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Optimization of Green Tea Leaf Extract Serum Using Xanthan Gum and Carbopol

Optimasi Serum Ekstrak Daun Teh Hijau Menggunakan Xanthan Gum dan Karbopol

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ABSTRACT

Green tea leaves (*Camellia sinensis*) contain polyphenolic compounds with antioxidant potential and can be developed into topical serum preparations. This study aimed to optimize the combination of xanthan gum and carbopol in a green tea leaf ethanol extract serum using the Simplex Lattice Design method. Serum formulations were prepared using different proportions of xanthan gum and carbopol, then evaluated for viscosity, spreadability, adhesiveness, pH, organoleptic properties, and physical stability using a cycling test. The optimum formulation consisted of 55% xanthan gum and 45% carbopol, with a desirability value of 1.0. Verification showed that the predicted and observed responses were not significantly different. The optimum formula met the initial physical quality requirements; however, the cycling test showed changes in viscosity, spreadability, and adhesiveness. These findings indicate that xanthan gum and carbopol can be optimized to produce green tea extract serum, although further stability improvement is required.

ABSTRAK

Daun teh hijau (*Camellia sinensis*) mengandung senyawa polifenol yang berpotensi sebagai antioksidan dan dapat dikembangkan dalam bentuk sediaan serum topikal. Penelitian ini bertujuan mengoptimasi kombinasi xanthan gum dan karbopol dalam formula serum ekstrak etanol daun teh hijau menggunakan metode *Simplex Lattice Design*. Formula serum dibuat dengan berbagai proporsi xanthan gum dan karbopol, kemudian dievaluasi terhadap viskositas, daya sebar, daya lekat, pH, sifat organoleptik, dan stabilitas fisik melalui cycling test. Formula optimum terdiri atas 55% xanthan gum dan 45% karbopol dengan nilai desirability 1,0. Hasil verifikasi menunjukkan bahwa respons prediksi dan observasi tidak berbeda signifikan. Formula optimum memenuhi persyaratan mutu fisik awal; namun, uji cycling test menunjukkan perubahan viskositas, daya sebar, dan daya lekat. Hasil ini menunjukkan bahwa kombinasi xanthan gum dan karbopol dapat dioptimasi untuk menghasilkan serum ekstrak teh hijau, meskipun peningkatan stabilitas masih diperlukan.

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1. INTRODUCTION

Green tea leaves (*Camellia sinensis*) are widely used as a natural source of bioactive compounds, particularly polyphenols, flavonoids, catechins, tannins, and other antioxidant constituents (Zhao et al., 2022). These compounds are associated with the ability to reduce oxidative stress caused by free radicals, which is one of the major factors contributing to skin damage and premature aging (Prasanth et al., 2019). Because of this antioxidant potential, green tea leaf extract has been increasingly explored as an active ingredient in cosmetic and topical preparations (Koch et al., 2019).

Serum is a topical dosage form commonly used in cosmetic preparations because it has a light texture, is easily absorbed, and is suitable for delivering active ingredients to the skin (Surber & Kottner, 2017). A good serum formulation should have acceptable physical properties, including appropriate viscosity, spreadability, adhesiveness, pH, and physical stability (Porcheron et al., 2014). These parameters are important because they influence product appearance, ease of application, residence time on the skin, and user acceptability (Porcheron et al., 2014). Therefore, the selection and optimization of excipients are essential in developing a stable and acceptable serum preparation (Chang et al., 2013).

Xanthan gum and carbopol are commonly used as viscosity-enhancing and gel-forming agents in semisolid and serum formulations. Xanthan gum can improve consistency and physical stability, whereas carbopol provides good thickening ability and clarity at appropriate concentrations (Mitura et al., 2020). However, the proportion of these polymers must be optimized because excessive viscosity may reduce spreadability, while insufficient viscosity may decrease adhesiveness and formulation stability (Tai et al., 2014). An optimization approach is therefore required to determine the most suitable polymer combination for producing a serum with balanced physical characteristics.

Simplex Lattice Design (SLD) is a useful method for optimizing formulations involving combinations of components because it can evaluate the effect of each component and their interaction on selected responses (Politis et al., 2017). Although green tea extract has been studied as a cosmetic active ingredient, optimization of xanthan gum and carbopol combinations in green tea leaf extract serum remains limited. Therefore, this study aimed to optimize the combination of xanthan gum and carbopol in an ethanol extract serum of green tea leaves using SLD, with viscosity, spreadability, and adhesiveness as the main response parameters.

