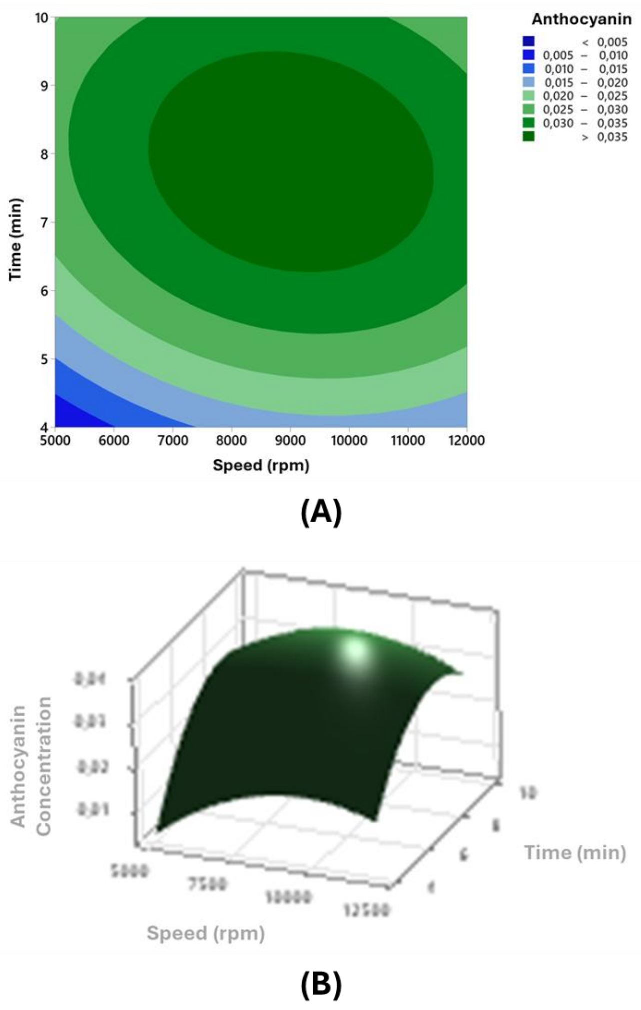


Figure 2. Effect of Extract Ratio and Homogenization Speed on Anthocyanin Concentration. X-axis: Extract Ratio (Red Beet : Waru Leaves) Y-axis: Homogenization Speed (rpm) Z-axis: Anthocyanin Concentration (%). Contour plot (a) and 3D surface plot (b) illustrating the combined effects of extract ratio and homogenization speed on anthocyanin concentration based on the RSM model. Higher beet content and optimized shear forces increased anthocyanin yield within the formulation.

