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Machine learning-driven optimization of Riceberry donut formulations for high sensory acceptance and low calorie

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Abstract: This study explores the enhancement of Riceberry donut formulations using Random Forest Regression (RFR) to develop recipes that are both nutritious and sensory appealing. A collected dataset has been utilized, highlighting crucial components such as component ratios (e.g., Wheat Flour, Riceberry Flour, Shortening, Egg), physical features (e.g., texture, wetness, chewiness), and nutrient composition (e.g., carbohydrates, lipids, proteins). The model was developed to forecast four principal output variables: Overall Liking, Taste, Texture, and Calories (kcal). The results exhibited great predictive accuracy, with predicted values closely matching real values for all sensory qualities, underscoring the model's robustness in reflecting consumer opinions. The experiment revealed that Riceberry flour considerably challenged the composition of nutrients and sensory features of the donuts. Employing the enhanced model, simulated recipes were generated by adjusting Riceberry flour (20-35%), shortening (15-19g), and protein (2.6-3.0g), and the most effective formulation, consisting of 30% Riceberry flour, 15g of shortening, and 2.7g of protein, obtained a predicted Overall Liking score of 7.37 and 114.5 kcal per 30g serving. The results presented underscore the potential advantages of Riceberry flour in producing health-focused baked goods that are also attractive to customer preferences, illustrating the efficacy of machine learning in balancing nutritional quantity and sensory pleasure in food composition.

Keywords: *Machine learning, Optimization, Random forest regression, Riceberry donut.*

1. Introduction

Riceberry rice, a hybrid of the Thai varieties of rice Thai Hom Mali 105 and Hom Nil), is distinguished by its vivid purple coloration, which is due to its high anthocyanin content, a potent antioxidant. This unique formulation has several health benefits, including anti-inflammatory, anti-cancer, and cardiovascular protective effects [1, 2]. As a result, Riceberry has become a preferred functional ingredient in health-oriented food products aimed at health-conscious consumers [3, 4].

When processed into flour, Riceberry has numerous beneficial attributes for baking: it is rich in nutritional fiber, possesses a low glycemic index, and includes vital vitamins and minerals. These characteristics enhance its viability as a partial or complete alternative to wheat flour, especially in the formulation of gluten-free or clean-label products. Furthermore, the inherent coloration enhances aesthetic allure and suggests nutritional worth in the final product [4-6].

The incorporation of Riceberry flour in baked products, particularly in fried foods such as donuts, poses significant formulation difficulties. The elevated fiber content and lack of gluten frequently lead to modified dough rheology, decreased gas retention, and alterations in texture, which may influence

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product volume and sensory appeal. These restrictions must be meticulously addressed to guarantee that Riceberry enriched goods fulfill consumer expectations regarding taste, mouthfeel, and appearance [7]. Consequently, advancements in formulation and processing, encompassing the application of hydrocolloids and sophisticated modeling techniques such as machine learning, have become essential for enhancing the utilization of Riceberry flour in value-added functional meals.

Due to their delicious flavor and texture, deep-fried donuts are very popular; unfortunately, the frying process absorbs a lot of oil, which results in a high fat and calorie content. This has raised health concerns, especially among contemporary customers pursuing lower-calorie and nutritionally enhanced options. Numerous studies indicate that the fat content in donuts may constitute over 20–25% of the product's weight as a result of oil absorption during frying [8, 9]. Substituting wheat flour with high-fiber, functional components such as Riceberry flour offers a chance to enhance the nutritional quality of fried items. Riceberry flour, which is gluten-free and abundant in anthocyanins and dietary fiber, positively impacts health but may also modify dough structure and the quality of the final product. In particular, a high fiber and gluten-free dough may have a detrimental effect on its viscoelasticity, gas retention, and expansion throughout the proofing and frying processes, leading to a reduction in volume, an increase in hardness, and alterations in its chewiness and appearance [10, 11].

To alleviate these impacts and improve product quality, hydrocolloids like Hydroxypropyl Methylcellulose (HPMC) and Methylcellulose (MC) have been extensively utilized in fried food systems. These chemicals create a thermal gel barrier on the food surface during frying, minimizing oil absorption and aiding in moisture retention thereby maintaining texture and sensory appeal [12-14]. The interactions among Riceberry flour, hydrocolloids, and the frying process are intricate, necessitating formulation adjustment to achieve a balance between sensory characteristics and oil reduction objectives.

