Project Portfolio

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Portfolio Overview

Consulting Project Summaries

- **Jam Recipe Optimization**: This project aims to optimize a chokeberry (Aronia) jam recipe by modeling how varying amounts of Aronia and Sugar affect sensory quality. The study involved 59 people who tasted different jam samples and rated them on five qualities—flavor, Texture, Sweetness, Aftertaste, and Overall liking—using Response Surface Methodology (RSM) and polynomial regression models to predict how these qualities would turn out. The objective is to determine the optimal combination of substances that enhances overall acceptability.
- **CBCT Use Among General Dentists in Nebraska**: This research employs survey data to examine the application and prevalence of Cone Beam Computed Tomography (CBCT) in 51 general dental practices in Nebraska. The primary goals were to assess the incidence of CBCT ownership, investigate its correlation with practice factors, including location, size, and use of digital radiography, and analyze referral patterns among practices without CBCT. While 70.6% of practices reported possessing CBCT, and the majority utilized digital radiography (96.1%), practices in suburban regions were much less likely to own CBCT compared to those in rural areas. Other variables likely associated with small sample sizes demonstrated trends but lacked statistical significance. The study identified model stability concerns related to practice size due to scant data in critical categories, utilizing descriptive statistics, logistic regression, and Chi-square tests.
- **Evaluating Salmonella Lethality in Beef Jerky Drying Processes:** This study investigates how drying temperature and jerky thickness affect Salmonella reduction in beef jerky. It also evaluates the influence of water activity (Aw) and compares two bacterial inoculation methods (meat-based vs. non-meat) to determine their impact on bacterial survival. The ultimate goal is to develop a predictive model for bacterial inactivation under various drying conditions.

I have only made this project's experimental design and probable model technique. The client is still collecting data. I have not got the chance to analyze the data for this project

- **Stat 802 Project:** I helped the Stat 802 students design their projects, then did the power analysis and simulated the dataset.

Reflections on Client Meetings

- Meeting 1: My first client came from the Dental College, UNMC. The initial meeting was held on February 10, 2025. The client showed me their research topic and idea in the first meeting. They used the survey data to examine the application and prevalence of CBCT in Nebraska. They held the next follow-up meeting on April 12. They finished the data collection and shared the hypothesis with me. I started analyzing the data and gave the report on April 23. We had several emails in the meantime, and in the end, the client was satisfied with the report.
- Meeting 2: My second client came from the Animal Science Department. We had the initial meeting on February 5, 2023. He shared his idea about his MS thesis research on "Evaluating Salmonella Lethality in Beef Jerky Drying Processes." That day, we mostly discussed the experimental design and data collection method. He again requested a follow-up meeting on February 24 to discuss the further part of his research. Initially, he collected the water activity count for the experimental unit. He discussed obtaining the microbiological growth rate count data during this meeting. On April 30, we met with him once more. He merely wanted to make sure that everything was proceeding as planned and to share his data collection procedure.
- Meeting 3: I met this client on March 26, 2025. He has already given SC3L access to his dataset and study concept. During this discussion, I was given a concise overview of his study goals and specifications. This project was fascinating. He wanted to optimize a jam recipe using aronia berries to achieve the best predicted sensory scores. After that meeting, I worked on analyzing the dataset. I made the draft report and had a follow-up meeting on April 11. He wanted to include new topics in his report and incorporate his previous work. I included the updated plots and table as per his requirement. In the meantime, we had some conversations through email where he asked to include the model equation along with the estimated coefficient values. Finally, I sent him the revised report on April 23.

Final Report

Abstract

This study optimized a chokeberry (Aronia) jam recipe by examining how Aronia and sugar levels affected flavor, texture, sweetness, aftertaste, and overall liking. A Central Composite Design (CCD) with Response Surface Methodology recorded linear, quadratic, and interaction ingredient effects. A 9-point hedonic scale was employed to assess sensory input by 99 untrained panelists. According to exploratory data analysis, most sensory scores were 4–7; sweetness varied slightly. Regression models showed that Aronia strongly affected most variables, especially Sweetness, while Sugar had more modest, nonlinear effects. Despite the models' modest predictive power (maximum $R^2 = 0.029$ for Overall like), the findings provide information for adjusting component quantities. Finally, the analysis found that moderate-to-high amounts of Aronia (1719g) and Sugar (1480g) generated the best sensory responses. RSM could aid functional food development and improve products, supporting Aronia's use as a key component in value-added foods. You can access all the code and project files for this analysis on the project's GitHub repository: https://github.com/maksudatoma/Jam-Recipe-Sensory-Attributes

1. Introduction

The rising consumer demand for functional meals and natural health products to prevent future health problems has led to the exploration and utilization of fruits rich in bioactive compounds (Canning 2010). Aronia berries (*Aronia melanocarpa*), also known as chokeberries, have attracted attention for their remarkable health benefits, primarily associated with their high levels of antioxidants, polyphenols, and anthocyanins (Sidor and Gramza-Michałowska 2019). These small black berries possess substantial antioxidant properties, reducing oxidative stress and potentially lowering the risk of chronic conditions such as cardiovascular diseases, cancer, and diabetes (Ren et al. 2022).

Despite their nutritional advantages, Aronia berries remain widely underutilized in mainstream food products, primarily due to their astringent taste and a lack of consumer knowledge (Kang et al. 2018). The Aronia industry seeks to promote the utilization of this fruit in value-added products to increase demand. This study addresses the deficiency by developing a jam recipe incorporating Aronia berries as the primary component. Jam, a distinguished fruit preserve, effectively facilitates the inclusion of Aronia berries in the diet in a palatable way while maintaining their nutritional benefits; this is due to the necessary amount of soluble dry matter in the jam, which influences the sensory characteristics of the food (Fügel, Carle, and Schieber 2005).

The safety of home-canned goods is crucial for consumers; insufficient food preservation may lead to the proliferation of harmful bacteria, such as *Escherichia coli* (Dufort et al. 2017).

Although chokeberries have a low pH (3.3–3.9) (King et al. 2022), which reduces the risk of *Clostridium botulinum* contamination ("Clostridium Botulinum" 2010), proper thermal processing is necessary to ensure the microbiological safety and quality of the canned product.

Moreover, the sensory attributes of the jam, including flavor, texture, and general appeal, are essential for consumer approval. The application of sensory evaluation through surface response methodology (RSM) aids in optimizing the recipe to achieve a balance between safety and flavor (Yusof, Yee, and Zakaria 2021). Its application enables systematic exploration of interactions between ingredients and processing conditions, helping to identify ideal combinations for consumer preference (Piepho 2019). This project examines the antioxidant capacity of Aronia berry jam post-thermal processing, offering insights into the retention of its potential health benefits.

This project will detail and thoroughly analyze the extensive process of modifying the jam recipe and identifying the optimal formulation based on judge ratings, using statistical modeling techniques to guide product optimization (Tapre and Kaware 2018).

2. Methods

2.1 Aronia Jam Preparation

A recipe for blackberry jam with added pectin was selected from the National Center for Home Food Preservation, and the blackberries were substituted with Aronia berries. Following USDA guidelines, canning jars (16 fl oz, 473 ml, Ball Canning Corporation, Muncie, IN) were sterilized, and two-piece canning lids were boiled for ten minutes before use ("Complete Guide to Home Canning" 2009). Fully ripe berries were sorted and washed to remove stems and caps. The berries were blended at high speed for ten minutes in a professional blender to ensure the homogeneity of the berry paste(Fügel, Carle, and Schieber 2005).

The paste was transferred to a saucepan, where pectin and butter were added. The mixture was heated to a rolling boil under constant stirring. Sugar was added, and the mixture was returned to a rolling boil for one minute. After removing the foam with a metal spoon, the hot jam was poured into sterilized jars, leaving ¼ inch of headspace. Jar rims were cleaned with a damp paper towel, and two-piece metal lids were secured finger-tight.