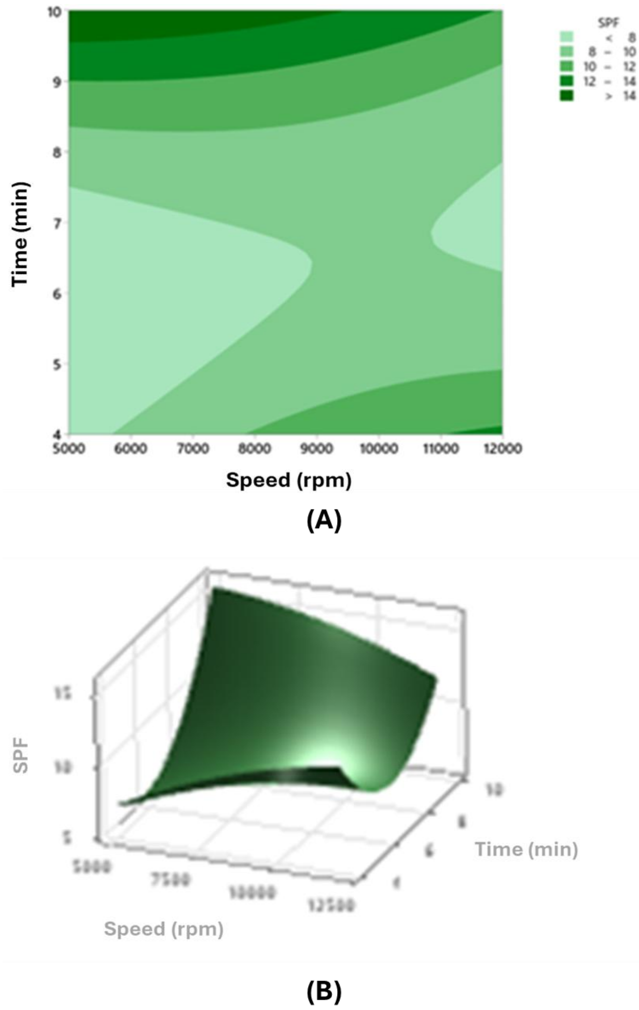


Figure 3. Combined Effects of Extract Ratio and Homogenization Time on SPF Value. X-axis: Extract Ratio (Red Beet : Waru Leaves) Y-axis: Homogenization Time (min) Z-axis: SPF Value. Contour plot (a) and 3D surface plot (b) showing the interaction between extract ratio and homogenization time on SPF values of the liptint formulation. Increased homogenization time enhanced pigment distribution and ZnO dispersion, improving SPF performance.

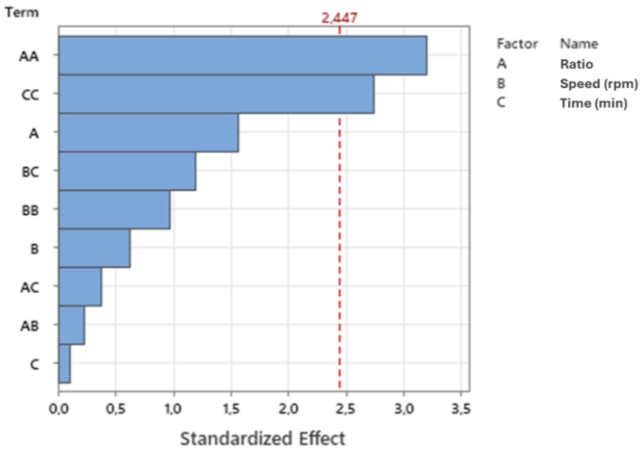


Figure 4. Pareto Chart of Standardized Effects for Factors Influencing Betacyanin Concentration. X-axis: Standardized Effect, Y-axis: Term / Factor and Interaction. Pareto chart illustrating the standardized effects of the experimental factors and their interactions on betacyanin concentration. The red significance threshold line (α = 0.05) indicates that the quadratic terms AA and CC exert the strongest significant effects on betacyanin levels, followed by factor A, demonstrating that extract ratio and time-dependent nonlinear effects are the primary determinants of pigment concentration.

on betacyanin levels in lip tint samples are the ratio of beetroot extract to Waru leaf extract (A), homogenization speed (rpm) (B), and homogenization time (min) (C). As shown in the graph, the AA term (the square of the extract ratio) and the CC term (the square of time) exceed the dotted red line, which represents the significance threshold of 2.447. This indicates that these variables have a statistically significant effect on betacyanin levels.

Meanwhile, the linear effects of homogenization speed (B) and homogenization time (C) fall below the significance threshold, indicating statistically non-significant contributions to betacyanin levels within the tested experimental domain. This non-significance likely reflects the limited sensitivity of betacyanin release to small incremental changes in these parameters, combined with inherent biological variability in plant-derived pigments. Nevertheless, these parameters remain functionally relevant for product performance. Homogenization speed governs shear-induced droplet disruption and pigment dispersion, which directly affects emulsion stability, optical uniformity, and long-term color retention. Likewise, processing time, although not statistically influential, supports adequate disintegration of plant particulates and prevents phase separation during storage. Thus, even statistically non-significant variables contribute to critical quality attributes of the lip tint by influencing microstructural organization and the robustness of the final formulation.