The necessity to create data-driven optimization techniques, such machine learning-based modeling, to comprehend and forecast the impacts of various formulation parameters is increasing in light of these difficulties. In the production of food products, these methods have shown effective in simulating non-linear interactions and determining the best component combinations for both quality and health advantages [15-19].

To mitigate the issues of oil absorption and textural deterioration in Riceberry flour-based donuts, hydrocolloids such Hydroxypropyl Methylcellulose (HPMC) and Methylcellulose (MC) are integrated into the formulations. These hydrocolloids create a thermal gel network during frying, serving as a barrier that diminishes oil migration into the product while enhancing water retention and mechanical qualities. Research indicates that MC and HPMC coatings can substantially diminish fat content in fried foods while preserving favorable textural attributes [20, 21].

The study used Random Forest, a powerful machine learning algorithm, to simulate the relationship between different concentrations of HPMC and MC and essential quality indicators, including moisture loss, fat content, texture profile, and sensory evaluation scores [22]. Random Forest models are very adept at managing non-linear interactions in multi-variable systems and have been successfully utilized in food formulation modeling and optimization Behr, et al. [23] and Zhang, et al. [24]. Ahmed and Hassanien [25] shown the effectiveness of Random Forest compared to other conventional models in forecasting food quality attributes. Moreover, recent studies have utilized machine learning and natural language models to categorize food processing stages, highlighting the increasing significance of AI in food science innovation [26].

This study aims to optimize the donut formulation with Riceberry flour by balancing sensory acceptance and nutritional quality. This project seeks to determine optimal formulation parameters for producing low-calorie, high-quality donuts by data-driven modeling and nutritional analysis, while ensuring consumer satisfaction. The results facilitate the creation of functional, health-oriented bread items.

2. Material and Method

2.1. Raw material

Riceberry rice was obtained from Chia Meng Marketing Co., Ltd., Thailand. The material was processed with a high-speed grinder (FRITSCH PULVERISETTE 5, Germany) and subsequently sifted over a 120-mesh screen. The flour was preserved at 4 °C in vacuum-sealed bags until required. Two hydrocolloids, hydroxypropyl methylcellulose (HPMC) and methylcellulose (MC), were generously supplied by Rama Production Co., Ltd. and were utilized as fat-reducing agents. As in previous research [27-29] other components were whole egg, powdered sugar, shortening, skim milk powder, yeast, salt, and all-purpose wheat flour.

Table 1.
Mean and Standard Deviation of Ingredients.

Variable	Mean	Standard Deviation (SD)
Wheat Flour (g)	71.25	11.88
RiceberryFlour (g)	26.25	10.61
HPMC (added, g)	1.25	2.31
MC (added, g)	1.25	2.31
Specific Volume (mL/g)	2.87	0.57
Hardness (N)	3.66	0.54
Cohesiveness	0.41	0.03
Springiness	0.84	0.04
Chewiness (N)	1.54	0.14
Fat in Dough (%)	16.45	0.59
Fat in Donut (%)	35.47	8.07
Moisture in Dough (%)	33.62	1.21
Moisture in Donut (%)	19.21	2.04
Sensory: Color	6.91	0.28
Sensory: Odor	6.81	0.32
Sensory: Taste	6.84	0.25
Sensory: Texture	7.35	0.43
Sensory: Overall Liking	7.33	0.26
HPMC (coated, g)	0.62	1.77
MC (coated, g)	1.88	2.59
Crust L*	38.55	1.90
Crust a*	8.00	1.03
Crust b*	10.60	2.68
Crumb L*	44.07	4.43
Crumb a*	5.94	1.97
Crumb b*	7.53	0.53

Table 1 presents the mean values and variability (standard deviation) of ingredient composition, texture analysis, sensory evaluations, and nutritional content for the eight donut recipes. The results demonstrate that wheat flour had a superior mean value (71.25 g) in comparison to Riceberry flour (26.25 g), underscoring its predominance in control formulations. Sensory evaluations, including overall like (mean = 7.33 ± 0.26) and texture (7.35 ± 0.43), indicate a broadly favorable consumer acceptability across the samples. The fat absorption in donuts exhibited significant variability (SD = 8.07%), underscoring the influence of hydrocolloids on oil absorption. These findings provide a foundation for further development of healthier or functionally enhanced donut products.