The jars were processed in a 23-liter boiling water canner (Victorio VKP1130; Victorio Kitchen Products, Orem, UT) for 15 minutes and then cooled overnight undisturbed. Proper sealing was confirmed the next day by checking for vacuum seals (Etzel, Willmore, and Ingham 2015).

2.1.2 Brix Degrees Measurement

After cooking each batch, jam samples were collected to measure solids content using a digital refractometer (Hanna HI96801, Hanna Instruments, Smithfield, RI) calibrated with distilled water. A small sample was placed on the cleaned prism surface, and Brix readings were recorded.

2.1.3 pH Measurement

To ensure proper acidity for boiling water canning, the pH of each batch was measured after cooking. Samples were diluted 1:1 with deionized water, transferred into plastic cups, and measured using a digital pH meter (Orion Star A111, Thermo Fisher Scientific, Waltham, MA). The probe was inserted and stabilized, and the final pH was recorded (Dufort et al. 2017).

2.2 Experimental Design

This study employed a Central Composite Design to assess the influence of two continuous variables—Aronia quantity and Sugar quantity—on the sensory attributes of Aronia jam. Twelve jam recipes were developed, utilizing low, high, axial, and center locations to assess linear, interaction, and quadratic effects. Pectin was maintained at a constant weight of 81.754 g in all recipes. Fifty-nine untrained panelists engaged in the sensory evaluation, each getting a randomized selection of nine dishes. Assessments were performed separately in tasting booths to reduce bias, and the sequence of recipes was randomized by unique codes supplied to each panelist.

Each row in the dataset represents a score for one of the following sensory attributes: texture, flavor, sweetness, aftertaste, or overall like. The observations are made at the panelist-attribute level. A 9-point hedonic scale was used to record sensory evaluations; values ranged from 1 (severe dislike) to 9 (extreme liking). Blind (panelist ID), Recipe (formulation code), Aronia, Sugar, Pectin (fixed), Attribute, and Grade are among the factors.

As shown in Table 1, 12 Aronia jam formulations were used in the experiment, each defined by a unique combination of Aronia and Sugar amounts (in grams). These combinations form the basis of the response surface design used for sensory evaluation.

Table 1: Combination of Aronia Jam Formulations

Recipe	Amount of Aronia (g)	Amount of Sugar (g)
1	1800	1610
2	2188	1610
3	1800	2240

Recipe	Amount of Aronia (g)	Amount of Sugar (g)
4	2188	2240
5	1994	1925
6	1994	1925
7	1719	1925
8	2268	1925
9	1994	1480
10	1994	2370
11	1994	1925
12	1994	1925

2.3 Exploratory Data Analysis (EDA)

First, we will look into the data distribution of the response variables. To do so, we're plotting Histograms, Boxplots, and Scatter plots for each response variable.

The histogram demonstrates that sensory values for Aftertaste, Flavor, Overall, Sweetness, and Texture are balanced, with most scores between 4 and 7. Almost all the attributes are symmetric, bell-shaped distributions. Aftertaste and Overall appear roughly symmetric with a moderate spread. Sweetness, however, steeply peaked at 5, indicating limited variation and modeling issues.

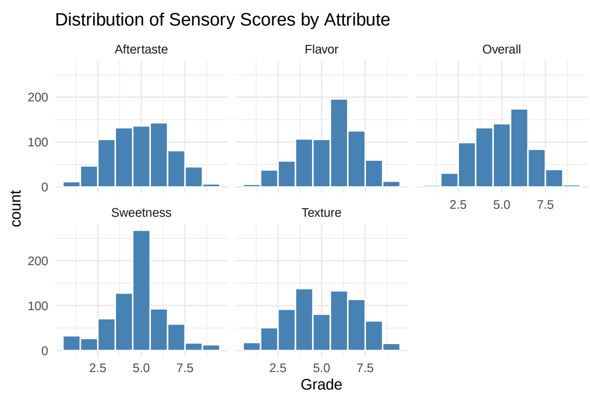
The boxplot of sensory scores for aftertaste, flavor, overall, sweetness, and texture shows a median of 5. Flavor and Texture appear to have the most variation, with greater upper quartiles, implying higher ratings and scores. In contrast, Aftertaste, Sweetness, and Overall had lower interquartile ranges, indicating more consistent assessments.

The Aronia versus Sugar scatterplot shows that the experimental design is a Central Composite Design (CCD) with low, central, and high ingredient combinations. The repeating center points indicate error estimation and curvature modeling.

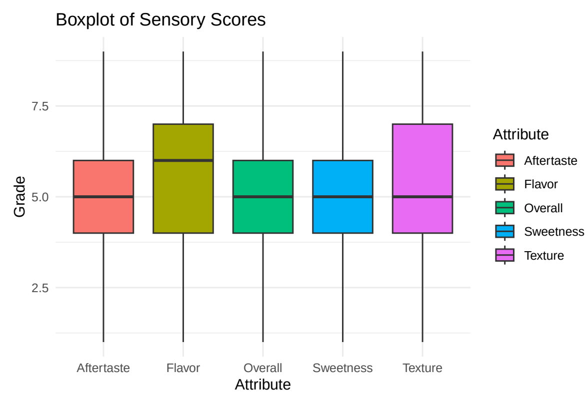
The Figure 2 provides an overview of the average sensory profiles for each of the twelve jam recipes across five key attributes: Aftertaste, Flavor, Overall, Sweetness, and Texture. These plots capture the variability in panelist evaluations, highlighting the strengths and weaknesses of each formulation.

Texture: Texture scores exhibit considerable variation across recipes, with Recipe 10 achieving the highest median score, indicating a superior textural profile. In contrast, Recipes 2 and 7 have lower median scores, suggesting less favorable textural qualities.

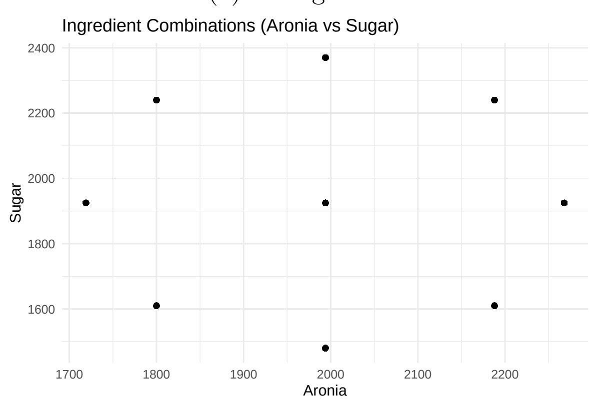
Flavor: Recipe 10 also stands out with a high median flavor score, reflecting a well-balanced and appealing flavor profile. In comparison, Recipes 7 and 8 received lower median flavor scores, indicating less favorable taste experiences. Despite these differences, panelist flavor evaluations were generally consistent across recipes.



(a) Histogram



(b) Box plot



(c) Scatter plot

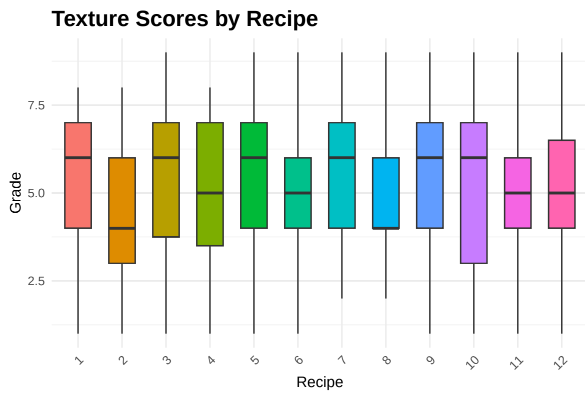
Figure 1: Histogram, Box plot and Scatter plot of the response variable.

Sweetness: The distribution of sweetness scores is narrower, suggesting more consistent panelist perceptions. Recipe 10 again achieves a higher median score, reinforcing its appeal. Recipes 7 and 8, with the lowest medians, may have been perceived as less balanced or overly tart.

