Development of Gluten Free Cookie Using Chestnut and Foxnut Flour Blend: Composition Optimization through Response Surface Methodology

Divya Singh Chauhan[a], Apoorva Behari Lal[a], Anto Pradeep Raja Charles[b], Amit Pratap Singh[a], Ashish Khare[a], Pranav Vashisht[c]

[a]Department of Food Technology, Raja Balwant Singh Engineering Technical Campus, Bichpuri, Agra, Uttar Pradesh, India.

[b]Food Ingredients and Biopolymers Laboratory, North Dakota State University, Fargo, ND 58102, USA.

[c]Department of Agricultural and Environmental Sciences, Tennessee State University, Nashville, TN, 37209, USA.

Corresponding Author:

Divya Singh Chauhan

Assistant Professor, Department of Food Technology,

Raja Balwant Singh Engineering Technical Campus

Bichpuri, Agra, Uttar Pradesh, India.

divyaachauhaan@gmail.com

Abstract

Cookies are baked goods that typically comprise the three main elements sugar, lipids and wheat flour alongside the additional minute components including eggs, milk, salt, and leavening agents. Gluten, a wheat protein found in wheat flour, contributes to the extensibility and elasticity of dough. For an individual with a celiac disease, the consumption of gluten should be avoided. In addition to those with celiac disease, those who observe religious fasts abstain from wheat and wheat-derived items. Religious fasting, often described as a fasting regimen carried out for spiritual or religious reasons, is a dietary pattern characterized by varying degrees of calorie restriction and abstention from particular foods. In order to make gluten-free cookies for fasting, water chestnut flour, foxnuts, and peanuts were combined with cardamom and clove as flavoring agent. The experimental planning and analysis were performed using the Response Surface Methodology. Two independent variables, specifically the foxnut powder and chestnut flour were selected and the Central Composite Design was applied. Altogether, thirteen experimental formulations were used for producing cookies. Along with sensory evaluation, the cookies' moisture, ash, fat, and protein contents were examined. For general acceptance, 25–30 semi-trained panelists were chosen to conduct the sensory analysis based on a numerical scoring test. The sample (S12; 60% chestnut and 5% foxnut flour) had the greatest overall acceptance score. The chemical components of S12, namely moisture, ash, fat, and protein, were 3.84%, 3.51%, 18.52%, and 6.92%, respectively. Compared to the control sample, this sample was preferred.

Keywords: Cookie formulation, Gluten free, Response Surface Methodology, Sensory evaluation.

1. Introduction

The water chestnut refers to the plant that is found in water bodies including lakes, ponds, and rivers. This hydrophyte is considered as a dependable food source for the flood prone areas due to its starch producing nature. It is abundant in nutrients and minerals.[1] According to Ismail et al., water chestnut provides abundant fat, amino acids, sugar, minerals, water- and fat-soluble vitamins, fibers, and antioxidants like flavonoids and phenols. It is known for its antidiabetic, anti-inflammatory, suppressing pain and bactericidal properties.[3,4] It is widely used in bakery and sweets products.[4]

Foxnut, also known as "makhana" in India, is a popped gorgon nut (Euryale ferox) kernel. Due to its gluten-free nature, it may be used effectively in food products that can be consumed while fasting and in the production of gluten-free products.[5] Carbohydrates, protein, and fat are fox nut's main components, ranging between 55-80%, 10-15%, and 0.2-0.7%, respectively. It is rich in phosphorus, potassium, magnesium, calcium, and sodium.[6,7] The protein in foxnut seed has a unique amino acid composition high in essential amino acids (leucine, isoleucine, methionine, and lysine). As a non-cereal cuisine, makhana is a perfect staple sustenance for devotees during their holy fast.[8] The edible seeds of a legume are called "peanuts" or "groundnuts" in several regions of the world. Protein, oil, and fibers are abundant in peanuts.[9-11] Consumers have shown a considerable interest in snack food products because of their taste and convenience.