2.2. Preparation of Donuts and Application of Hydrocolloids

The control donut recipe included exclusively wheat flour. In the experimental groups, 30% of the wheat flour was replaced with Riceberry flour. Six treatment groups were established using HPMC or MC, delivered through surface coating, incorporation into dough, or a combination of both methods. Hydrocolloid solutions for surface application were formulated by dissolving 0.06 g of HPMC or MC in

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6.25 g of water and applying the mixture to the donut surface before frying. Incorporated samples utilized 5% hydrocolloid (w/w) relative to flour weight. These were derived from the works of SirichoNworraNit, et al. [28]. The donut recipes are comprised as present in Table 2.

Table 2.
Donut Formulation Descriptions.

Formula	Key Ingredients	Description
Control	100% Wheat Flour	Control sample without Riceberry flour or hydrocolloids.
RB	30% Riceberry Flour	Partial replacement of wheat flour with 30% Riceberry flour; no hydrocolloids added.
RBCH	30% Riceberry Flour + Coated HPMC	Riceberry flour formulation with HPMC applied by surface coating.
RBCM	30% Riceberry Flour + Coated MC	Riceberry flour formulation with MC applied by surface coating.
RBH	30% Riceberry Flour + Added HPMC	HPMC added directly into the formulation with 30% Riceberry flour.
RBM	30% Riceberry Flour + Added MC	MC added directly into the formulation with 30% Riceberry flour.
RBHCH	30% Riceberry Flour + Added + Coated HPMC	Combined method: HPMC added and coated in Riceberry flour formula.
RBMCM	30% Riceberry Flour + Added + Coated MC	Combined method: MC added and coated in Riceberry flour formula.

Donut dough was produced by combining dry ingredients, subsequently including eggs and water, and finally adding shortening. The amalgamation was kneaded utilizing a stand mixer (KitchenAid Heavy Duty, USA) for 15 minutes. Dough balls were proofed at 30 °C and 70% relative humidity for 30 minutes, then fried in rice bran oil at 170 °C for 2 minutes on each side. Donuts were extracted and preserved in airtight containers.

2.3. Physicochemical analysis

Color measurements of the crust and crumb were conducted using a Hunter Lab ColorQuest XE (USA) under D65 lighting in CIE Lab* space. The specific volume was determined utilizing the rapeseed displacement method. Texture analysis was performed utilizing a TA Plus texture analyzer (Lloyd Instruments, UK) equipped with a 20 mm probe, compressing samples to 50% of their original height at a rate of 2 mm/s to evaluate hardness, cohesion, springiness, and chewiness.

The moisture and fat content were assessed according to established AOAC (2012) methodologies. Oil absorption and moisture evaporation were determined using the mass balance equations as employed by Kim, et al. [20].

2.4. Sensory evaluation

A hedonic evaluation utilizing a 9-point scale was performed with 60 untrained panelists aged 18 to 60. The assessed attributes comprised color, scent, flavor, texture, and overall acceptability. Donuts were presented in a coded and randomized manner to reduce bias, and evaluations were conducted on two separate days for validation.

2.5. Random forest regression (RFR) model

The Random Forest Regression (RFR) model is an ensemble machine learning method that builds numerous decision trees during training and produces the average prediction from the individual trees. This method is particularly adept at modeling intricate, nonlinear interactions and high-dimensional data, rendering it a dependable approach for food formulation and quality prediction.

This study utilized RFR to forecast essential response characteristics such as oil uptake (%), moisture loss (%), textural parameters (hardness, cohesion, springiness, chewiness), and sensory evaluations

(overall like). The input features were hydrocolloid type (HPMC or MC), application method (coating, incorporation, or both), and formulation composition (ratio of wheat to Riceberry flour).
The modeling procedure encompassed the following stages:

- Data Preparation: All continuous variables were normalized via StandardScaler. Categorical variables (e.g., hydrocolloid kind and application method) were transformed using one-hot encoding.
- Model Training: The dataset was divided into 75% for training and 25% for testing. A Random Forest model comprising 100 decision trees (n_estimators = 100) was developed utilizing the scikit-learn module in Python.
- Evaluation Metrics: The performance of the model was evaluated utilizing Mean Absolute Error (MAE).
- The feature importances attribute of the trained Random Forest Regressor model was utilized to ascertain the relative significance of each input variable, facilitating the interpretation of which formulation aspects most significantly affect the predicted quality attributes.

This research employs RFR to facilitate accurate prediction and optimization, aiding in the development of low-calorie Riceberry donuts with enhanced sensory appeal. The model's capacity to manage nonlinear interactions corresponds with prior applications in food texture modeling and quality assurance [1-3].