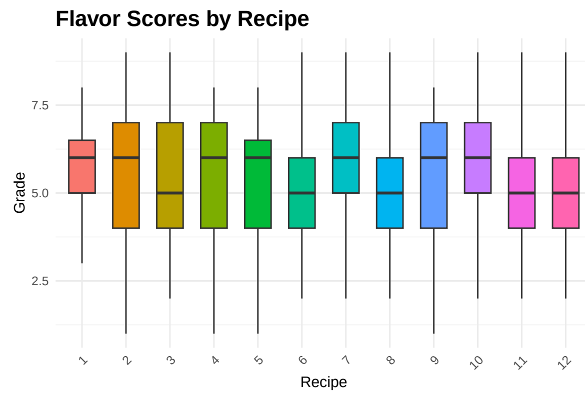
Aftertaste: Recipe 10 leads in aftertaste, with the highest median score, confirming its overall positive reception. In contrast, Recipes 7 and 11 received lower aftertaste ratings, possibly reflecting ingredient imbalances or pronounced Aronia flavors that linger unfavorably.

Overall: Consistently, Recipe 10 has the highest median overall score, indicating a strong overall acceptability among panelists. In contrast, Recipes 7, 11, and 12 scored lower, reflecting less favorable overall impressions.

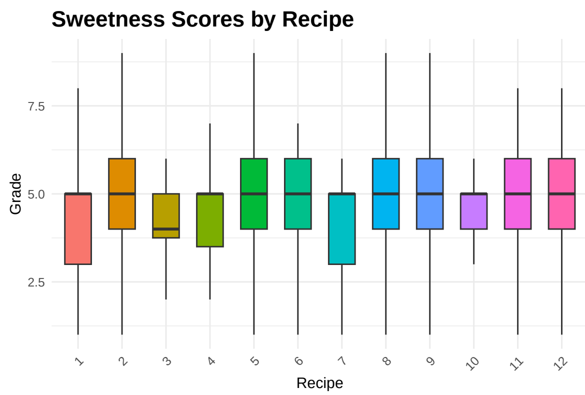
In summary, recipe 10 consistently ranks higher across all sensory dimensions, suggesting it offers the most favorable overall experience. Conversely, Recipes 7, 11, and 12 may benefit from reformulation to enhance their sensory profiles and improve overall acceptance.



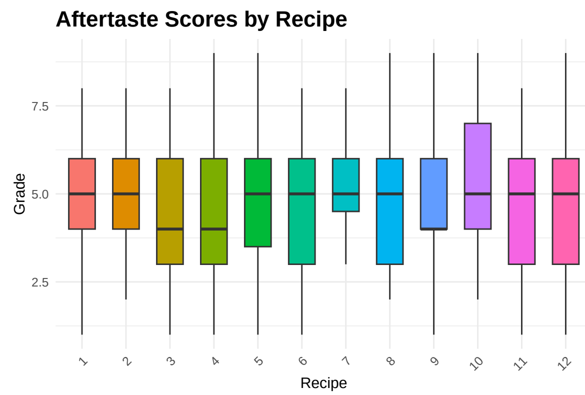
(a) Texture



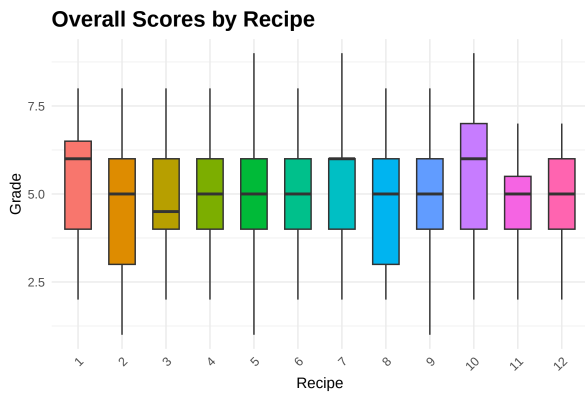
(b) Flavor



(c) Sweetness



(d) Aftertaste



(e) Overall

Figure 2: Sensory Attribute Scores Across 12 Recipes

2.4 Model Formulation

I have experimented with several models to enhance data fitting. I started with fitting first-order Response Surface Methodology, second-order models, and Mixed Models and also experimented with Multinomial Logistic Regression. Of all the models, the linear regression model worked better. Finally, I fitted second-order polynomial regression models for Texture, Flavor, Sweetness, Aftertaste, and Overall impression to assess the effects of ingredient levels. To model each characteristic as a response variable, the dataset was reshaped from long to wide. Each model contained linear, quadratic, and interaction factors for Aronia and Sugar to represent non-linear effects and ingredient interactions. Response surface methodology is used to determine how ingredient combinations affect sensory outcomes and optimize jam recipes based on expected sensory performance.

For each sensory attribute (Texture, Flavor, Sweetness, Aftertaste, and Overall), we fit the following second-order polynomial regression model with interaction terms:

$$\text{Score} = \beta_0 + \beta_1 A + \beta_2 A^2 + \beta_3 S + \beta_4 S^2 + \beta_5 AS + \beta_6 AS^2 + \beta_7 A^2 S + \beta_8 A^2 S^2 + \varepsilon$$

Where:

Score = predicted sensory rating (on a 1–9 scale), A = Aronia level (in grams), S = Sugar level (in grams), ε = random error term [$\varepsilon \sim \mathcal{N}(0, \sigma^2)$], $\beta_0, \ldots, \beta_8$= model coefficients estimated from the data.

2.5 Assumption Checking

To ensure that the fitted models meet the assumptions of linear regression, residual plots, histograms, and Q-Q plots were examined for each sensory attribute: Texture, Flavor, Sweetness, Aftertaste, and Overall. These diagnostics help verify linearity, homoscedasticity, and normality of errors.

The residuals vs. fitted plots Figure 3 show that residuals are evenly scattered around the horizontal reference line, indicating no major violations of linearity or unequal variance. The models appear to predict consistently across the range of fitted values.

Figure 4 displays histograms of residuals with overlaid normal curves. The bell-shaped distributions centered around zero indicate that the residuals approximate a normal distribution, as expected under linear regression.

Figure 5 presents Q-Q plots for the residuals. While slight deviations from normality were observed at the tails, most points follow the theoretical line, indicating acceptable normality. Such deviations are common in sensory studies and do not substantially affect model validity.

Overall, the diagnostic plots provide strong support that the regression models satisfy key assumptions for inference and prediction.

