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Optimization and sensory analysis of a beetroot, apple, and oat-based beverage using response surface methodology

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Abstract

This study aimed to optimize a functional beverage formulation comprising beetroot juice, apple juice, and oats, with a focus on enhancing taste, consistency, and overall acceptability. Optimization was carried out using Response Surface Methodology (RSM) to identify the ideal proportions of ingredients that would maximize sensory quality. The developed regression models demonstrated high predictive accuracy, with R^2 values exceeding 0.94, indicating a strong correlation between the experimental data and model predictions. The optimized formulation 10.07% beetroot juice, 59.99% apple juice, and 8.86% oats yielded the highest sensory scores: 8.40 for taste, 7.19 for consistency, and 8.12 for overall acceptability. Lack-of-fit tests confirmed the adequacy and reliability of the models. Results revealed that apple juice effectively moderated the earthy flavor of beetroot juice, while oats improved texture when used at moderate levels but detracted from sensory appeal at higher concentrations. Overall, the study highlights the effectiveness of RSM in optimizing multi-ingredient beverage formulations based on sensory criteria.

Keywords: Fruit-vegetable beverage, Beetroot juice, Apple juice, Oats, Response surface methodology (RSM), Sensory analysis, Optimization

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INTRODUCTION

In recent years, there has been a growing consumer demand for healthy and natural beverages, which has, in turn, stimulated scientific research into the development of formulations incorporating plant-based ingredients (Tireki et al., 2021). These beverages are expected to provide not only nutritional benefits but also high levels of sensory acceptability (Gupta et al., 2023). Among the various plant-derived components, beetroot juice (*Beta vulgaris*) has garnered significant attention due to its rich content of betalain pigments, dietary nitrates, and antioxidant compounds, all of which have been linked to cardiovascular health and improved exercise performance (Zamani et al., 2020). Nevertheless, at elevated concentrations, beetroot juice can contribute a distinctly earthy and slightly bitter flavor, potentially diminishing overall consumer acceptance (Kardas et al., 2024).

To mitigate the sensory limitations associated with beetroot juice, the addition of sweet and acidic components such as apple juice (*Malus domestica*) is a commonly employed strategy to enhance the overall flavor profile of beetroot-based beverages (Petrović et al., 2021). The natural sugars and organic acids present in apple juice contribute to a more balanced taste and improved sensory appeal (Jakubczyk et al., 2024). Furthermore, oats (*Avena sativa*), known for their high soluble dietary fiber content, particularly β-glucan, offer functional benefits by improving texture and increasing viscosity (Kasim et al., 2022). While β-glucan aids in stabilizing the beverage matrix, its use at elevated concentrations may result in an undesirable sticky mouthfeel, thereby reducing consumer acceptability (Chakraborty et al., 2019).

In beverage formulation research, statistical optimization techniques such as Response Surface Methodology (RSM) are widely utilized to evaluate interactions among ingredients and to identify the most effective combinations for achieving desired product attributes (Wanyonyi et al., 2025). RSM facilitates the modeling of

complex, multivariate relationships and has been extensively applied in the development and optimization of food products (Kidane, 2021).

Building upon this approach, the present study aims to determine the optimal formulation of a functional beverage comprising beetroot juice, apple juice, and oats, focusing specifically on the sensory attributes of taste, consistency, and overall acceptability. The objective is to develop a formulation that maximizes consumer preference while maintaining nutritional integrity. Additionally, this study seeks to enrich the current body of knowledge by evaluating the sensory effects of combining these specific plant-based ingredients. During the optimization process, the individual and interactive effects of each component were assessed using statistical modeling, and the results were contextualized with findings from previous research. The outcomes are expected to provide valuable insights for the development of health-oriented beverages with enhanced sensory appeal.

MATERIALS AND METHODS

Materials

The raw materials beetroot, apple, and oat were procured from a local market in Şanlıurfa, Turkey, to ensure freshness and consistent quality for the beverage formulation..

Experimental design

The beverages formulated with beetroot, apple, and oat were blended in varying proportions and optimized using Response Surface Methodology (RSM), following the procedure outlined by Nayi and Kumar (2021). The proportions of beetroot juice, apple juice, and oats were treated as equidistant factors in accordance with the experimental design principles described by Montgomery (2017). Specifically, beetroot juice (10–30 mL), apple juice (40–60 mL), and oats (6–9 g) were designated as independent variables. The selection of these factor ranges was informed by preliminary trials, in which sensory attributes namely taste, consistency, and overall acceptability were evaluated and defined as dependent response variables.