3. Results

The dataset included comprehensive formulations of eight donut samples, featuring a control (100% wheat flour) and seven experimental recipes that partially replaced wheat flour with Riceberry flour at a rate of 30%. Each formulation included supplementary ingredients such as sugar, shortening, skim milk powder, and egg. Hydrocolloid variants (HPMC, MC) were utilized by either incorporation or coating techniques.

The macronutrient contents (carbohydrates, fats, and proteins) were calculated for each formulation utilizing conventional nutrient composition values for the raw materials.
The total caloric values were computed utilizing the formula:

$$\text{Calories} = (4 \times \text{Carbohydrates}) + (9 \times \text{Fats}) + (4 \times \text{Proteins}) \qquad (1)$$

All nutritional assessments and comparisons were standardized to a 30g portion, representing the average weight of an individual donut sample utilized in this investigation. This normalization facilitates uniform and equitable comparisons among various formulations, irrespective of the total batch size or formulation weight.

Furthermore, presenting values per serving conforms to food labeling regulations (e.g., FDA, Codex), hence enhancing practical significance for consumers and prospective product innovation. A 30g foundation offers precision in assessing macronutrient composition, calorie consumption, and appropriateness for particular dietary objectives.

Figure 1 depicts the comparative macronutrient composition—namely carbohydrates, fats, and proteins across eight donut formulations, standardized per 30-gram serving. Carbohydrates consistently constituted the predominant macronutrient in all formulations, varying from roughly 17.8 to 18.3 grams, indicative of the significant contribution from wheat or Riceberry flour and sugar. The fat level exhibited minor variations, with the majority of recipes averaging approximately 4.2 grams per serving. Protein concentrations remained consistently steady throughout all samples, with measurements ranging from 2.6 to 2.8 grams. The RBM and RBCH formulations exhibited similar macronutrient profiles to the control, indicating that the partial replacement of wheat flour with Riceberry flour when paired with hydrocolloid incorporation or coating—can preserve nutritional equilibrium while providing possible functional or health advantages. This graph substantiates the viability of creating a lower-calorie, nutritionally balanced donut product utilizing Riceberry flour.

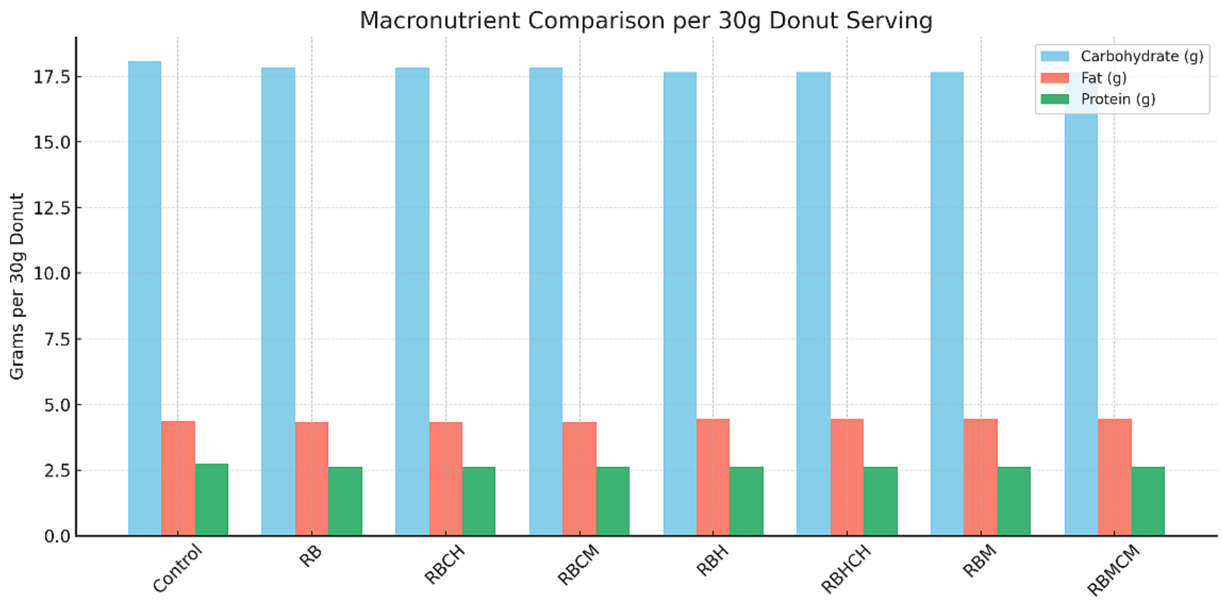

Figure 1.
Macronutrient Comparison per 30g Donut Serving.