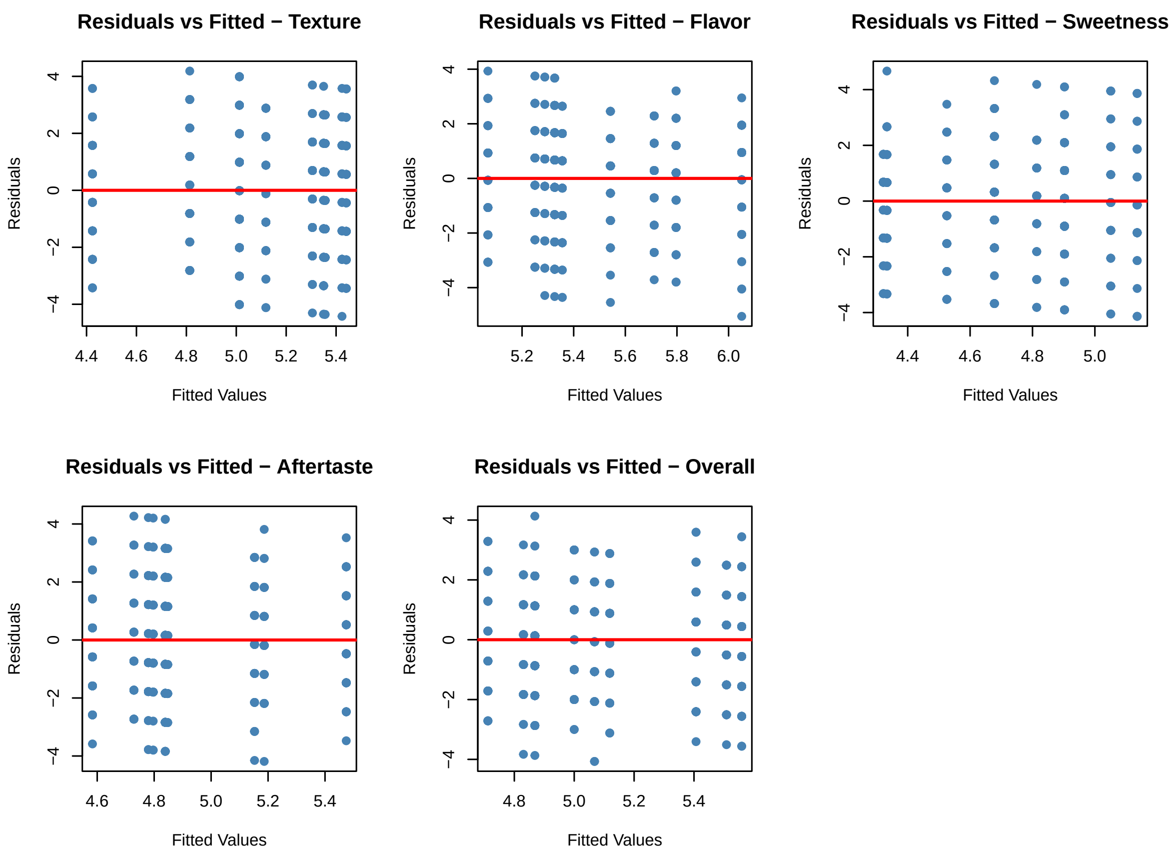


Figure 3: Residuals vs Fitted Values for All Sensory Models

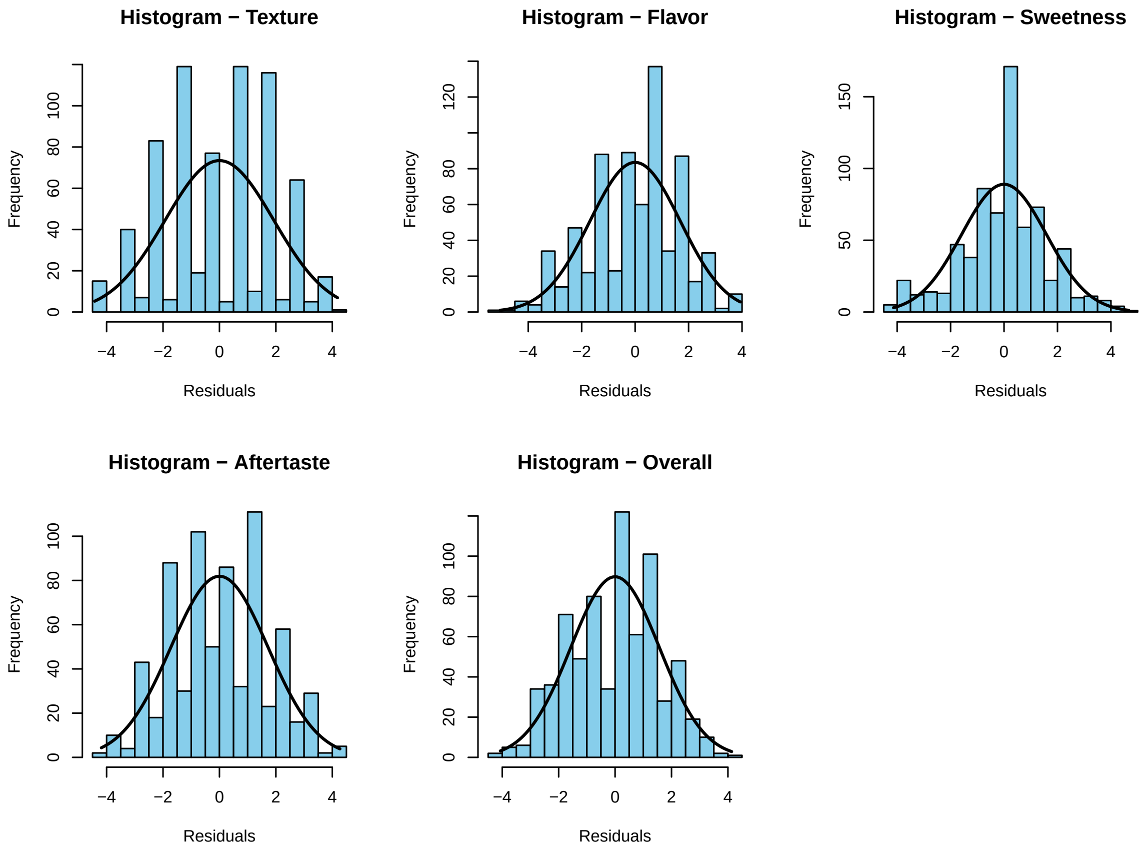


Figure 4: Histograms of Residuals with Normal Curve for All Sensory Models

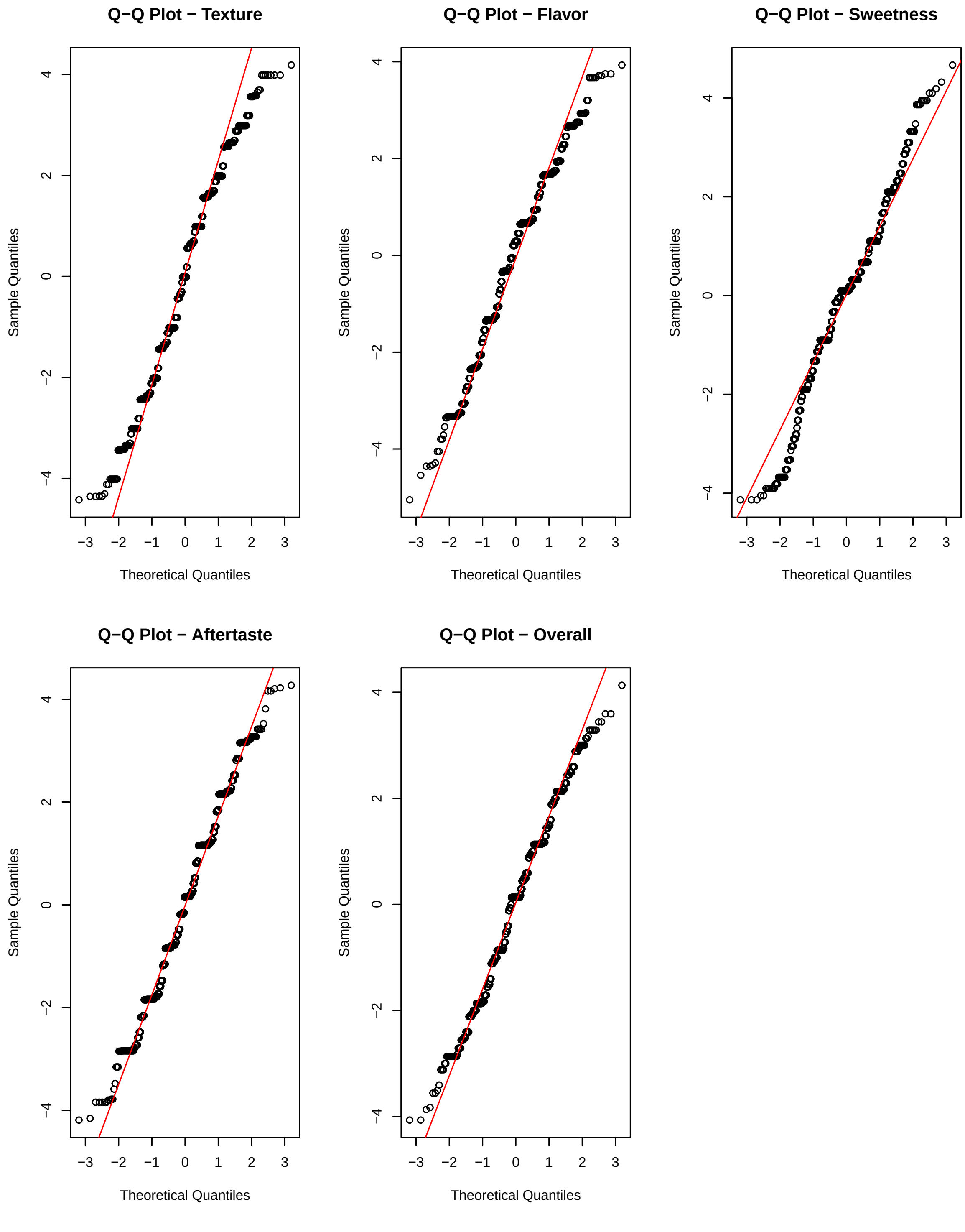


Figure 5: Q-Q Plots for Residuals of All Sensory Models

Table 2: Modeled Mean Sensory Scores for Aronia Jam Recipes

Recipe	Aronia	Sugar	Texture	Flavor	Sweetness	Aftertaste	Overall
1	1800	1610	5.36	5.71	4.53	5.15	5.51
2	2188	1610	4.42	5.29	5.05	4.85	4.83
3	1800	2240	5.35	5.25	4.33	4.58	5.00
4	2188	2240	5.12	5.36	4.68	4.78	5.12
5	1994	1925	5.01	5.33	4.90	4.84	4.87
6	1994	1925	5.01	5.33	4.90	4.84	4.87
7	1719	1925	5.44	5.80	4.32	5.19	5.41
8	2268	1925	4.81	5.07	5.14	4.73	4.71
9	1994	1480	5.31	5.54	4.81	4.80	5.07
10	1994	2370	5.42	6.05	4.68	5.47	5.56
11	1994	1925	5.01	5.33	4.90	4.84	4.87
12	1994	1925	5.01	5.33	4.90	4.84	4.87

3. Result

In this section, we'll talk about the result after fitting the model. How the Aronia and Sugar level working for each attributes.

3.1 Mean Sensory Score for Aronia Jam Recipe

The table 2 represents the estimated mean sensory scores for 12 different Aronia jam recipes based on participant ratings for five factors: Texture, Flavor, Sweetness, Aftertaste, and Overall Liking. Overall, Recipe 10 (Aronia: 1994 g, Sugar: 2370 g) got the best scores for Flavor (6.05) and Liked It the Most (5.56), making it a standout combination. Recipe 2 also turned out well, getting good marks for Flavor and Overall. Recipe 3 on the other hand got lower predicted scores for Sweetness and Aftertaste, which suggests that it won't be as appealing to consumers.

In general, recipes with moderate to high amounts of sugar and moderate to high amounts of aronia seemed to give better sensory results.

Modeled Mean Sensory Scores for Aronia Jam Recipes

3.2 ANOVA Result

Note that model results are summarized using p-values to indicate which ingredient effects were statistically significant for each sensory attribute. Full ANOVA outputs are available in the appendix for reference. We employed statistical models to determine how Aronia, Sugar,

Table 3: ANOVA Table with Significance Levels by Attribute

Attribute	Aronia	Aronia^2	Sugar	Sugar^2	Aronia:Sugar	Aronia:Sugar^2	Aronia^2:Sugar	Aronia^2:Sugar^2
Texture	0.0041 **	0.8775	0.2306	0.1936	0.1643	0.6981	0.4665	0.3029
Flavor	0.0324 *	0.6681	0.6121	0.0387 *	0.2267	0.2526	0.0755 .	0.1742
Sweetness	0.0006 ***	0.2688	0.1978	0.2189	0.6651	0.6390	0.5254	0.5375
Aftertaste	0.2412	0.8936	0.6240	0.2816	0.2610	0.3950	0.0126 *	0.1978
Overall	0.0085 **	0.6509	0.4213	0.0125 *	0.0523 .	0.4669	0.1163	0.6209

and their combinations affect panelists' sensory ratings of jam recipes. The analysis examined texture, flavor, sweetness, aftertaste, and overall like. We examined whether ingredient levels affected panelist assessments for each attribute.

Aronia consistently affected Texture, Flavor, Sweetness, and Overall Perception. Aronia levels have a big impact on jam sweetness, showing that aronia is a crucial factor in the multidimensional jam experience.

Sugar has more subtle and nuanced effects. Sugar did not affect most qualities alone. Sugar had a significant effect on flavor and overall like when considered quadratic (curved). This suggests that moderate sugar levels may be better than very low or extremely high ones and that sugar's effect is not linear.

Most Aronia-Sugar interactions were not significant. However, squared Aronia and Sugar interacted meaningfully in the Aftertaste, suggesting that particular combinations of these constituents alter the aftertaste. A similar interaction was nearly significant for Overall liking, suggesting a combined effect worth investigating.