2. METHODS

2.1. Materials and Instruments

The instruments used in this study included a maceration vessel, analytical balance (Ohaus®, United States), pH meter (Smart Sensor, China), digital viscometer (Brookfield RV, United States), hot plate (C-MAG HS 7®, Germany), rotary evaporator (Heidolph, Germany), grinder (Herba Medicine Grinder FW 177, Indonesia), mortar and pestle (Haldenwanger, Germany), oven (Memmert, Germany), furnace (B-One, Indonesia), crucibles, desiccator, stopwatch, glassware, No. 40 sieve, adhesiveness tester, and spreadability tester.

The materials used were green tea leaves obtained from the Research Institute for Tea and Cinchona, PPTK, Indonesia; 96% ethanol, technical grade, from UD. Pelita Hati; hydrochloric acid; ferric chloride; xanthan gum (Qingdao ICD Biochemistry, China); carbopol 940 (Corel Pharma Chem, India); glycerin (PT. Wilmar Nabati Indonesia, Indonesia); methylparaben (Ueno Fine Chemicals Industry, Japan); triethanolamine (TEA; Petronas, Malaysia); and distilled water.

2.2. Plant Material and Extract Preparation

Green tea leaf simplicia (*C. sinensis*) was obtained from the Research Institute for Tea and Cinchona, PPTK, Ciwidey, Bandung, West Java, Indonesia. Plant authentication was performed at the BRIN Laboratory, Cibinong, Bogor, West Java, Indonesia. Plant authentication was recorded under certificate number B-2598/II.6.2/IR.01.02/6/2025.

Green tea leaf extraction was carried out by maceration using 500 g of green tea leaf powder and 5,000 mL of 96% ethanol as the solvent (Illah et al., 2024). The mixture was allowed to stand for 24 h, after which the macerate was separated from the residue. The maceration process was repeated twice using the same solvent. All resulting macerates were pooled and concentrated via rotary evaporation at 40 °C. Subsequent concentration was performed using a water bath at 50 °C for 30–60 minutes to yield a thick extract with the target consistency.

2.3. Formulation Design and Serum Preparation

The serum formulation was optimized using Design-Expert version 13 with the Simplex Lattice Design method. Xanthan gum and carbopol were selected as the optimized components, while viscosity, adhesiveness, and spreadability were used as response parameters. The lower and upper limits for each component were set at 0% and 100%, respectively. The total polymer concentration in the serum formulation was fixed at 0.5%; therefore, the percentage values generated by the design represented the relative proportions of xanthan gum and carbopol within the total polymer concentration.

The experimental runs generated using Design-Expert are presented in **Table 1**. The eight experimental runs consisted of five formula combinations and three repeated design points. The relative polymer proportions were then converted into the complete serum formulation. The full composition of each green tea leaf extract serum formulation is presented in **Table 2**.

Table 1. Composition of xanthan gum and carbopol generated using Design-Expert

Run	Xanthan gum (%)	Carbopol (%)
1	0	100
2	75	25
3	50	50
4	100	0
5	0	100
6	25	75
7	100	0
8	50	50

Table 2. Composition of green tea leaf extract serum formulations

Ingredient	Function	F 1	F2	F3	F4	F5	F6	F7	F8
Green tea leaf extract	Active ingredient	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Xanthan gum	Thickening agent	0	0.375	0.25	0.5	0	0.125	0.5	0.25
Carbopol 940	Thickening agent	0.5	0.125	0.25	0	0.5	0.375	0	0.25
Glycerin	Penetration enhancer	45	45	45	45	45	45	45	45
Methylparaben	Preservative	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
TEA	Alkalizing agent	q.s.	q.s.	q.s.	q.s.	q.s.	q.s.	q.s.	q.s.
Distilled water	Solvent	ad 100	ad 100	ad 100	ad 100	ad 100	ad 100	ad 100	ad 100

Note: Values are expressed as % w/w unless otherwise stated. TEA = triethanolamine; q.s. = quantum satis; ad 100 = added to 100%.

Serum preparation began by preparing the instruments and weighing all ingredients according to the formulation shown in **Table 2**. Carbopol 940 was dispersed in hot water at 70–80°C using 20 times its weight of water to form the carbopol dispersion (Indriastuti & Puspita, 2024). Xanthan gum was separately dispersed in distilled water at 50 °C to form the xanthan gum dispersion (Wulandari et al., 2023). The two polymer dispersions were then combined and stirred until homogeneous.