Preparation of the Beetroot-Based Beverage

Freshly sourced fruits and vegetables were thoroughly washed under running tap water to eliminate surface contaminants. The beetroot was peeled and cut into small pieces prior to juice extraction using a centrifugal juicer (Philips HR1832/00). The resulting juice was subsequently filtered through muslin cloth to remove particulate matter and obtain a clear extract. Apple juice was prepared following the same procedure, utilizing the same juicer and filtration method to ensure consistency and clarity.

Subsequently, the two freshly extracted juices were combined with finely ground oats in varying proportions, as outlined in Table 1. The mixtures were homogenized using a high-speed blender (Tefal Powelix) to ensure uniform dispersion of the ingredients. Sensory evaluation was performed immediately after blending to assess the initial sensory properties of the formulations. The freshly prepared beverages were then transferred into pre-sterilized glass tubes, sealed with crown caps, and stored under frozen conditions for subsequent physicochemical and sensory analyses.

Sensory Evaluation

To evaluate the sensory attributes of the beverages, a composite scoring method and a 9-point hedonic scale were employed, following the protocols described by Dambalkar et al. (2015) and Ranganna (2004). The sensory panel comprised 15 trained individuals (8 females and 7 males), aged between 20 and 25 years, all of whom were associate degree students enrolled in the Food Technology Program. Panelists were selected based on their availability, interest in sensory analysis, and prior experience in similar evaluations. The demographic homogeneity of the panel was intentional, aimed at minimizing perceptual variability among participants. Prior to the evaluation, panelists were briefed on the study objectives and procedures, and verbal informed consent was obtained. All panelists received standardized training to evaluate the samples based on taste, consistency, and overall acceptability.

Statistical Analysis

The experimental design, data modeling, and optimization processes were conducted using Response Surface Methodology (RSM) with Design-Expert software (version 13.0; Stat-Ease Inc., Minneapolis, MN, USA). A reduced quadratic model was employed to evaluate the effects of beetroot juice, apple juice, and oat content on the sensory responses of taste, consistency, and overall acceptability. Analysis of variance (ANOVA) was used to assess the statistical significance of the models and the individual effects of each factor. Model adequacy was evaluated using lack-of-fit tests, as well as the coefficients of determination (R^2), adjusted R^2, and predicted R^2. All experiments were performed in triplicate ($n = 3$), and differences were considered statistically significant at $p < 0.05$.

RESULTS AND DISCUSSION

Sensory Properties of Beetroot-Based Beverages

The experimental design based on Response Surface Methodology (RSM) was employed to optimize the formulation of the beetroot-based beverages, and the results were systematically recorded. In accordance with the

design matrix, the mean values of triplicate measurements for each response variable, along with the corresponding sensory responses of the blended beverages, are presented in Table 1.

Table 1. Variables and Responses For Optimization of Beetroot Based Beverages

Variables				Responses		
Run	**Beetroot juice(mL)**	**Apple juice(mL)**	**Oat (g)**	**Taste**	**Consistency**	**Overall acceptability**
1	20	50	6	6.54	6.85	6.72
2	20	60	3	7.67	5.25	5.98
3	10	40	6	7.47	6.92	6.16
4	30	40	6	6.42	6.32	6.41
5	30	50	3	6.33	5.51	5.43
6	20	50	6	6.54	6.85	6.72
7	20	50	6	6,54	6.85	6.72
8	20	40	3	5.45	5.14	5.57
9	30	50	9	6.65	5.78	6.21
10	10	50	9	8,35	7.11	7.05
11	20	50	6	6.54	6.85	6.72
12	20	50	6	6.54	6.85	6.72
13	20	60	9	7.11	7.02	7.16
14	20	40	9	7.32	7.14	6.14
15	10	60	6	8.24	7.08	8.12
16	10	50	3	7.49	5.05	5.27
17	30	60	6	7.45	6.14	6.21

The sensory attributes of the blended beverages taste, consistency, and overall acceptability were observed to vary within the ranges of 5.45 to 8.35, 5.05 to 7.14, and 5.27 to 8.12, respectively (Table 1). Response surface plots were generated by varying one ingredient across its specified range while maintaining the other variables at constant levels. A steep slope or pronounced curvature in the response surface indicates a high sensitivity of the response to that particular ingredient, whereas a relatively flat slope suggests minimal sensitivity to changes in that component.

To visualize the combined effects of the three independent variables on each response, three-dimensional (3D) surface plots were generated based on the fitted models. The experimental data were analyzed using linear, quadratic, and interaction models, and statistical evaluations were conducted for each sensory attribute (Tables 2–4).