Cookies are typically enjoyed as a snack item and are the ideal delivery system for dietary supplements. They are the major segment of the confections and bakery which potentially contributes to environment through the utilization of major byproducts including clarified butter residues and whey.[12,13] With non-wheat flours including buckwheat, cassava, quinoa, etc., gluten free cookies have been prepared previously by several researchers using different raw materials like quinoa flour, rice flour, coconut flour, sweet potato flour, and cassava-based composite flour.[10,14-17] There is a need to create gluten-free cookies employing ingredients with functional properties to cater to those with gluten sensitivity while also providing extra health advantages.[18] Gluten content, which enables air cell expansion and provides stiffness after baking, enables it to carry out these duties.[19] Patients with celiac disease, however, must cut out gluten from their diets. Gül et al. report that 26 to 49% of children who come to tertiary care facilities in India with chronic diarrhea are later found to have celiac disease.[20] As per Mohta et al. studies the instances of celiac disease are dependent on the people’s consumption patterns of wheat (gluten), which were higher in northern (1.23%) and lower in the southern (0.10%) Indian region.[21] Gliadin can rapidly and transiently boosts the porosity of the epithelial cells of the intestine. Although the mucosa of the small intestine is thick, it is coiled up into many folds and finger-like projections known as villi. Due to the small intestine's injured mucosa's decreased ability to absorb nutrients from food, nutritional deficiencies develop.[22]

As per the reports cookie sector would be 44.01 billion USD by 2025, with CAGR of 5.3%, where Asian Pacific is projected to have the most spontaneous growth (6.8%). The main factors contributing to this growth include urbanization, modern way of living and elevated incomes. Chestnut and foxnut flour play a critical role in delivering the nutritional benefits to the cookie. However, the scarcity of literature that delves into these flours' effects on sensory quality and consumer acceptability pushed the need for this study. The objective of this study was to assess the impact of chestnut and foxnut flour composition upon physical, nutritional, and sensory properties of gluten-free cookie. The study utilized the Response Surface Methodology to choose the optimal blend of these flours to develop cookies with better consumer acceptability.

2. Materials and Methods

2.1. Material

Foxnut (Tulsi Brand), water chestnut flour (Bansal Ji Spices), groundnut, sugar (Good Life refined sugar), cardamom, clove, and baking powder (Ajanta) were procured from Agra, Uttar Pradesh, India's market. Sodium bicarbonate (Qualigens Fine Chemicals) was obtained from the Department of Food Technology at Raja Balwant Singh Engineering Technical Campus, Bichpuri, Agra, India. The xanthan gum (Sattvic Foods) was purchased online from Amazon.

2.2. Preparation of foxnut powder

The black spots on the foxnuts were first removed, and then the foxnuts were broken into small pieces and dried in a tray dryer at a temperature of 80℃ for 30 min to attain 6% moisture content. Following it, the foxnuts were cooled and ground to produce foxnut powder.

2.3. Preparation of groundnut paste

The groundnuts were cracked open, and the red skin was removed. Then, the groundnuts were ground to paste by adding approximately 25 mL of Millipore water (18.4 MΩ.cm)

2.4. Preparation of cookies

Cookie samples were prepared using the creamery method and the following ingredients: 0.2% of baking soda, 0.3% of baking powder, 25% of sugar and 0.5% of Xanthan gum.[5] Based on the preliminary experiments, the amounts of xanthan gum, sodium bicarbonate, and baking powder were raised to 5%, 1%, and 2%, respectively. The peanut paste (35%) and sugar were combined in a dish and creamed. The sifting was done for the dry materials, such as the foxnut powder and water chestnut flour. Then, the prepared cream was combined with the major components (water chestnut and foxnut flour) and minor elements (leavening and binding agents) to create a smooth dough. The prepared dough was given a rest for 30 min, then sheeted to a thickness of 7 mm, and a round cookie cutter with a 5 cm diameter was used to cut it. Following it, the cookies were cooked in the oven at three different steps: i) the bottom plate was heated to 100℃ and the top plate to 80 ℃ for 15 min; ii) the bottom plate was heated to 80℃ and the top plate to 120℃ for 10 min; iii) the bottom and top plate temperatures were set to 70℃ for 7 min. The cookies were baked, cooled to room temperature, and then stored in a moisture-proof container. Based on the amount of chestnut and foxnut utilized, a total of 13 cookies combination were produced (as per the response surface methodology design) and all the 13 combinations were cooked in the above-mentioned three different conditions (Table 1.).

2.5. Chemical analysis of raw material and cookies

For the evaluation of moisture, protein, ash, and fat content of the samples official AOAC methods were followed.[23] Moisture and ash was assessed using a gravimetric method while for protein and fat content standard Kjeldahl and Mojonnier methods were followed, respectively.