Methylparaben and glycerin were mixed separately until homogeneous and then incorporated into the combined polymer base. The ethanol extract of green tea leaves was added as the active ingredient and homogenized. The pH of the preparation was measured, and TEA was added gradually until the pH reached 4.5–6.5. Distilled water was then added to obtain the final formula weight (Sawiji et al., 2024).

2.4. Physical Evaluation

The serum was evaluated to determine whether the 96% ethanol extract serum of green tea leaves met the expected physical quality parameters. The evaluation included organoleptic properties, homogeneity, pH, spreadability, viscosity, adhesiveness, and physical stability.

Organoleptic properties were evaluated by observing the physical appearance, color, and odor of the serum (Septyani et al., 2024). Homogeneity was assessed by placing 0.5 g of serum on a glass slide and covering it with another slide. The preparation was visually examined for the presence of coarse particles or unmixed components (Widyaningrum et al., 2024).

The pH of the serum was measured using a semisolid pH meter. The electrode was inserted into the preparation and allowed to stabilize before the value was recorded. The acceptable facial skin pH range was 4.5–6.5 (Angraini et al., 2024).

Spreadability was evaluated by placing 0.5 g of serum at the center of a round glass plate with a diameter of 15 cm. Another glass plate and a 150 g weight were placed over the sample and left for 1 min. The spread diameter was then measured and recorded. The optimal spreadability range for comfortable semisolid application is 5–7 cm (Widyaningrum et al., 2024).

Viscosity was measured by placing 100 mL of serum in a beaker glass. The spindle number and rotational speed were first optimized. The sample was then positioned under the Brookfield viscometer until the spindle was immersed to the required level. The viscometer was operated until the viscosity value was displayed and recorded (Sawiji et al., 2024).

Adhesiveness was evaluated by placing 0.25 g of serum between two glass slides. A 1 kg load was placed on the slides for 5 min. The slides were then mounted on the adhesiveness tester, and an 80 g load was applied. The load was released, and the time required for the two slides to separate was recorded (Happe et al., 2024). A good adhesiveness value is greater than 4 s (Voigt, 1995).

All quantitative physical evaluations were performed in triplicate, and the results are presented as mean ± standard deviation.

2.5. Stability Evaluation

Physical stability was evaluated using a cycling test. The serum was stored in a refrigerator at 4°C for 24 h and then transferred to an oven at 40°C for 24 h. This procedure was repeated for six cycles. The physical condition of the serum before and after the cycling test was then compared (Dahlizar et al., 2022). The evaluated parameters included organoleptic properties, color, odor, physical form, homogeneity, pH, viscosity, spreadability, and adhesiveness (Rohmanah et al., 2024).

2.6. Verification and Statistical Analysis

The optimum formula was verified by comparing the predicted values generated by Simplex Lattice Design with the experimental values for spreadability, adhesiveness, and viscosity. The comparison was analyzed using a one-sample *t*-test (Suryani et al., 2017). A two-tailed significance value greater than 0.05 indicated no significant difference between the experimental and predicted values, whereas a value below 0.05 indicated a significant difference (Pertiwi et al., 2025).

3. RESULTS AND DISCUSSION

3.1. Green tea leaf extract

Green tea leaf simplicia was extracted by maceration using 96% ethanol. The resulting extract had a thick consistency, a brownish-green color, and the characteristic odor of green tea leaves, as shown in **Figure 1A**. The extraction process produced a yield of 32.69%, indicating that 96% ethanol extracted a substantial proportion of soluble constituents from the simplicia. This yield exceeded the minimum extract yield requirement of 7.8% (Kementerian Kesehatan Republik Indonesia, 2017), suggesting that the extraction process was adequate for further formulation development. The use of 96% ethanol was suitable for extracting polar to semi-polar compounds from green tea leaves (Alara et al., 2021). The high yield obtained in this study indicates that the extraction conditions were appropriate for recovering extractable constituents. However, extract yield alone does not determine formulation quality or functional performance. Therefore, the extract was incorporated into serum formulations and further evaluated based on physical quality parameters.

3.2. Physical appearance and homogeneity of serum formulations

Green tea leaf extract serum was prepared in eight formulations using different proportions of xanthan gum and carbopol as thickening agents. The prepared formulations are shown in **Figure 1B**. All formulations had a green tea-like odor, brownish-green color, and homogeneous appearance. The main difference among the formulations was their texture, which varied according to the xanthan gum–carbopol ratio.