Overall, Aronia was the most important element, with Sugar having a secondary but still important function. These data assist in improving recipes by indicating which ingredient levels produce a good sensory experience.

ANOVA Table

3.4 Estimated Polynomial Models for Sensory Attributes

Let A denote **Aronia** level (in grams) and S denote **Sugar** level (in grams). The second-order polynomial models estimated for each sensory attribute are presented below. The estimated value, Standard Error, ANOVA table are included in the appendix.

3.4.1 Texture Model

The model suggests a slight positive effect of Aronia and Sugar, with both linear terms showing moderate coefficients (0.7853 and 0.7566 respectively). However, the quadratic terms and interactions are small, implying nonlinear effects exist but may not be very strong. Texture seems to improve with moderate levels of both ingredients but may plateau or decline at higher values.

$$\begin{aligned}\text{Score (Texture)} = & -751.6 + 0.7853A - 0.00012019A^2 + 0.7566S - 0.00018665S^2 \\ & + 0.0007824AS + 0.0000001926AS^2 + 0.0000000204A^2S + \varepsilon\end{aligned}$$

3.4.2 Flavor Model

Both Aronia (0.6859) and Sugar (0.8379) have relatively larger positive coefficients, suggesting strong contributions to flavor. Negative quadratic terms imply that too much of either might reduce flavor ratings, hinting at an optimal mid-range formulation. Interaction terms are small but should not be ignored.

$$\text{Score(Flavor)} = -699.5 + 0.6859A - 0.0001648A^2 + 0.8379S - 0.0002429S^2 - \\ 0.0008156AS + 0.0000002367AS^2 + 0.0000001961A^2S - 0.00000005705A^2S^2 + \varepsilon$$

3.4.3 Sweetness Model

Here, Sugar (0.3171) has a notable positive effect, as expected, while Aronia has a smaller role. Again, the quadratic and interaction terms suggest a nonlinear relationship, with potential saturation of sweetness scores beyond certain sugar levels. This is intuitive given human taste perception.

$$\text{Score(Sweetness)} = -283.6 + 0.2972A - 0.00007714A^2 + 0.3171S - 0.00009014S^2 - \\ 0.0003283AS + 0.00000009323AS^2 + 0.00000008563A^2S - 0.00000002428A^2S^2 + \varepsilon$$

3.4.4 Aftertaste Model

The model shows that both Aronia (0.5711) and Sugar (0.7546) contribute positively to aftertaste, suggesting a balanced blend improves the lingering flavor. However, the quadratic terms are negative, indicating that very high levels of Aronia or Sugar may reduce aftertaste satisfaction. The interaction terms are small in magnitude, suggesting minor but non-negligible joint effects between Aronia and Sugar. Overall, moderate quantities of both ingredients likely yield the most pleasant aftertaste.

$$\text{Score(Aftertaste)} = -581.5 + 0.5711A - 0.0001379A^2 + 0.7546S - 0.0002316S^2 - 0.0007371AS \\ +0.0000002269AS^2 + 0.0000001786A^2S - 0.00000005514A^2S^2 + \varepsilon$$

3.4.5 Overall Model

The Overall score model integrates the combined influence of all other sensory attributes. The coefficients for Aronia (0.1396) and Sugar (0.2461) are smaller than in other models, indicating each ingredient contributes moderately but not overwhelmingly on its own. Quadratic and interaction terms again suggest nonlinear relationships, helping fine-tune the prediction for overall appeal. The positive signs for interaction terms imply that the combined effect of Aronia and Sugar enhances the overall score when used in appropriate proportions.

$$\begin{aligned}\text{Score(Overall)} = -139.8 + 0.1396A - 0.00003183A^2 + 0.2461S - 0.00008542S^2 - 0.0002372AS \\ +0.00000008246AS^2 + 0.00000005501A^2S - 0.00000001931A^2S^2 + \varepsilon\end{aligned}$$

These models were fitted using second-order interaction terms to capture the non-linear and joint effects of Aronia and Sugar on sensory scores.