Figure 2 depicts the total calorie value per 30g serving for each donut formulation. The control sample demonstrated the highest energy value, while formulations using Riceberry flour specifically RB, RBCH, and RBCM—exhibited marginally lower caloric content, averaging approximately 120–121 kcal. This indicates that the partial replacement of wheat flour with Riceberry flour may lead to a slight reduction in energy content, without markedly affecting the total macronutrient composition.

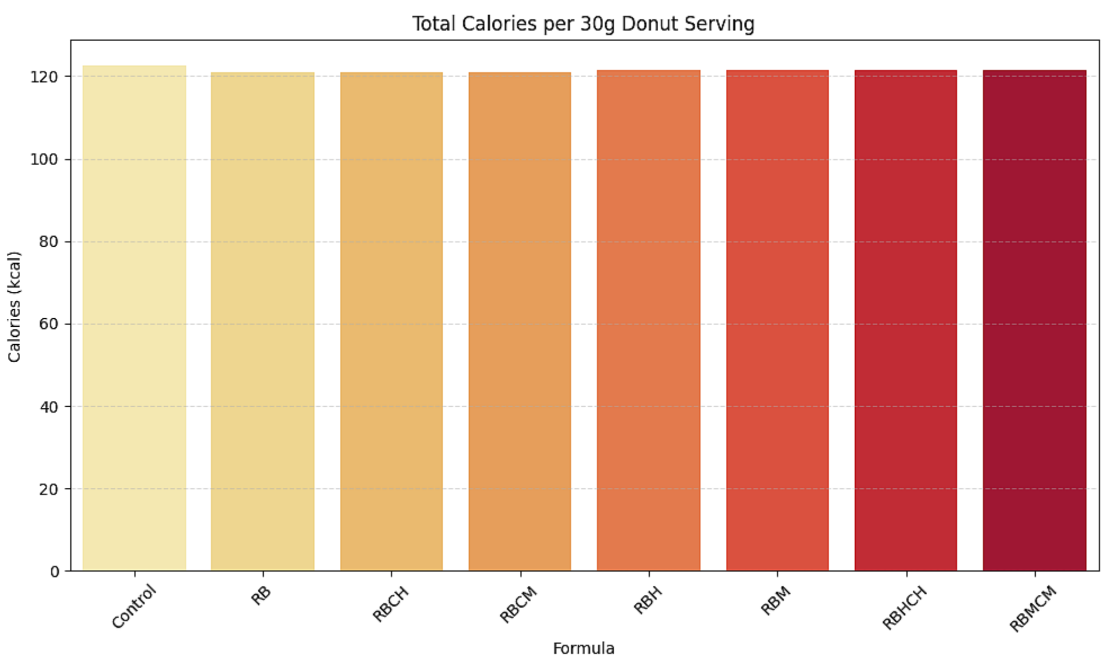

Figure 2.
Macronutrient Comparison per 30g Donut Serving.

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A Random Forest Regression (RFR) model was utilized to optimize Riceberry donut compositions that are nutritionally balanced and sensory satisfactory. The model was trained with a curated dataset that eliminated superfluous variables and emphasized essential features such as ingredient ratios (e.g., Wheat Flour, Riceberry Flour, Shortening, Egg), physical attributes (e.g., texture, moisture, chewiness), and nutritional composition (e.g., carbohydrate, fat, protein) as presented in Fig3. This model was explicitly developed to forecast four output variables: Overall Liking, Taste, Texture, and Calories (kcal).