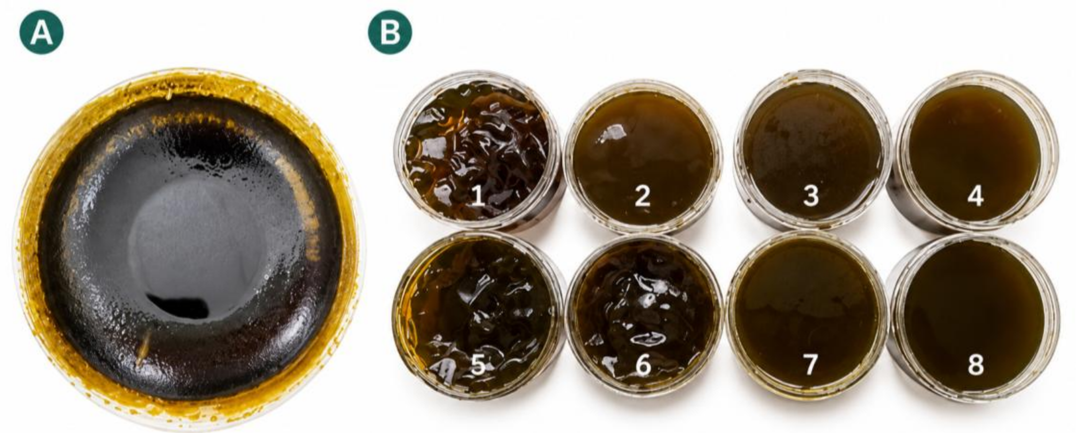

Figure 1. Green tea leaf extract (A) and green tea leaf extract serum formulations (B)

Table 3. Organoleptic and homogeneity evaluation of the eight serum formulations

Formula	Odor	Color	Texture	Homogeneity
1	Green tea-like	Brownish green	Semisolid, heavy on skin	Homogeneous
2	Green tea-like	Brownish green	Thick liquid, spreadable, slightly sticky	Homogeneous
3	Green tea-like	Brownish green	Thick liquid, spreadable, slightly sticky	Homogeneous
4	Green tea-like	Brownish green	Thick liquid, spreadable, slightly sticky	Homogeneous
5	Green tea-like	Brownish green	Semisolid, heavy on skin	Homogeneous
6	Green tea-like	Brownish green	Thick liquid, spreadable, slightly sticky	Homogeneous
7	Green tea-like	Brownish green	Thick liquid, spreadable, slightly sticky	Homogeneous
8	Green tea-like	Brownish green	Thick liquid, spreadable, slightly sticky	Homogeneous

The organoleptic and homogeneity results show that variations in xanthan gum and carbopol did not alter the odor, color, or visible uniformity of the serum. The brownish-green color was mainly derived from the green tea leaf extract, while the characteristic odor reflected the natural aroma of the extract. The homogeneous appearance across all formulations suggests that the extract and excipients were sufficiently dispersed in the serum base. However, formulations with higher carbopol content produced a denser texture, whereas formulations containing a higher proportion of xanthan gum were generally easier to spread.

3.3. Physical response evaluation

Viscosity, spreadability, and adhesiveness were selected as the main response parameters because they directly influence the practical quality of a topical serum. Viscosity affects flow behavior and ease of product application, spreadability determines how easily the serum distributes on the skin, and adhesiveness reflects the ability of the preparation to remain in contact with the application surface. The response values of the eight formulations are presented in **Table 4**.

The response data showed a consistent relationship among viscosity, spreadability, and adhesiveness. Formulations with higher viscosity tended to have lower spreadability and longer adhesiveness, whereas formulations with lower viscosity spread more easily but showed shorter adhesion time. This pattern is consistent with the general behavior of semisolid preparations, where increased internal resistance limits flow and spreading but improves contact duration on the surface (Calixto et al., 2015; Calixto & Campos, 2017).

The highest viscosity values were observed in formulations containing higher carbopol proportions, particularly Formulas 1 and 5. These formulations also showed longer adhesiveness and lower spreadability. By contrast, Formula 7, which contained xanthan gum without carbopol, showed the lowest viscosity and adhesiveness but the highest spreadability. These findings indicate that carbopol contributed more strongly to viscosity and adhesiveness, while xanthan gum promoted better spreadability. Small differences between repeated design points may have been caused by manual preparation factors, including mixing intensity, polymer hydration, and dispersion uniformity during serum preparation.

3.4. Model fitting and response analysis

The response values were analyzed using Design-Expert version 13 based on the Simplex Lattice Design model. ANOVA and model-fit parameters were used to determine whether the selected models adequately described the effects of xanthan gum and carbopol on viscosity, spreadability, and adhesiveness. The model-fit results are presented in **Table 5**.