3.5 Optimal Point

To identify the best combinations of Aronia and Sugar for each sensory attribute (such as Texture, Flavor, Sweetness, Aftertaste, and Overall), we used a mathematical technique called optimization. This approach systematically finds ingredient levels that maximize anticipated sensory scores based on our models. The model determined the ingredient combination with the highest panel rating for each attribute. After finding these optimal settings, we estimated the standard error and generated a 95% confidence range to determine our prediction confidence. The ideal Aronia and Sugar levels, estimated score, and uncertainty range for each sensory attribute were listed in a single table.

The table 4 presents the optimal combinations of Aronia and Sugar that are predicted to produce the highest sensory ratings for each attribute based on our statistical models. For each attribute, the model identifies the ingredient levels that are most likely to maximize the panelists' scores. The predicted rating (on a 1–9 scale) is provided alongside a standard error (SE), which reflects the uncertainty of the prediction, and a 95% confidence interval (CI), indicating the range where the true score is likely to fall. For example, the model suggests that a recipe using 1719 units of Aronia and 1480 units of Sugar would receive an Overall score of approximately 6.07, with a CI from 4.71 to 7.43. Notably, the ideal amount of Aronia and Sugar varies depending on the sensory attribute being optimized—for instance, Sweetness was maximized at a higher Aronia level (2268), demonstrating that ingredient preferences can shift depending on the desired sensory outcome. This table provides practical guidance for formulating jam recipes tailored to specific sensory goals.

Optimal Table

Table 4: Optimal Aronia and Sugar Levels for Maximizing Predicted Sensory Scores

Attribute	Aronia	Sugar	Predicted_Grade	SE	CI
Texture	1719.000	2017.444	5.449	0.252	[4.95, 5.94]
Flavor	1719.000	1723.971	5.978	0.258	[5.47, 6.48]
Sweetness	2268.000	1793.840	5.198	0.212	[4.78, 5.61]
Aftertaste	2024.031	2370.000	5.497	0.226	[5.05, 5.94]
Overall	1719.000	1480.000	6.068	0.693	[4.71, 7.43]

3.7 3D Plots

The following 3D surface plots visualize how each sensory attribute — *Texture*, *Flavor*, *Sweetness*, *Aftertaste*, and *Overall* — changes based on different combinations of Aronia and Sugar levels. Surface height and color gradients represent model-predicted ratings, with yellow peaks indicating higher scores and purple valleys indicating lower ones.

3.7.1 Texture

The Figure 6 3D surface plot shows how predicted scores vary with Aronia and Sugar levels. The optimal texture score of 5.45 (out of 9) is predicted at approximately 1719g of Aronia and 2017g of Sugar. Texture tends to improve with moderate Aronia and higher Sugar, while extreme values in either direction reduce the rating.

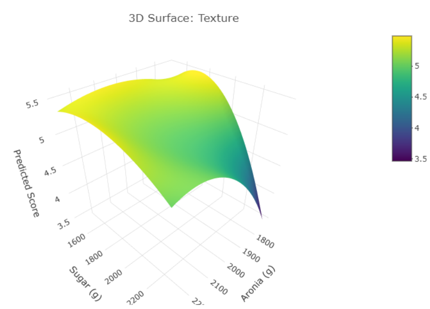


Figure 6: Texture Surface Plot

3.7.2 Flavor

Flavor Figure 7 scores peak at around 5.98 when using approximately 1719g of Aronia and 1724g of Sugar. The plot reveals that both overly low and high ingredient levels reduce the predicted flavor rating, emphasizing the importance of balance.

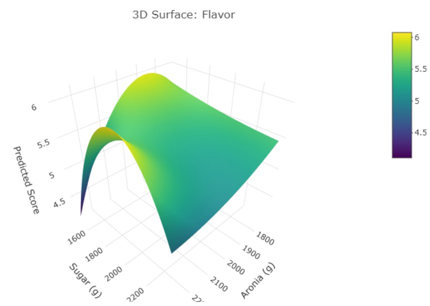


Figure 7: Flavor Surface Plot

3.7.3 Sweetness

Sweetness Figure 8 improves steadily with increased Aronia up to about 2268g, paired with roughly 1794g of Sugar, producing a predicted score of 5.20. Excessive levels in either ingredient show diminishing returns.

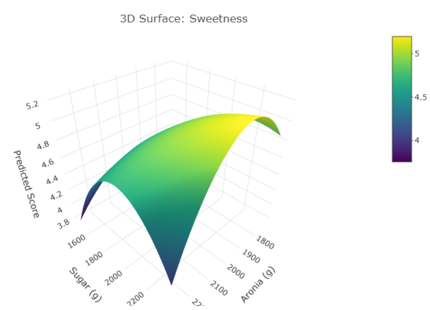


Figure 8: Sweetness Surface Plot

3.7.4 Aftertaste

Aftertaste Figure 9 is optimized at approximately 2024g of Aronia and 2370g of Sugar, with a predicted rating of 5.50. Higher Sugar improves this attribute, but balance with Aronia is necessary to avoid score decline.

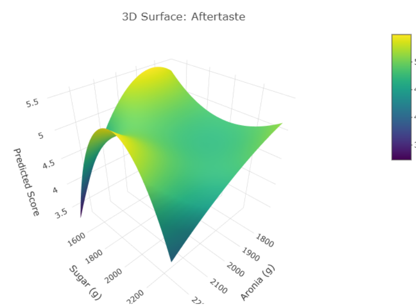


Figure 9: Aftertaste Surface Plot

3.7.5 Overall

The Overall Figure 10 score reaches its maximum predicted value of 6.07 when the jam contains around 1719g of Aronia and 1480g of Sugar. The plot highlights a distinct peak, suggesting this combination is most likely to yield the most accepted product.

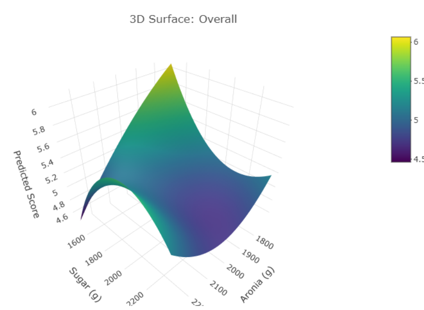


Figure 10: Overall Acceptance Surface Plot

4. Discussion

4.1 Conclusion

This analysis explored how different levels of Aronia and Sugar affect the sensory qualities of jam, focusing on Texture, Flavor, Sweetness, Aftertaste, and Overall acceptance. By applying second-order polynomial regression models with interaction terms, we captured both linear and non-linear ingredient effects. Aronia consistently had a strong and significant influence on key attributes, whereas Sugar played a more nuanced role, especially through its quadratic and interaction effects. Optimization analysis identified the ideal ingredient levels, showing that Flavor and Overall liking were maximized when using approximately 1719g of Aronia and 1480–1720g of Sugar.