2.6. Physical Analysis of Cookies

2.6.1. Weight

Sample's weights were assessed using a calibrated balance where values were taken spontaneously post tempering.[24]

2.6.2. Diameter

For diameter evaluation value for four cookies (kept edge to edge) were taken by using a measuring scale. Samples were pivoted perpendicularly for another set of reading. Both the values were averaged to determine the mean diameter.[24]

2.6.3. Thickness

The cookies' thickness was evaluated using a vernier caliper (0.01 mm precision). Six cookies were stacked randomly, and their height was measured. The average thickness of each individual cookie was calculated.[24]

2.7. Sensory Analysis

Sensory analysis for appearance, flavour, chewability, and overall acceptability was analysed using the numerical scoring test. Numerical scoring was performed: excellent:

9–10, good: 6–8, fair: 4–5, and poor: 1–3. Every panelist was asked to evaluate the sample on a 10-point scale.

2.8. Experimental Design and Analysis

To develop the design Response Surface Methodology (RSM) was applied (Design expert version 13, Stat-Ease 360). A three-factor design at five levels was adopted. Thirteen experiments were conducted as per the experimental design and the independent variables were water chestnut flour and foxnut powder. The dependent variables include sensory parameters; appearance, flavour, chewability. Statistical significance (at 5% level) of every factor upon the response was evaluated using ANOVA. All the experiments were conducted in triplicate and values were reported as mean ± std deviation.

3. Results and Discussion

3.1. Chemical composition of raw materials

The moisture, ash, fat, and protein content of water chestnut flour, foxnut, and groundnut were subjected to analysis, with the results presented in Table 2. Notably, groundnut exhibited the highest protein content (22.70 ± 0.73%) among the three flours, followed by foxnut (9.70 ± 0.71%) and WCF (6.01 ± 0.89%). The findings align with the protein content reported by Pawar and Singh for foxnut flour.[25] Our Water chestnut flour's protein content values surpassed those reported by Shafi et al. (4.18%) but were lower than Ahmed et al. analysis (8.4%).[26,27] The low protein content of the flour (6.01± 0.89%) was likely due to the presence of non-protein constituents such as crude fiber, reducing and non-reducing sugars, and starch.

The fat content was also significantly elevated in groundnut (43.20 ± 0.86%) compared to foxnut (0.50 ± 0.06%) and Water chestnut (0.81 ± 0.09%). Therefore, ground nut presents promising potential to produce high-nutrition cookies and may serve as a natural emulsifier. Shafi et al. and Bala et al. reported a fat content of approximately 0.52% for Water chestnut flour.[26,28] While foxnut flour by has around 0.4% fat.[25] Foxnut had the highest moisture content (12.80 ± 0.91%), while both Water chestnut and groundnut exhibited similar moisture levels (5.71 ± 0.37%). Regarding ash content, water chestnut flour had the highest value (1.82 ± 0.61%), followed by groundnut (1.72 ± 0.20%) and foxnut (0.62 ± 0.02%).

3.2. Physical properties of cookies (weight, diameter, and thickness)

The weight of the cookies was in the range of 12.14 and 14.76 g (Table 3). Notably, the cookie sample S9 emerged as the heaviest and most voluminous, however S2 weigh lowest (12.14 g). The augmentation in weight can be attributed to the elevated incorporation of foxnut powder in the sample. Jana et al. and Shafi et al. analysis demonstrated that foxnut flour has higher bulk density than chestnut flour.[26,29] Therefore, the substantial addition of foxnut flour exerts a pronounced influence on bulk density, consequently contributing to the increased weight of the cookies. Bulk density plays a pivotal role in assessing packaging requirements for any product, offering the opportunity for compact packaging by accommodating higher weight within a constant.[30,31] volume Furthermore, this observation can be linked to the elevated moisture content and the moisture and oil absorption capacity inherent to foxnut powder. Similar observations were reported in the studies of Kumar et al., where the substitution of popped makhana (foxnut) flour for wheat flour resulted in an increased weight of cookies.[32] However, in the studies conducted by Shafi et al., the increased weight was ascribed to chestnut flour, which possessed a higher bulk density in comparison to wheat flour.[26]