The model *p*-values for all response parameters were below 0.05, indicating that the models were statistically significant. The lack-of-fit values were above 0.05, showing that lack of fit was not significant and that the models were suitable for explaining the experimental responses (Pertiwi et al., 2025). The R^2 values for viscosity, spreadability, and adhesiveness were above 0.70, indicating that a high proportion of response variability was explained by the models.

The differences between adjusted R^2 and predicted R^2 were below 0.20 for all responses, suggesting acceptable agreement between the fitted and predicted models (Apriani et al., 2023). Adequate precision values were greater than 4, indicating an adequate signal-to-noise ratio and confirming that the models could be used to navigate the design space (Dritsa et al., 2009; Hajrin et al., 2021). Overall, these statistical results support the reliability of the selected models for optimizing the xanthan gum–carbopol combination.

The polynomial equations generated by Simplex Lattice Design are shown in **Table 6**. In these equations, A represents xanthan gum and B represents carbopol.

Table 4. Physical response values of green tea leaf extract serum formulations

Formula	Viscosity (cPs)	Spreadability (cm)	Adhesiveness (s)
1	29,546 ± 174.41	5.51 ± 0.25	22.09 ± 1.34
2	2,644 ± 16.02	6.48 ± 0.03	5.92 ± 0.74
3	3,633 ± 27.35	6.74 ± 0.10	8.31 ± 0.27
4	2,278 ± 15.55	7.04 ± 0.02	2.80 ± 0.44
5	26,616 ± 137.28	5.92 ± 0.01	16.76 ± 1.73
6	12,366 ± 116.14	5.88 ± 0.12	14.70 ± 2.80
7	1,867 ± 0.00	7.64 ± 0.07	0.86 ± 0.09
8	3,544 ± 41.60	6.79 ± 0.12	5.24 ± 0.72

Note: Values are presented as mean ± SD.

Table 5. ANOVA and model-fit parameters for each response

Parameter	Standard	Viscosity	Spreadability	Adhesiveness
Model (*p*-value)	< 0.05	< 0.0001	0.0028	0.0004
Lack of fit (*p*-value)	> 0.05	0.2518	0.5680	0.5000
R^2	> 0.70	0.9888	0.7974	0.8924
Adjusted R^2	-	0.9844	0.7637	0.8745
Predicted R^2	-	0.9713	0.6096	0.8032
Adjusted R^2 − Predicted R^2	< 0.20	0.0131	0.1541	0.0713
Adequate precision	> 4	30.9770	9.1640	13.3046
Mixture order	-	Quadratic	Linear	Linear

Table 6. Simplex Lattice Design equations for each response

Response	Equation
Viscosity	$Y = 2519.76A + 27748B - 44185AB$
Spreadability	$Y = 7.32A + 5.59B$
Adhesiveness	$Y = 0.7847A + 18.30B$

Note: A = xanthan gum; B = carbopol.

The viscosity response followed a quadratic model, indicating that both individual polymer effects and polymer interaction influenced viscosity. Carbopol showed a larger positive coefficient than xanthan gum, demonstrating its stronger contribution to viscosity. The negative interaction coefficient suggests that combining xanthan gum and carbopol reduced viscosity compared with the expected additive contribution of each polymer (**Figure 2A**). This result indicates that carbopol was the dominant viscosity-building component in the serum system.

The spreadability response followed a linear model. Xanthan gum had a larger coefficient than carbopol, indicating that increasing the proportion of xanthan gum increased spreadability. This finding is consistent with the response data, where formulations containing higher xanthan gum proportions showed greater spreading capacity. The contour plot in **Figure 2B** further illustrates that increasing xanthan gum and reducing carbopol shifted the formulation toward higher spreadability.

The adhesiveness response also followed a linear model. Carbopol had a substantially larger coefficient than xanthan gum, showing that carbopol contributed more strongly to adhesion time. This result reflects the ability of carbopol to form a stronger gel network, which can increase the residence time of the preparation on the application surface. The contour plot in **Figure 2C** supports this interpretation by showing that higher carbopol proportions were associated with increased adhesiveness.

3.5. Optimum formula recommendation

The optimum formula was selected by setting acceptable limits for viscosity, spreadability, and adhesiveness. The optimization targets are presented in **Table 7**. All response goals were set as "in range" because the purpose of the formulation was to obtain a balanced serum that met the required physical quality limits rather than maximizing or minimizing a single response.