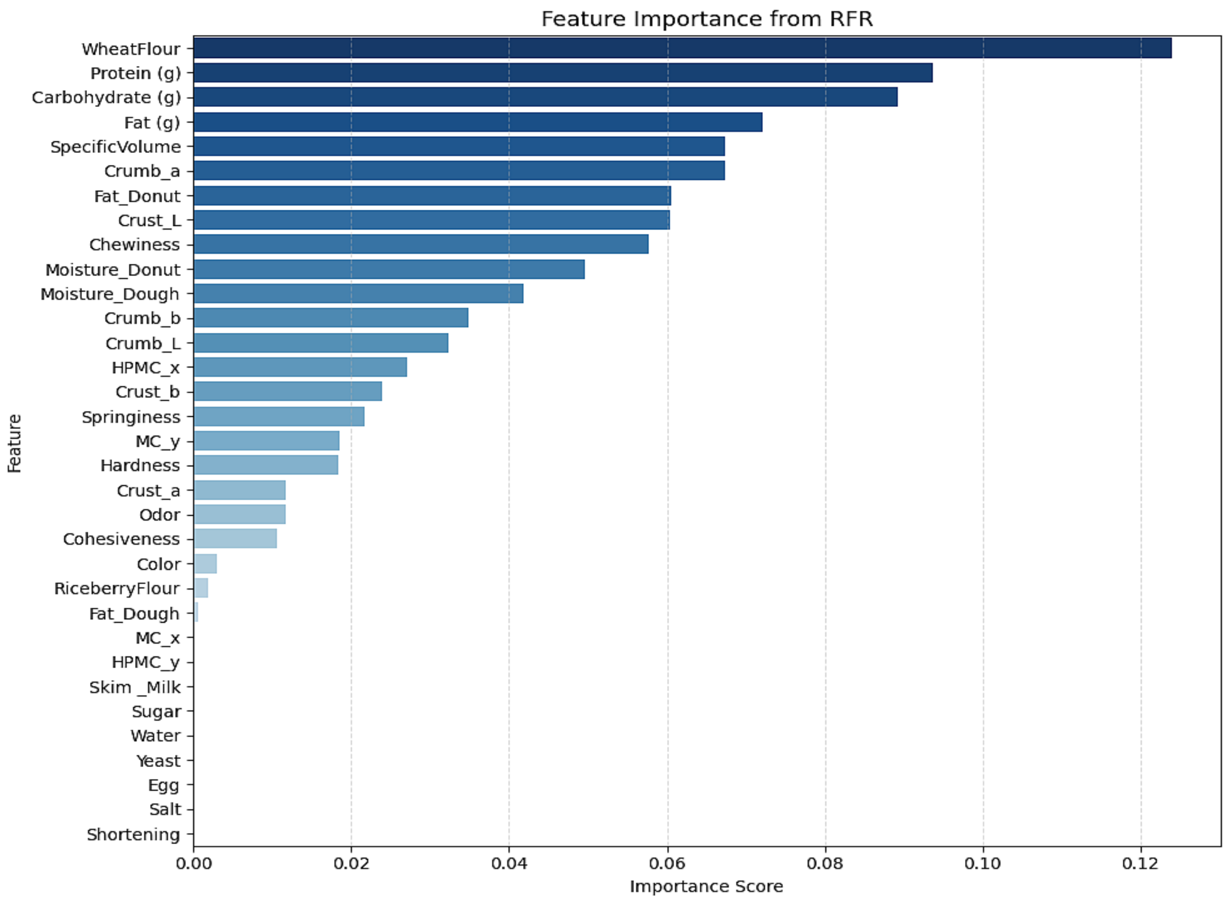

Figure 3.
Feature Importance from RFR Macronutrient.

Figures 4, 5, and 6 present a comparative examination of actual versus predicted values for taste, texture, and overall liking of several donut compositions. In each chart, the Predicted values nearly correspond with the Actual values, illustrating the model's robust predictive accuracy. The Random Forest model accurately represents the sensory properties, exhibiting negligible discrepancies between the predicted and real values for all three variables. This demonstrates that the model consistently predicts customer evaluations of Taste, Texture, and Overall Liking across the recipes, underscoring its potential for enhancing donut formulations based on sensory satisfaction.