4.2 Recommendation

Based on the analysis, we recommend using Aronia as the primary ingredient to enhance overall sensory appeal, as it significantly boosts ratings for Flavor, Sweetness, and Overall liking. Sugar should be optimized in moderation, contributing meaningfully to Aftertaste and Overall, but showing diminishing returns at higher levels. To maximize general consumer satisfaction, the optimal formulation lies around 1719g of Aronia and 1480–1720g of Sugar, as identified by the model. For more targeted improvements—such as boosting Aftertaste or Sweetness—recipes can be further refined using the attribute-specific optimal values identified in the study.

5. Acknowledgement

I'm grateful to Dr. Howard for letting me work on this project to make the portfolio for the Advanced Consulting Class. Your insights and advice have motivated me throughout this process. I would also like to thank Dr. Stroup for his valuable suggestions and continuous support and my supervisor, Tyler, for his timely assistance and encouragement whenever it was needed.

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Appendix

R Code

```
Call:
lm(formula = Texture ~ (Aronia + I(Aronia^2)) * (Sugar + I(Sugar^2)),
    data = dat)

Residuals:
    Min      1Q  Median      3Q     Max 
-4.4237 -1.4237 -0.0127  1.5763  4.1864 

Coefficients:
                         Estimate Std. Error t value Pr(>|t|)
(Intercept)            -7.516e+02  7.094e+02  -1.059    0.290
```

```
Aronia                 7.853e-01  7.109e-01   1.105    0.270
I(Aronia^2)           -2.019e-04  1.781e-04  -1.134    0.257
Sugar                  7.566e-01  7.345e-01   1.030    0.303
I(Sugar^2)            -1.866e-04  1.901e-04  -0.982    0.327
Aronia:Sugar          -7.824e-04  7.360e-04  -1.063    0.288
Aronia:I(Sugar^2)      1.926e-07  1.905e-07   1.011    0.312
I(Aronia^2):Sugar      2.004e-07  1.844e-07   1.087    0.277
I(Aronia^2):I(Sugar^2) -4.920e-11  4.772e-11  -1.031    0.303

Residual standard error: 1.937 on 700 degrees of freedom
Multiple R-squared:  0.02114,   Adjusted R-squared:  0.009952
F-statistic:  1.89 on 8 and 700 DF,  p-value: 0.05877


Call:
lm(formula = Flavor ~ (Aronia + I(Aronia^2)) * (Sugar + I(Sugar^2)),
    data = dat)

Residuals:
    Min      1Q  Median      3Q     Max
-5.0508 -1.3263  0.2881  1.2034  3.9322

Coefficients:
                         Estimate Std. Error t value Pr(>|t|)
(Intercept)           -6.995e+02  6.236e+02  -1.122    0.262
Aronia                 6.859e-01  6.249e-01   1.098    0.273
I(Aronia^2)           -1.648e-04  1.565e-04  -1.053    0.293
Sugar                  8.379e-01  6.456e-01   1.298    0.195
I(Sugar^2)            -2.429e-04  1.671e-04  -1.453    0.147
Aronia:Sugar          -8.156e-04  6.469e-04  -1.261    0.208
Aronia:I(Sugar^2)      2.367e-07  1.674e-07   1.414    0.158
I(Aronia^2):Sugar      1.961e-07  1.620e-07   1.210    0.227
I(Aronia^2):I(Sugar^2) -5.705e-11  4.194e-11  -1.360    0.174

Residual standard error: 1.703 on 700 degrees of freedom
Multiple R-squared:  0.02387,   Adjusted R-squared:  0.01271
F-statistic:  2.14 on 8 and 700 DF,  p-value: 0.03028


Call:
lm(formula = Sweetness ~ (Aronia + I(Aronia^2)) * (Sugar + I(Sugar^2)),
    data = dat)
```

```
Residuals:
    Min      1Q  Median      3Q     Max 
-4.1356 -0.9025  0.0975  0.9492  4.6667 

Coefficients:
                         Estimate Std. Error t value Pr(>|t|)
(Intercept)            -2.836e+02  5.853e+02  -0.484    0.628
Aronia                  2.972e-01  5.865e-01   0.507    0.613
I(Aronia^2)            -7.714e-05  1.469e-04  -0.525    0.600
Sugar                   3.171e-01  6.060e-01   0.523    0.601
I(Sugar^2)             -9.014e-05  1.568e-04  -0.575    0.566
Aronia:Sugar           -3.283e-04  6.072e-04  -0.541    0.589
Aronia:I(Sugar^2)       9.323e-08  1.572e-07   0.593    0.553
I(Aronia^2):Sugar       8.563e-08  1.521e-07   0.563    0.574
I(Aronia^2):I(Sugar^2) -2.428e-11  3.937e-11  -0.617    0.538

Residual standard error: 1.598 on 700 degrees of freedom
Multiple R-squared:  0.02431,	Adjusted R-squared:  0.01316 
F-statistic:  2.18 on 8 and 700 DF,  p-value: 0.02711



Call:
lm(formula = Aftertaste ~ (Aronia + I(Aronia^2)) * (Sugar + I(Sugar^2)), 
    data = dat)

Residuals:
    Min      1Q  Median      3Q     Max 
-4.1864 -1.1864  0.1525  1.1610  4.2712 

Coefficients:
                         Estimate Std. Error t value Pr(>|t|)
(Intercept)            -5.815e+02  6.359e+02  -0.914    0.361
Aronia                  5.711e-01  6.373e-01   0.896    0.370
I(Aronia^2)            -1.379e-04  1.596e-04  -0.864    0.388
Sugar                   7.546e-01  6.584e-01   1.146    0.252
I(Sugar^2)             -2.316e-04  1.704e-04  -1.359    0.174
Aronia:Sugar           -7.371e-04  6.597e-04  -1.117    0.264
Aronia:I(Sugar^2)       2.269e-07  1.707e-07   1.329    0.184
I(Aronia^2):Sugar       1.786e-07  1.653e-07   1.081    0.280
I(Aronia^2):I(Sugar^2) -5.514e-11  4.277e-11  -1.289    0.198
```

```
Residual standard error: 1.736 on 700 degrees of freedom
Multiple R-squared:  0.01782,	Adjusted R-squared:  0.006599 
F-statistic: 1.588 on 8 and 700 DF,  p-value: 0.1247



Call:
lm(formula = Overall ~ (Aronia + I(Aronia^2)) * (Sugar + I(Sugar^2)), 
    data = dat)

Residuals:
    Min      1Q  Median      3Q     Max 
-4.0678 -1.0678  0.1314  1.1314  4.1314 

Coefficients:
                         Estimate Std. Error t value Pr(>|t|)
(Intercept)            -1.398e+02  5.801e+02  -0.241    0.810
Aronia                  1.396e-01  5.814e-01   0.240    0.810
I(Aronia^2)            -3.183e-05  1.456e-04  -0.219    0.827
Sugar                   2.461e-01  6.006e-01   0.410    0.682
I(Sugar^2)             -8.542e-05  1.555e-04  -0.549    0.583
Aronia:Sugar           -2.372e-04  6.018e-04  -0.394    0.694
Aronia:I(Sugar^2)       8.246e-08  1.558e-07   0.529    0.597
I(Aronia^2):Sugar       5.501e-08  1.508e-07   0.365    0.715
I(Aronia^2):I(Sugar^2) -1.931e-11  3.902e-11  -0.495    0.621

Residual standard error: 1.584 on 700 degrees of freedom
Multiple R-squared:  0.02928,	Adjusted R-squared:  0.01818 
F-statistic: 2.639 on 8 and 700 DF,  p-value: 0.007448 

Analysis of Variance Table