The recommended optimum formula consisted of 55% xanthan gum and 45% carbopol, with a desirability value of 1.00 (**Table 8**). The predicted responses were 2936 cPs for viscosity, 6.542 cm for spreadability, and 8.667 s for adhesiveness. A desirability value close to 1.00 indicates that the selected formula closely meets the optimization criteria (Nurcholis et al., 2023, 2024).

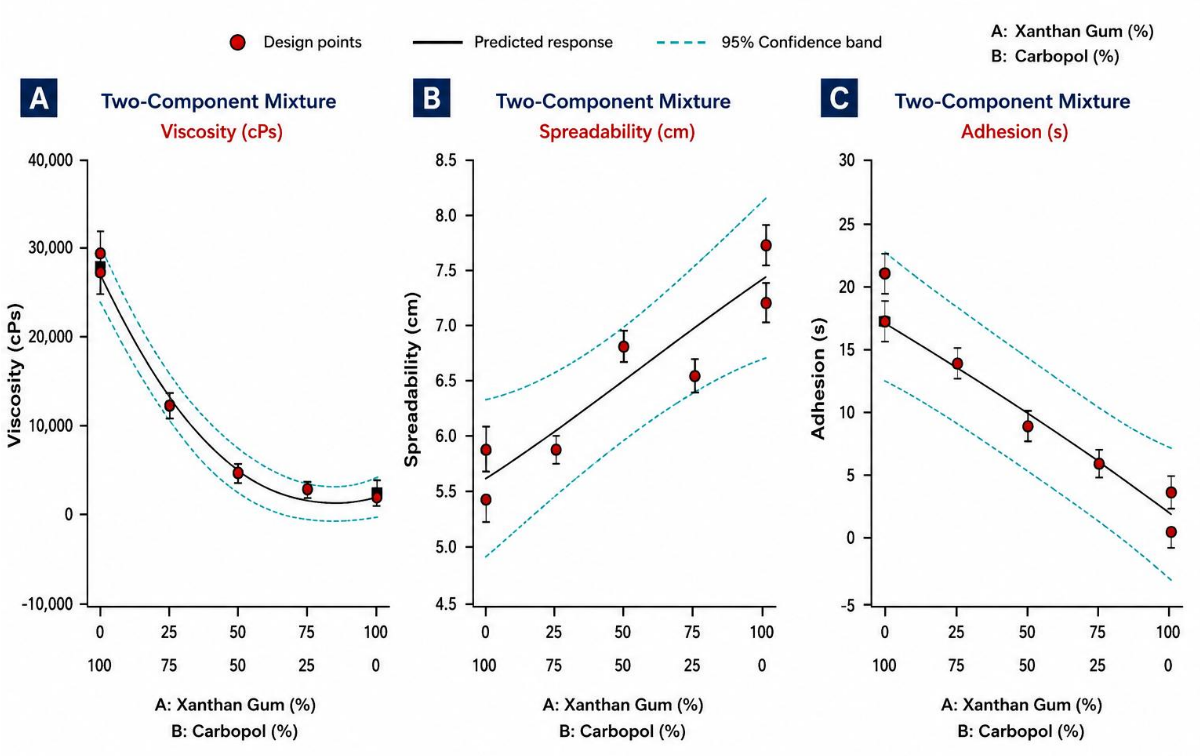

Figure 2. Contour plot of the viscosity (A), spreadability (B), and adhesion (C) responses

Table 7. Optimization criteria for the response parameters

Response	Goal	Lower limit	Upper limit
Viscosity	In range	2,000 cPs	50,000 cPs
Spreadability	In range	5 cm	7 cm
Adhesiveness	In range	4 s	300 s

Table 8. Recommended optimum formula generated by Simplex Lattice Design

Xanthan gum (%)	Carbopol (%)	Viscosity (cPs)	Spreadability (cm)	Adhesiveness (s)	Desirability
55	45	2936	6.542	8.667	1.000

The predicted polymer ratio was then converted into the final optimum formula composition. Because the total polymer concentration was fixed at 0.5%, the optimum formula contained 0.275% xanthan gum and 0.225% carbopol. The complete composition of the optimum formula is shown in **Table 9**.

The selected formula was considered appropriate because it produced a balanced physical profile. The combination of xanthan gum and carbopol allowed the serum to maintain sufficient viscosity and adhesiveness while remaining spreadable. This balance is important for a topical serum because excessive viscosity may reduce user comfort, whereas very low viscosity may reduce contact time and product retention on the skin.