3.3 *Result Optimization*

3.3.1 *Determining the optimum value of the variables that have been determined using the desirability function approach.*

This approach was employed to determine the optimum values of the independent variables, which were then adjusted to obtain the estimated optimum value, denoted as d(i), where $0 \le d \le 1$. The desirability function analysis represents the outcome of modifying combinations of the independent variables to achieve the optimum response, as presented in Table 3.

Based on Table 3, two experiments were conducted using optimal formulation parameters: an extract ratio of 4.4, a homogenization speed of 9,595 rpm (rounded to 10,000 rpm), and a homogenization time of 9.03 min. In the experiment containing ZnO, the formulation exhibited betacyanin and anthocyanin contents of 0.0104% and 0.0593%, respectively, with an SPF value of 13.8924. In contrast, the formulation without ZnO showed similar pigment levels (0.0109% betacyanin and 0.0434% anthocyanin) but a lower SPF of 11.0472. The increased SPF in the ZnO-containing sample can be attributed to the role of ZnO as a physical UV filter, with its fine particles scattering, reflecting, and partially absorbing UVA and UVB radiation, thereby enhancing photoprotective performance regardless of pigment concentration. Based on the predicted optimum curve, the error percentage for the formulation without ZnO was relatively low (0.336%), whereas the ZnO-containing formulation exhibited a higher error (20.22%). This elevated error is primarily related to the SPF response, as the actual SPF exceeded the predicted target. Mechanistically, minor variations in ZnO dispersion, particle agglomeration, or distribution within the emulsion can lead to disproportionate increases in SPF, resulting in greater deviation from the model prediction. These findings indicate that, although pigment levels remain relatively stable, the photoprotective response is highly sensitive to ZnO behavior within the formulation.

Although the predicted and experimental values generally showed good agreement, the higher deviation observed in the ZnO-containing sample indicates that UV-active ingredients introduce greater

Table 3. Predicted and experimental optimization results of the liptint formulation

Data Type	Extract ratio (red beet: waru leaves)	Speed (rpm)	Time (min)	Betacyanin Content (%)	Anthocyanin Content (%)	SPF value	Composite Desirability
Prediction (Without ZnO)	4.4	9595	9.03	0.0132	0.0403	11.0843	0.8184
Testing With ZnO	4.4	10,000	9.03	0.0104	0.0593	13.8924	-
Testing Without ZnO	4.4	10,000	9.03	0.0109	0.0434	11.0472	-

variability due to their sensitivity to dispersion efficiency and particle–pigment interactions. Overall, these results confirm that the selected formulation parameters provide a robust processing window for producing a stable, high-performance natural lip tint.

4. Conclusion

Based on the results and discussion, the liptint formulation using red beet (*Beta vulgaris* L.) and waru leaves (*Hibiscus tiliaceus* L.) extracts was successfully optimized with the incorporation of ZnO under selected experimental conditions. The optimization process conducted through Response Surface Methodology (RSM) yielded optimal conditions to achieve the targeted SPF value while also evaluating the effect of ZnO addition. In the formulation containing ZnO, betacyanin and anthocyanin contents reached 0.0104% and 0.0593%, respectively, with an SPF value of 13.8924, whereas the formulation without ZnO showed 0.0109% betacyanin, 0.0434% anthocyanin, and an SPF value of 11.0472. These differences can be explained by the role of ZnO as an inorganic UV filter whose particles scatter and absorb UV radiation and can also interact with natural pigment molecules; partial adsorption of anthocyanin and betacyanin onto the ZnO surface may increase their photostability, thereby improving overall SPF effectiveness. These results demonstrate that extract ratio, homogenization speed, and processing time significantly influence pigment concentration and SPF performance, contributing to the stability of the oil-in-water (O/W) emulsion system. Overall, this study indicates that integrating ZnO into a natural pigment-based lip tint enhances not only UV protection but also the functional performance of the formulation, highlighting its potential for development as a multifunctional, plant-derived cosmetic product.

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