Response: Texture
                        Df  Sum Sq Mean Sq F value   Pr(>F)   
Aronia                   1   31.07 31.0665  8.2777 0.004136 **
I(Aronia^2)              1    0.09  0.0892  0.0238 0.877527   
Sugar                    1    5.40  5.4041  1.4399 0.230558   
I(Sugar^2)               1    6.35  6.3542  1.6931 0.193623   
Aronia:Sugar             1    7.27  7.2727  1.9378 0.164346   
Aronia:I(Sugar^2)        1    0.57  0.5651  0.1506 0.698110   
I(Aronia^2):Sugar        1    1.99  1.9922  0.5308 0.466499   
I(Aronia^2):I(Sugar^2)   1    3.99  3.9889  1.0629 0.302922   
Residuals              700 2627.12  3.7530                    
```

```
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Analysis of Variance Table

Response: Flavor
                      Df  Sum Sq Mean Sq F value  Pr(>F)
Aronia                 1   13.32 13.3186  4.5935 0.03244 *
I(Aronia^2)            1    0.53  0.5335  0.1840 0.66808
Sugar                  1    0.75  0.7463  0.2574 0.61207
I(Sugar^2)             1   12.43 12.4331  4.2881 0.03875 *
Aronia:Sugar           1    4.24  4.2440  1.4637 0.22675
Aronia:I(Sugar^2)      1    3.80  3.8018  1.3112 0.25257
I(Aronia^2):Sugar      1    9.19  9.1898  3.1695 0.07546 .
I(Aronia^2):I(Sugar^2)   1    5.36  5.3638  1.8499 0.17423
Residuals            700 2029.64  2.8995
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Analysis of Variance Table

Response: Sweetness
                      Df  Sum Sq Mean Sq F value    Pr(>F)
Aronia                 1   30.27 30.2709 11.8499 0.0006109 ***
I(Aronia^2)            1    3.13  3.1292  1.2250 0.2687658
Sugar                  1    4.24  4.2443  1.6615 0.1978290
I(Sugar^2)             1    3.87  3.8675  1.5140 0.2189448
Aronia:Sugar           1    0.48  0.4790  0.1875 0.6651227
Aronia:I(Sugar^2)      1    0.56  0.5627  0.2203 0.6389641
I(Aronia^2):Sugar      1    1.03  1.0313  0.4037 0.5253762
I(Aronia^2):I(Sugar^2)   1    0.97  0.9719  0.3805 0.5375482
Residuals            700 1788.16  2.5545
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Analysis of Variance Table

Response: Aftertaste
                      Df  Sum Sq Mean Sq F value Pr(>F)
Aronia                 1    4.15  4.1488  1.3759 0.2412
I(Aronia^2)            1    0.05  0.0539  0.0179 0.8936
Sugar                  1    0.73  0.7251  0.2405 0.6240
```

```
I(Sugar^2)               1    3.50  3.5006  1.1609 0.2816
Aronia:Sugar             1    3.82  3.8167  1.2657 0.2610
Aronia:I(Sugar^2)        1    2.18  2.1844  0.7244 0.3950
I(Aronia^2):Sugar        1   18.86 18.8647  6.2563 0.0126 *
I(Aronia^2):I(Sugar^2)   1    5.01  5.0107  1.6617 0.1978
Residuals              700 2110.74  3.0153
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Analysis of Variance Table

Response: Overall
                        Df  Sum Sq Mean Sq F value   Pr(>F)
Aronia                   1   17.48 17.4820  6.9659 0.008493 **
I(Aronia^2)              1    0.51  0.5144  0.2050 0.650876
Sugar                    1    1.62  1.6249  0.6475 0.421299
I(Sugar^2)               1   15.73 15.7342  6.2695 0.012510 *
Aronia:Sugar             1    9.48  9.4802  3.7775 0.052347 .
Aronia:I(Sugar^2)        1    1.33  1.3296  0.5298 0.466935
I(Aronia^2):Sugar        1    6.21  6.2053  2.4726 0.116301
I(Aronia^2):I(Sugar^2)   1    0.61  0.6143  0.2448 0.620937
Residuals              700 1756.76  2.5097
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Table 5: Estimated Coefficients for Each Attribute Model

Attribute	Term	Estimate	Std. Error
Aftertaste	(Intercept)	-581.48752	635.89416
Aftertaste	Aronia	0.57113	0.63726
Aftertaste	I(Aronia^2)	-0.00014	0.00016
Aftertaste	Sugar	0.75459	0.65836
Aftertaste	I(Sugar^2)	-0.00023	0.00017
Aftertaste	Aronia:Sugar	-0.00074	0.00066
Aftertaste	Aronia:I(Sugar^2)	0.00000	0.00000
Aftertaste	I(Aronia^2):Sugar	0.00000	0.00000
Aftertaste	I(Aronia^2):I(Sugar^2)	0.00000	0.00000
Flavor	(Intercept)	-699.45145	623.55810
Flavor	Aronia	0.68589	0.62489
Flavor	I(Aronia^2)	-0.00016	0.00016

Flavor	Sugar	0.83790	0.64559
Flavor	I(Sugar^2)	-0.00024	0.00017
Flavor	Aronia:Sugar	-0.00082	0.00065
Flavor	Aronia:I(Sugar^2)	0.00000	0.00000
Flavor	I(Aronia^2):Sugar	0.00000	0.00000
Flavor	I(Aronia^2):I(Sugar^2)	0.00000	0.00000
Overall	(Intercept)	-139.78011	580.12813
Overall	Aronia	0.13965	0.58137
Overall	I(Aronia^2)	-0.00003	0.00015
Overall	Sugar	0.24609	0.60062
Overall	I(Sugar^2)	-0.00009	0.00016
Overall	Aronia:Sugar	-0.00024	0.00060
Overall	Aronia:I(Sugar^2)	0.00000	0.00000
Overall	I(Aronia^2):Sugar	0.00000	0.00000
Overall	I(Aronia^2):I(Sugar^2)	0.00000	0.00000
Sweetness	(Intercept)	-283.55734	585.28990
Sweetness	Aronia	0.29716	0.58654
Sweetness	I(Aronia^2)	-0.00008	0.00015
Sweetness	Sugar	0.31710	0.60597
Sweetness	I(Sugar^2)	-0.00009	0.00016
Sweetness	Aronia:Sugar	-0.00033	0.00061
Sweetness	Aronia:I(Sugar^2)	0.00000	0.00000
Sweetness	I(Aronia^2):Sugar	0.00000	0.00000
Sweetness	I(Aronia^2):I(Sugar^2)	0.00000	0.00000
Texture	(Intercept)	-751.60042	709.42727
Texture	Aronia	0.78529	0.71095
Texture	I(Aronia^2)	-0.00020	0.00018
Texture	Sugar	0.75660	0.73449
Texture	I(Sugar^2)	-0.00019	0.00019
Texture	Aronia:Sugar	-0.00078	0.00074
Texture	Aronia:I(Sugar^2)	0.00000	0.00000
Texture	I(Aronia^2):Sugar	0.00000	0.00000
Texture	I(Aronia^2):I(Sugar^2)	0.00000	0.00000

```
$par
[1] 1719.000 2017.444

$value
[1] 5.4488
```

```
$counts
function gradient
      25       25

$convergence
[1] 0

$message
[1] "CONVERGENCE: REL_REDUCTION_OF_F <= FACTR*EPSMCH"


$par
[1] 1719.000 1723.971

$value
[1] 5.977636

$counts
function gradient
      15       15

$convergence
[1] 0

$message
[1] "CONVERGENCE: REL_REDUCTION_OF_F <= FACTR*EPSMCH"


$par
[1] 2268.00 1793.84

$value
[1] 5.197602

$counts
function gradient
      18       18

$convergence
[1] 0

$message
[1] "CONVERGENCE: REL_REDUCTION_OF_F <= FACTR*EPSMCH"
```

```
$par
[1] 2024.031 2370.000

$value
[1] 5.496522

$counts
function gradient
      18       18

$convergence
[1] 0

$message
[1] "CONVERGENCE: NORM OF PROJECTED GRADIENT <= PGTOL"

$par
[1] 1719 1480

$value
[1] 6.068093

$counts
function gradient
      15       15

$convergence
[1] 0

$message
[1] "CONVERGENCE: NORM OF PROJECTED GRADIENT <= PGTOL"
```