3.6. Verification of the optimum formula

The optimum formula was prepared and evaluated to verify the accuracy of the predicted responses generated by the SLD model. The organoleptic and homogeneity evaluation showed that the formula had the characteristic odor of green tea leaves, a brownish-green color, a thick liquid texture that was easy to spread and slightly sticky, and a homogeneous appearance (**Table 10**).

The physical evaluation showed that the optimum formula had a pH of 5.0 ± 0, viscosity of 2933.33 ± 88.44 cPs, spreadability of 6.61 ± 0.065 cm, and adhesiveness of 7.58 ± 1.86 s (**Table 11**). These values were within the targeted ranges, indicating that the selected xanthan gum–carbopol combination produced acceptable initial physical properties.

The one-sample *t*-test showed that the experimental values did not differ significantly from the predicted values generated by the Simplex Lattice Design model. The significance values for viscosity, spreadability, and adhesiveness were all above 0.05 (**Table 12**). This result confirms that the model was able to predict the physical responses of the optimum formula with acceptable accuracy (Pertiwi et al., 2025).

Table 9. Composition of the optimum green tea leaf extract serum formula

Ingredient	Function	Formula (%)
Green tea leaf extract	Active ingredient	0.9
Xanthan gum	Thickening agent	0.275
Carbopol 940	Thickening agent	0.225
Glycerin	Penetration enhancer	45
Methylparaben	Preservative	0.3
TEA	Alkalizing agent	q.s.
Distilled water	Solvent	ad 100

Note: TEA = triethanolamine; q.s. = quantum satis; ad 100 = added to 100%.

Table 10. Organoleptic and homogeneity evaluation of the optimum formula

Replicate	Odor	Color	Texture	Homogeneity
1	Green tea-like	Brownish green	Thick liquid, spreadable, slightly sticky	Homogeneous
2	Green tea-like	Brownish green	Thick liquid, spreadable, slightly sticky	Homogeneous
3	Green tea-like	Brownish green	Thick liquid, spreadable, slightly sticky	Homogeneous

Table 11. Physical evaluation of the optimum formula

Replicate	pH	Viscosity (cPs)	Spreadability (cm)	Adhesiveness (s)
1	5.0	2967	6.67	6.60
2	5.0	2833	6.62	6.42
3	5.0	3000	6.54	9.74
Mean ± SD	5.0 ± 0	2933.33 ± 88.44	6.61 ± 0.065	7.58 ± 1.86

Table 12. Comparison of predicted and experimental responses of the optimum formula

Response	Predicted value	Experimental value	Sig. (2-tailed)	Interpretation
Viscosity (cPs)	2936	2933.33 ± 88.44	0.953	Not different
Spreadability (cm)	6.542	6.61 ± 0.065	0.214	Not different
Adhesiveness (s)	8.667	7.58 ± 1.86	0.422	Not different

3.7. Stability evaluation of the optimum formula

The physical stability of the optimum formula was evaluated using a cycling test at 4 °C and 40 °C for six cycles. The test was designed to simulate repeated temperature changes that may occur during storage and distribution (Baki, 2023; Chang et al., 2013). Organoleptic properties and homogeneity remained unchanged throughout the six cycles. The serum maintained its green tea-like odor, brownish-green color, thick liquid texture, and homogeneous appearance (**Table 13**).

The quantitative physical parameters changed gradually during the cycling test, as shown in **Table 14**. The pH decreased slightly from 5.0 to 4.9, but remained within the acceptable facial skin pH range of 4.5–6.5. This result indicates that the serum remained compatible with the expected topical pH range despite repeated temperature stress. The slight decrease in pH may be related to temperature-induced changes in the polymer matrix or changes in the chemical environment of the formulation during storage (Wahidah et al., 2024).

Table 13. Organoleptic and homogeneity evaluation during six cycling-test cycles

Cycle	Odor	Color	Texture	Homogeneity
1	Green tea-like	Brownish green	Thick liquid, spreadable, slightly sticky	Homogeneous
2	Green tea-like	Brownish green	Thick liquid, spreadable, slightly sticky	Homogeneous
3	Green tea-like	Brownish green	Thick liquid, spreadable, slightly sticky	Homogeneous
4	Green tea-like	Brownish green	Thick liquid, spreadable, slightly sticky	Homogeneous
5	Green tea-like	Brownish green	Thick liquid, spreadable, slightly sticky	Homogeneous
6	Green tea-like	Brownish green	Thick liquid, spreadable, slightly sticky	Homogeneous

Table 14. Physical evaluation of the optimum formula during six cycling-test cycles