Table 2. ANOVA results for the Taste model

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model (Reduced Quadratic)	8.69	6	1.45	57.14	<0.0001
A - Beetroot Juice	2.76	1	2.76	108.89	<0.0001
B - Apple Juice	1.81	1	1.81	71.55	<0.0001
C - Oat	4.65	1	4.65	142.42	<0.0001
AB	1.17	1	1.17	28.6	0.0003
AC	0.25	1	0.25	6.13	0.0328
A^2	0.27	1	0.27	8.34	0.0148
Residual	0.36	11	0.0327		
Lack of Fit	0.36	7	0.0513		
Pure Error	0.0	4	0.0		
R^2	0,9547				
Adjusted R^2	0,9043				
Predicted R^2	0,7214				

The analysis of variance (ANOVA) revealed that the reduced quadratic model was statistically significant for the taste response ($p < 0.0001$). The model accounted for approximately 95.47% of the total variation in the data ($R^2 = 0.9547$), and the high adjusted R^2 value (0.9043) further confirmed the model's robustness and goodness of fit. Additionally, the lack-of-fit test was non-significant ($p > 0.05$), indicating that the model adequately described the experimental data. Among the variables, significant linear and interaction effects particularly those involving oat and beetroot juice demonstrated their strong influence on taste. The predicted R^2 value of 0.7214 also supported the model's reliability in predicting future observations.

Table 3. ANOVA results for the Consistency model

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model (Reduced Quadratic)	8.8	5	1.76	53.92	<0.0001
A - Beetroot Juice	0.726	1	0.726	22.23	0.0006
C - Oat	0.775	1	0.775	30.56	0.0003
AC	0.801	1	0.801	24.53	0.0004
A^2	1.47	1	1.47	58.04	<0.0001
C^2	2.26	1	2.26	69.17	<0.0001
Residual	0.2536	10	0.0254		
Lack of Fit	0.2536	6	0.0423		
Pure Error	0.0	4	0.0		
R^2	0,9473				
Adjusted R^2	0,9157				
Predicted R^2	0,7415				

The ANOVA results indicated that the reduced quadratic model for consistency was statistically significant ($p < 0.0001$), with an R^2 value of 0.9473, suggesting that approximately 94.73% of the variation in consistency scores was explained by the model. The adjusted R^2 value of 0.9157 further supported the model's robustness by accounting for the number of predictors. The predicted R^2 value of 0.7415 confirmed the model's capacity to generate reliable predictions. Moreover, the non-significant lack-of-fit ($p > 0.05$) indicated that there was no considerable discrepancy between the model and the observed data. Among the independent variables, oat content (C) and its quadratic term (C^2) exhibited the strongest influence on beverage consistency. Additionally, the interaction between beetroot juice and oat (AC) was also found to be statistically significant.

Table 4. ANOVA results for the Overall Acceptability model.

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model (Reduced Quadratic)	7.33	6	1.22	29.95	<0.0001
A - Beetroot Juice	0.6844	1	0.6844	16.79	0.0022
B - Apple Juice	1.27	1	1.27	31.19	0.0002
C - Oat	2.32	1	2.32	56.94	<0.0001
BC	1.48	1	1.48	58.21	<0.0001
B^2	0.3144	1	0.3144	12.4	0.0055
C^2	1.63	1	1.63	40.05	<0.0001
Residual	0.4078	10	0.0408		
Lack of Fit	0.4078	6	0.068		
Pure Error	0.0	4	0.0		
R^2	0,9608				
Adjusted R^2	0,9430				
Predicted R^2	0,7810				

The ANOVA results indicate that the reduced quadratic model for overall acceptability is statistically significant ($p < 0.0001$), explaining 96.08% of the variability in the data ($R^2 = 0.9608$). The adjusted R^2 (0.9430) confirms that the model fits well even after adjusting for the number of predictors, while the predicted R^2 (0.7810) demonstrates satisfactory predictive performance. The non-significant lack-of-fit test ($p > 0.05$) indicates that the model sufficiently represents the experimental data. Among the variables, oat (C) and its quadratic effect (C^2), as well as the interaction between apple juice and oat (BC), showed highly significant influence on overall acceptability. These results suggest that a balance between sweetness (apple juice) and texture (oat) is essential for optimizing sensory appeal.