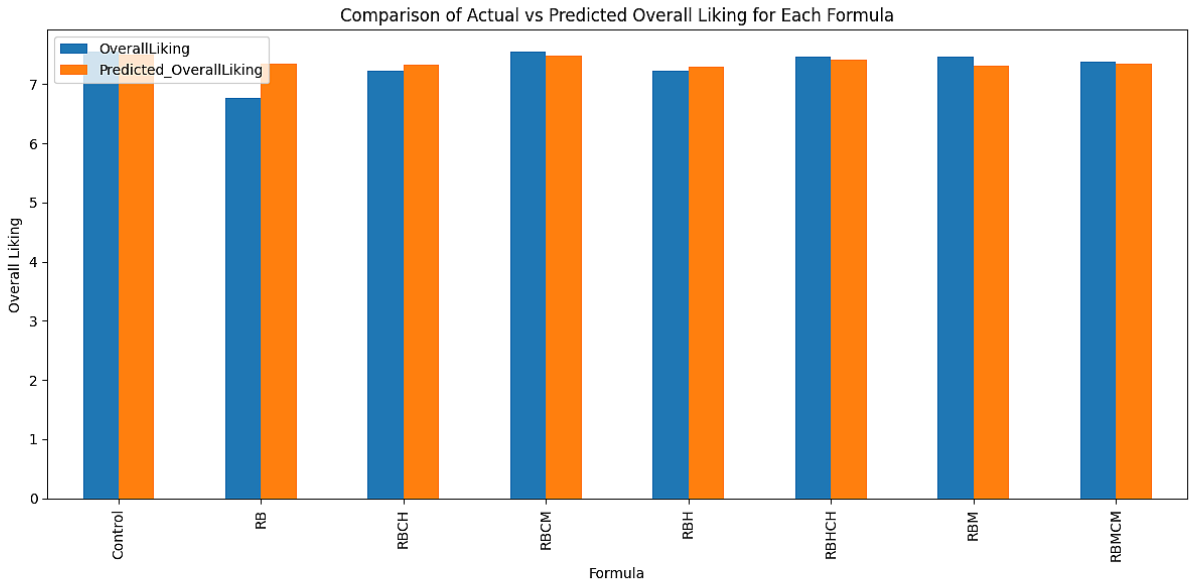

Figure 4.
The comparison of Actual and Predicted Overall Liking for each formula.

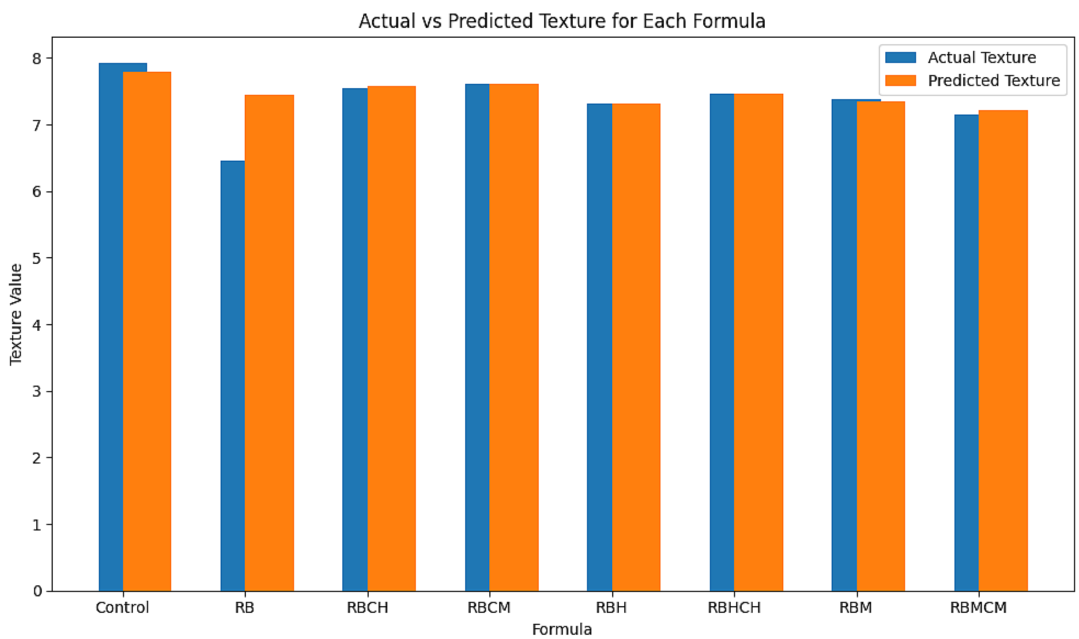

Figure 5.
The comparison of Actual and Predicted Texture for each formula.