Cycle	Viscosity (cPs)	pH	Spreadability (cm)	Adhesiveness (s)
1	2733.33 ± 33.50	5.0	6.70 ± 0.10	6.77 ± 0.25
2	2577.66 ± 50.84	5.0	7.05 ± 0.24	6.15 ± 1.14
3	2533.33 ± 33.50	5.0	7.16 ± 0.90	5.89 ± 0.76
4	2511.33 ± 41.60	4.9	7.36 ± 0.04	5.31 ± 0.57
5	2333.33 ± 27.35	4.9	7.57 ± 0.06	4.82 ± 0.30
6	2278.00 ± 15.55	4.9	7.88 ± 0.04	4.13 ± 0.15

Note: Values are presented as mean ± SD, n = 3.

Viscosity decreased progressively from 2733.33 ± 33.50 cPs in cycle 1 to 2278.00 ± 15.55 cPs in cycle 6. This decrease was accompanied by increased spreadability and reduced adhesiveness. The pattern suggests that repeated heating and cooling may weaken polymer interactions in the xanthan gum–carbopol gel network, resulting in a less viscous preparation with lower adhesion and greater spreading capacity (Slamet et al., 2020). This interpretation is consistent with the relationship observed in the initial response evaluation, where lower viscosity was associated with higher spreadability.

The increase in spreadability from 6.70 ± 0.10 cm to 7.88 ± 0.04 cm indicates that the serum became easier to spread after repeated temperature stress. However, the spreadability value exceeded the target range of 5–7 cm after the second cycle. Adhesiveness decreased from 6.77 ± 0.25 s to 4.13 ± 0.15 s but remained above the minimum acceptable value of 4 s by the sixth cycle. These findings suggest that the optimum formula maintained several key physical quality parameters, including organoleptic stability, homogeneity, pH, viscosity, and adhesiveness, but showed reduced control of spreadability during cycling.

Overall, the optimized formula met the initial physical quality requirements and was successfully predicted by the Simplex Lattice Design model. Nevertheless, the cycling test showed that repeated temperature stress affected viscosity, spreadability, and adhesiveness. The main limitation of the formula was the increase in spreadability beyond the targeted range during stability testing. Further formulation refinement may therefore be required to improve resistance to temperature-induced physical changes, particularly if the product is intended for storage or distribution under variable temperature conditions.

4. CONCLUSION

The combination of xanthan gum and carbopol influenced the physical characteristics of the green tea leaf extract serum, particularly viscosity, spreadability, and adhesiveness. Optimization using the SLD method produced an optimum formula containing 55% xanthan gum and 45% carbopol within a total polymer concentration of 0.5%, equivalent to 0.275% xanthan gum and 0.225% carbopol. The optimum formula showed acceptable initial physical properties, with a viscosity of 2933.33 ± 88.44 cPs, spreadability of 6.61 ± 0.065 cm, adhesiveness of 7.58 ± 1.86 s, and pH of 5.0 ± 0. The predicted and experimental values were not significantly different, indicating that the SLD model adequately predicted the optimum formulation. However, the cycling test showed changes in viscosity, spreadability, and adhesiveness, with spreadability exceeding the target range after repeated temperature stress. These findings indicate that the xanthan gum–carbopol combination can be used to optimize the initial physical quality of green tea leaf extract serum, although further formulation refinement is needed to improve its physical stability during storage.

AUTHOR CONTRIBUTIONS

Conceptualization, N.F. and R.D.P.; methodology, N.F., R.D.P., and H.Z.; software, H.Z.; validation, N.F. and R.D.P.; formal analysis, R.D.P. and H.Z.; investigation, H.Z.; resources, N.F. and R.D.P.; data curation, N.F. and H.Z.; writing—original draft preparation, R.D.P,and H.Z.; writing—review and editing, N.F. and H.Z.; visualization, H.Z.; supervision, N.F. and R.D.P.; project administration, N.F.; funding acquisition, N.F. All authors have read and agreed to the published version of the manuscript.

INSTITUTIONAL REVIEW BOARD STATEMENT

Not applicable. This study did not involve human participants, human biological materials, or experimental animals.

INFORMED CONSENT STATEMENT

Not applicable.

DATA AVAILABILITY STATEMENT

Data supporting the findings of this study are available upon reasonable request from the corresponding author.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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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, grammar, and readability of the text. After using this tool, the authors thoroughly reviewed, edited, and verified the entire content to ensure that it accurately represents their own ideas, data, analyses, and interpretations. The authors take full responsibility for the integrity, accuracy, and originality of the published work.

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