Effect of Beverage Formulation on Taste

The taste scores of the beverage formulations ranged from 5.45 to 8.35. The three-dimensional (3D) surface plots presented in Figure 1 illustrate the effects of beetroot juice, apple juice, and oat content on sensory perception. These plots were generated by systematically varying one independent variable while holding the others constant, thereby allowing visualization of the individual influence of each component on taste.

Apple juice played a pivotal role in balancing the taste profile of the beverage by counteracting the intense aromatic notes of beetroot juice, thereby enhancing overall consumer acceptability. However, when used in excessive amounts, apple juice imparted an overly sweet flavor, which negatively affected sensory appeal. Although oats did not directly influence the taste, they modulated taste perception through their impact on the beverage's texture. At moderate concentrations, oats contributed to a smooth and creamy mouthfeel, whereas higher levels resulted in an undesirable sticky texture, ultimately diminishing sensory acceptance.

The response surface plots indicate that a well-balanced formulation, achieved through the optimal combination of beetroot juice, apple juice, and oats, can significantly improve taste quality and maximize consumer acceptability. These findings underscore the critical role of ingredient optimization in the development of functional beverages that meet consumer sensory expectations.

These findings are largely consistent with previous studies reported in the literature. El-Dakak and Youssef (2017) observed that while beetroot juice imparts a distinctive sensory profile to beverages, its use at high concentrations intensifies earthy flavor notes, thereby diminishing consumer preference. Similarly, Tobolková et al. (2020) demonstrated that apple juice plays a crucial role in balancing the flavor profile, effectively softening the dominant taste attributes of beetroot juice when incorporated at optimal levels.

Additionally, studies by Chakraborty et al. (2019) indicated that oats can enhance the sensory acceptability of beverages; however, excessive use may result in an undesirable sticky mouthfeel, negatively affecting consumer perception. Consistent with these findings, the present study confirms that a well-balanced combination of beetroot juice and apple juice contributes positively to the beverage's taste profile, while oats enhance consistency but may lead to adverse sensory responses when used beyond an optimal threshold.

The regression equation representing the relationship between the ingredient ratios and taste scores is given below:

$$Y_{Taste}=6.57-0.5875A+0.4763B-0.3219C-0.6071BC+0.5904A^2+0.2729B^2$$

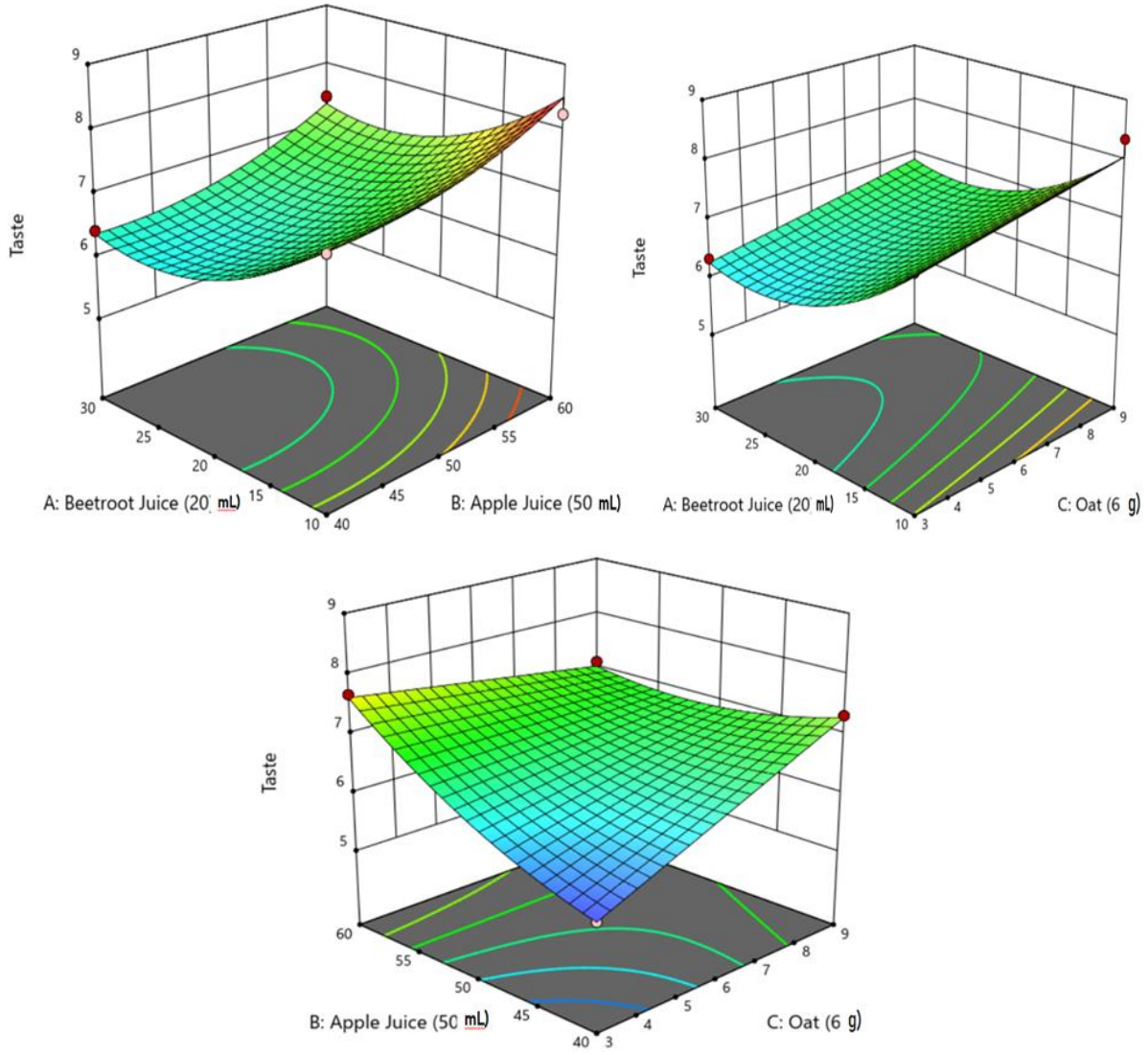

Figure 1. 3D Surface Plots Illustrating the Effect of Beverage Formulation on Taste

Effect of Beverage Formulation on Consistency

The consistency scores of the formulated beverages ranged from 5.05 to 7.14. Response surface analysis (Figure 2) revealed that beetroot juice alone had a minimal impact on viscosity. However, in combination with other components particularly oats significant changes in texture were observed. While the interaction between

beetroot juice and apple juice exhibited limited influence on consistency, oat content emerged as the primary factor contributing to increased viscosity, especially when combined with either beetroot or apple juice.

Oats, which are rich in soluble dietary fiber particularly β-glucan significantly contributed to increased beverage thickness. While moderate levels of oats imparted a desirable creamy texture, higher concentrations reduced fluidity and produced a sticky mouthfeel, adversely affecting sensory acceptability. Therefore, precise control of oat concentration is essential to achieve optimal consistency without compromising consumer perception.

These findings are in agreement with previous studies. El-Dakak and Youssef (2017) reported that while apple juice had minimal impact on texture, it played a key role in balancing flavor. Chakraborty et al. (2019) emphasized the contribution of oats to increased viscosity and texture stabilization, noting, however, that excessive amounts compromised drinkability. Similarly, Kumar and Kumar (2015) demonstrated that although the rheological behavior of beetroot juice is influenced by its soluble solids content, its contribution to viscosity is relatively limited compared to that of oats. In line with these reports, the present study confirms that oat concentration is the primary determinant of beverage consistency.

Therefore, to achieve optimal beverage consistency, the oat content must be carefully regulated to preserve the sensory balance between beetroot and apple juices while avoiding excessive viscosity that could diminish consumer acceptability. The regression equation describing the relationship between ingredient proportions and consistency values is presented below:

$$Y_{Consistency}=6.70-0.3012A+0.7625C-0.4475AC-0.2539A^2-0.7314C^2$$

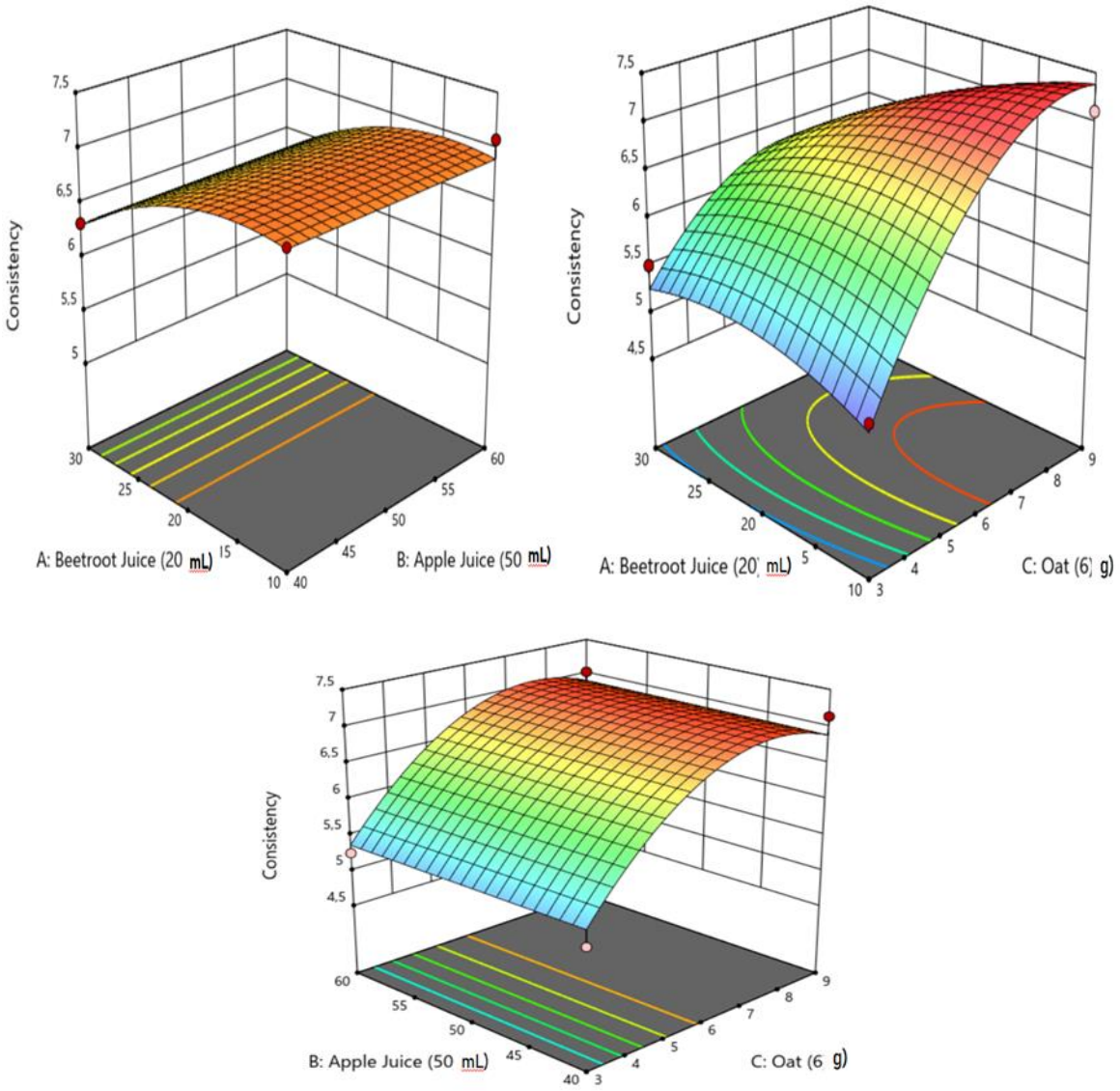

Figure 2. 3D Surface Plots Illustrating the Effect of Beverage Formulation on Consistency
Effect of Beverage Formulation on Overall Acceptability

The overall acceptability scores of the formulations ranged from 5.27 to 8.12. Response surface plots (Figure 3) indicated that increasing the concentration of apple juice had a positive effect on overall preference, likely due to its natural sweetness and acidity, which helped to mask the earthy flavor notes associated with beetroot juice.

Moderate levels of oats enhanced overall acceptability by improving the beverage's texture; however, higher concentrations led to a sticky mouthfeel, which negatively affected consumer satisfaction. Similarly, the combined effect of apple juice and oats contributed positively to overall acceptability only up to a certain threshold, beyond which excessive viscosity diminished sensory appeal.

These findings underscore the importance of achieving an optimal balance among ingredients to enhance sensory performance. Apple juice plays a key role in moderating the dominant flavor characteristics of beetroot juice, while oats contribute to mouthfeel and body. Determining the ideal proportions of these components is essential for developing a beverage with high consumer acceptability.