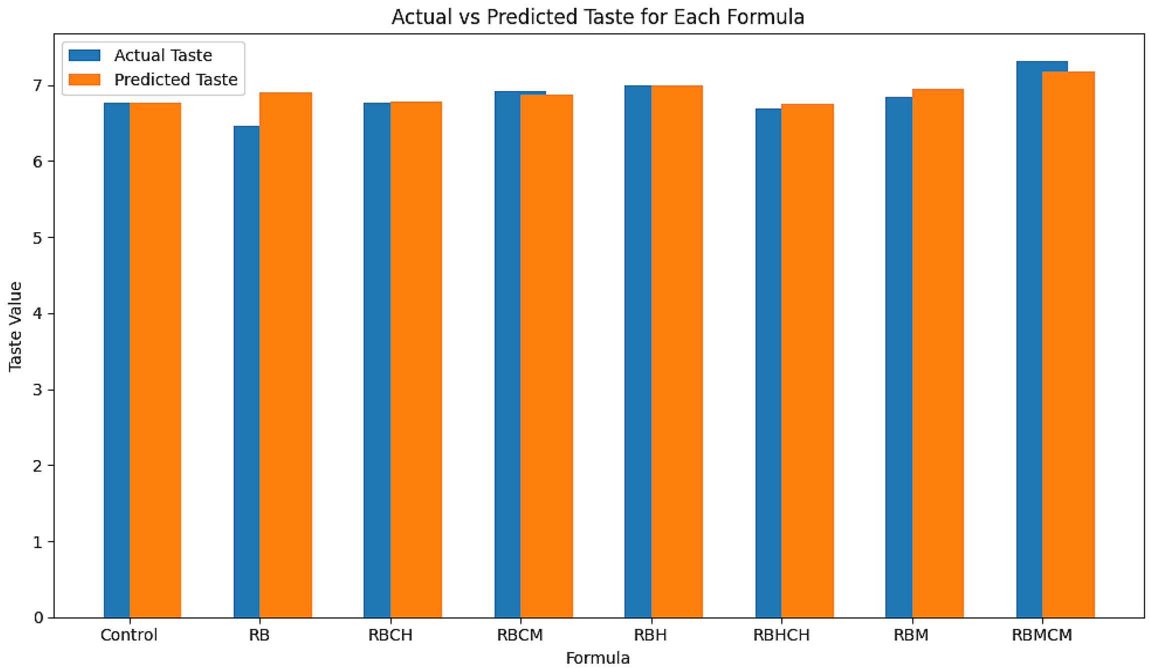

Figure 6.
The comparison of Actual and Predicted Taste for each formula.

Riceberry flour played a major impact in determining the nutritional profile and sensory qualities of the donuts. Following model retraining, the most influential features were Riceberry flour, Wheat flour, Calories from Fat, Chewiness, and Protein. Utilizing this revised model, simulated recipes were generated by altering the Riceberry flour amount (20–35%), shortening (15–19g), and protein (2.6–3.0g). The optimal formulation, comprising 30% Riceberry flour, 15g of shortening, and 2.7g of protein, attained a projected Overall Liking score of 7.37 and, when appropriately scaled, provided approximately 114.5 kcal per 30g serving.

The findings underscore the promise of Riceberry flour as a crucial component in the development of health-focused, low-calorie baked goods while maintaining consumer enjoyment. They illustrate the viability of employing data-driven machine learning techniques to enhance the equilibrium between nutritional quality and sensory attractiveness, facilitating advancements in healthier bread products.

4. Conclusion and Discussion

This study shows how Random Forest Regression (RFR) may be used effectively to enhance Riceberry donut compositions that are both aesthetically pleasing and nutritionally balanced. Utilizing a refined dataset that omitted superfluous variables and highlighted critical ingredients and characteristics, we created a prediction model adept at forecasting significant sensory and nutritional outcomes, such as Overall Liking, Taste, Texture, and Calories. The algorithm precisely forecasted these results across multiple donut recipes, as evidenced by the nearly perfect correlation between the projected and real values for each sensory characteristic (Taste, Texture, and Overall Liking).

The results highlight Riceberry flour as a crucial component in determining the nutritional attributes and sensory characteristics of the donuts. The model revealed critical factors affecting sensory quality, including Riceberry flour, Wheat flour, and caloric content from fat, chewiness, and protein, which informed the development of an optimal recipe. The ideal formulation, comprising 30% Riceberry

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flour, 15g of shortening, and 2.7g of protein, attained a predicted Overall Liking score of 7.37 and roughly 114.5 kcal per 30g serving, demonstrating a balance between nutritional quality and sensory appeal.

This study demonstrates the efficacy of data-driven machine learning in optimizing food formulas. Utilizing RFR enabled us to accurately forecast user assessments, thereby aiding in the creation of healthier, low-calorie baked products that maintain sensory appeal. The results underscore the feasibility of Riceberry flour as a crucial element in the creation of health-oriented food items, enhancing both nutritional advantages and consumer satisfaction.

In conclusion, the findings of this study indicate that machine learning methodologies, particularly Random Forest Regression, provide an effective means of enhancing food compositions. Utilizing these technologies enables the equilibrium of nutritional value and sensory attributes, facilitating the creation of healthier, more palatable bakery products that address consumer demands and preferences. The effective incorporation of Riceberry flour indicates its promise as a crucial component in health-oriented culinary developments.

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Transparency:
The authors confirm that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.

Authors' Contributions:
All authors contributed equally to the conception and design of the study. All authors have read and agreed to the published version of the manuscript.

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