The results of this study are consistent with previous research. El-Dakak and Youssef (2017) reported that incorporating 30% apple juice enhanced acceptability in beetroot–carrot–apple blends. Bhavya et al. (2019) found that a 10% beetroot concentration yielded the most favorable results in tropical juice mixtures. Similarly, Michiu et al. (2024) observed the highest consumer acceptance in whey–beetroot beverages containing 20% beetroot juice. In alignment with these findings, the present study confirms that achieving a balanced formulation particularly between beetroot and apple juice and maintaining controlled oat content are critical for maximizing consumer approval in plant-based beverages. The regression equation representing the relationship between ingredient proportions and overall acceptability is provided below:

$$Y_{\text{Overall Acceptability}} = 6.72 - 0.2925A + 0.3988B + 0.5388C - 0.5400AB - 0.2500AC - 0.6210C^2$$

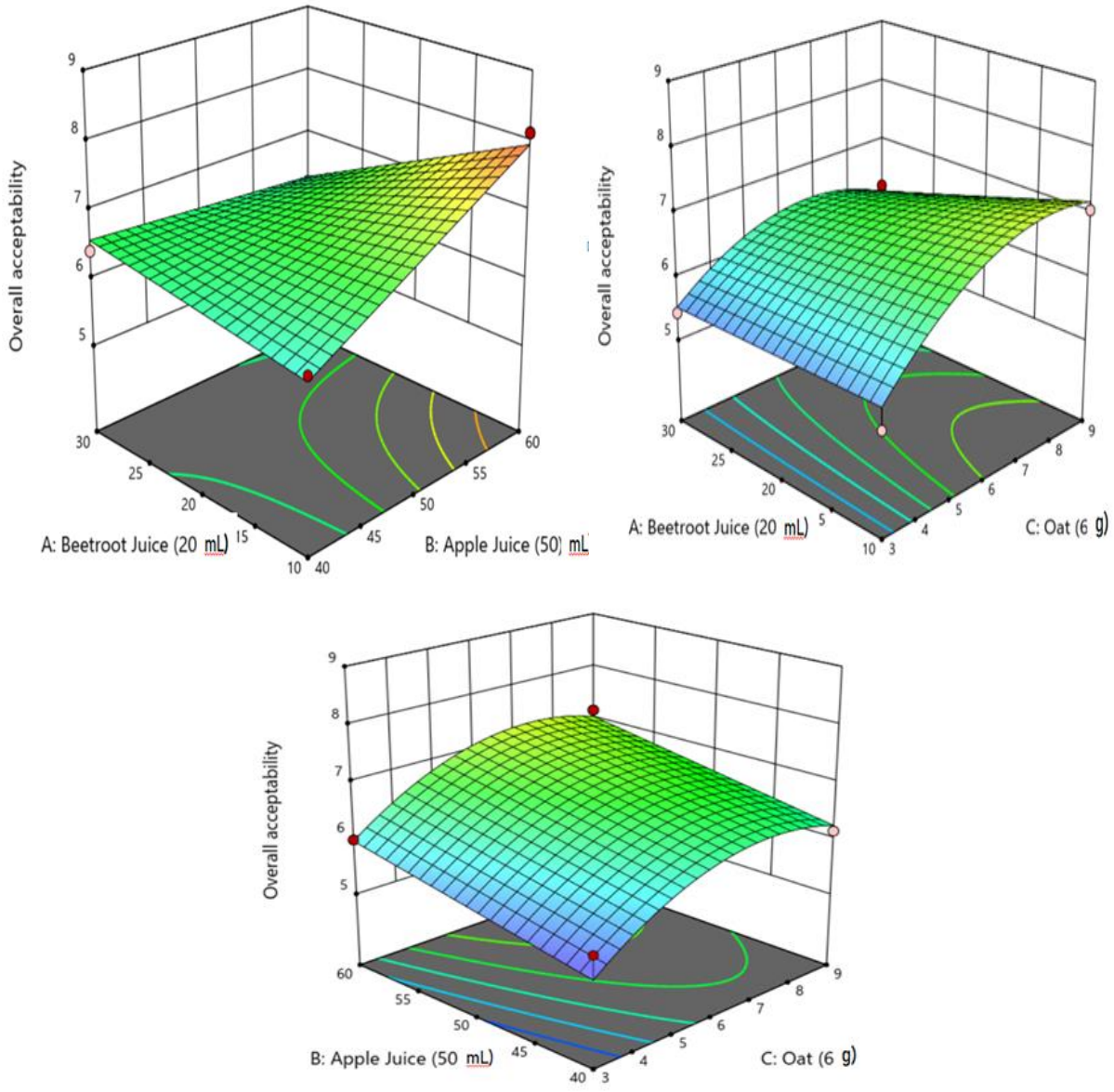

Figure 3. 3D Surface Plots Illustrating the Effect of Beverage Formulation on Overall Acceptability

Optimization of the Beetroot-Based Beverage

In this study, the effects of beetroot juice, apple juice, and oat content on taste, consistency, and overall acceptability were optimized using Response Surface Methodology (RSM). The F-values for all models were statistically significant at the 5% confidence level, indicating that the model terms were relevant and that the selected variables had a significant influence on the sensory and physicochemical properties of the beverage formulations.

To evaluate the goodness-of-fit of the models, the coefficients of determination (R^2) were examined. The R^2 values for taste, consistency, and overall acceptability were 0.9717, 0.9608, and 0.9473, respectively. These results indicate that the models account for more than 94% of the variability in the experimental data, thereby confirming their high predictive accuracy. Furthermore, the minimal discrepancy between the predicted and observed values reinforces the validity and reliability of the regression models.

The adequacy of the model was further confirmed by the lack-of-fit test, which yielded a non-significant F-value, indicating that the model provides a reliable fit within the studied range of factor levels. Based on these results, it was concluded that an optimal balance of beetroot juice, apple juice, and oat content can effectively maximize taste, consistency, and overall acceptability in the beverage formulation.

As a result of response surface optimization, the optimal ingredient ratios that maximized sensory acceptability were identified and are presented in Table 5. Furthermore, the industrial production potential of the optimized formulation was evaluated. These findings underscore the effectiveness of mixture design-based modeling as a robust approach for optimizing both sensory and physicochemical properties in beverage development.

Table 5. Coded and Actual Ranges of Independent Variables Used in the RSM Design

Constraints	**Goals**	**Optimization**	
		Lower limit	**Upper limit**
Factor			
A- beetroot Juice	in range	10	30
B- Apple Juice	in range	40	60
C-Oat	in range	3	9
Response			
Taste	maximize	5.45	8.35
Consistency	maximize	5.05	7.14
Overall Acceptability	maximize	5.27	8.12

For the simultaneous optimization of multiple responses, Design-Expert® software (version 10.0.6; Stat-Ease Inc., Minneapolis, MN, USA; http://www.statease.com) was employed using numerical optimization techniques. The variables were subjected to specific constraints based on predefined targets for each ingredient and response parameter, and the optimal formulation was subsequently determined.

During the optimization process, the objective was to maximize the sensory responses of taste, consistency, and overall acceptability by varying the proportions of beetroot juice, apple juice, and oats within the defined experimental limits. As shown in Table 6, the optimal beverage formulation was determined to consist of 10.07% beetroot juice, 59.99% apple juice, and 8.86% oats. Under these optimized conditions, the predicted sensory scores were 8.40 for taste, 7.19 for consistency, and 8.12 for overall acceptability.

Table 6. Optimum levels and predicted optimum values of responses.

Variable	Optimum value	Response	Predicted value
A- beetroot Juice	10.07	Taste	8.40
B- Apple Juice	59.99	Consistency	7.19
C-Oat	8.86	Overall Acceptability	8.12

The optimized formulation was validated through confirmation tests, thereby demonstrating the reliability and predictive accuracy of the model. These results indicate that the optimal combination of ingredients maximizes consumer acceptance based on both sensory and physicochemical parameters. The formulation recommended by the Design-Expert software serves as a promising foundation for the development of beverages with high sensory appeal and enhanced stability, offering valuable potential for application in the beverage industry.

CONCLUSION

In this study, a beverage formulated with beetroot juice, apple juice, and oats was optimized for taste, consistency, and overall acceptability using Response Surface Methodology (RSM). All regression models were found to be statistically significant, with R^2 values exceeding 94%, indicating strong predictive accuracy. The optimal formulation comprising 10.07% beetroot juice, 59.99% apple juice, and 8.86% oats achieved the highest sensory scores across all evaluated parameters.

The findings confirm that apple juice plays a crucial role in balancing the flavor profile, beetroot juice contributes a distinctive sensory character when used at appropriate levels, and oats primarily affect texture. While moderate amounts of oats enhance mouthfeel, excessive concentrations lead to increased viscosity, thereby reducing overall sensory appeal. The validity of the optimization model was supported by a non-significant lack-of-fit analysis, confirming its reliability. Overall, this study demonstrates that Response Surface Methodology (RSM) is an effective tool for developing sensory-optimized beverages and offers practical insights for formulating products aligned with consumer preferences. One limitation of the present study is that the optimized formulation was not re-prepared and subjected to independent sensory validation. Future research should address this gap by reproducing the optimized formulation and comparing predicted versus observed sensory scores to further confirm the model's accuracy.

Compliance with Ethical Standards

Peer-review

Externally peer-reviewed.

Declaration of Interests

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Author contribution

The author read and approved the final manuscript. The author verifies that the Text, Figures, and Tables are original and that they have not been published before.

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