The diameter of the cookies displayed a reduction ranging from 56.1 to 49.0 mm for S10 and S9, respectively (Table 3). Kumar et al. also observedthe decline in the cookie diameter with the increased substitution of popped makhana flour in the blends.[32] This phenomenon may be attributed to the enhanced water absorption capacity associated with the blend, which in turn leads to a reduction in the width of the cookie samples. The higher water absorption can be ascribed to the lower lipid content present in the flour.[33] A similar diminishing trend was observed in the thickness of the cookie samples, with values ranging from 7.8 to 9.6 mm (Table 3). S10 sample exhibited the maximum (9.6 mm) thickness, however S11 had the least (7.8 mm) value. Notably, the thickness of the cookies experienced a significant decline with an increasing level of substitution with foxnut powder. These findings, however, contradict those of Kumar et al.[32]

3.3. Proximate composition of cookie (moisture, ash, fat, and protein)

The variation in moisture, ash, fat, and protein content of cookies with respect to the incorporation ratio of water chestnut flour and foxnut powder has been demonstrated in Table 4. Moisture for the samples were between3.50% and 3.84%, where maximum value was obtained for S12 while lowest was in the case of S11.

The findings were in correspondence with Pawar et al. where the moisture content of the cookies decreased with amaranth and foxnut flour substitution.[34] Moisture has been significantly correlated with the product's shelf life, where elevated moisture increases the microbial enumeration hence paces the spoilage.[35]The ash content of cookies ranged from 3.32% to 3.98% where the highest content was in S11 and the lowest was in S10. The higher ash content is directly correlated to the mineral content of the product. It was observed that the ash content declined with increased foxnut powder content, which is attributed to the lowest ash content of the foxnut flour among all the three flours used.

The fat of the samples was between 17.51% and 18.63%. Fat is an essential component which provides three times the energy needed by the human body as well as it is a carrier of fat-soluble vitamins.[36] Higher fat content can affect the shelf stability of the cookie. The value highest fat content was observed in S8 (18.63%) while the lowest value was observed in S11 (17.51%). The findings were in contrary with Kumar et al., where the foxnut powder addition boosted the fat content of the cookies.[32] This might be because the relative fat content of the foxnut powder might be higher than the other ingredients used in their cookie formulation.

Protein is another essential component of cookies which assists in the growth of the human body.[36] The increased awareness towards health has elevated the market for high protein food products. The protein of the samples was between 6.92% and 8.97%. The value of protein content for fresh sample was highest (8.97%) for S9 and lowest value (6.92%) was observed for S12. The findings were in correspondence with Kumar et al., that increase in the popped makhana flour proportion increased the protein content of the cookies.[32]

3.4. Sensory characteristics of cookies

The responses obtained at different ratio of chestnut and foxnut for the formulation of gluten free cookies for fasting purpose are demonstrated in Table 5. The second order polynomial equations were studied for the responses at different flour ratios. The models thus developed with coded variables are as follows:

$$Y_{Appearance} = 125.58 - 4.25A - 0.78B + 0.004AB + 0.04A^2 + 0.01B^2$$

$$Y_{Flavor} = 6.61 + 226.87A + 225.19B + 0.04AB + 160.75A^2 - 159.99B^2$$

$$Y_{Chewability} = 127.31 - 4.28A - 0.65B + 0.003AB + 0.04A^2 + 0.01B^2$$

The coefficients of regressions for all the responses at different input parameters have been shown in Table 6 and ANOVA results obtained for appearance, flavor and chewability were demonstrated in Table 7.1, 7.2, and 7.3.Intergated influence of more than one variable was demonstrated through RSM (figure 1, 2 and 3).

3.4.1. Appearance

The maximum score observed for appearance was 7.9 and the minimum score was 2.5 (Table 7.1), with actual, predicted, and adjusted R^2 values of 0.9177, 0.8996, and 0.9043, respectively. Both actual and predicted R^2 values were in agreement with the adjusted R^2. Developed model was significant at $P<0.05$ hence both the variables (water chestnut and foxnut content) had significant influence on the appearance of the samples.Figure 1 illustrates the response surfaces detailing the impact of both chestnut and foxnut on the outcome. Notably, all model terms pertaining to appearance held significant value. With the progressive increase in foxnut content, a diminishing effect on the cookies' coloration was observed, imparting a slightly negative aspect to their appearance. The increased lightness can be attributed to the elevated moisture content found in foxnut flour.[37,38] Kumar et al., also observed the decline in Lightness (L*) value as the proportion of popped makhana flour in the blend of popped makhana and wheat flour increased.[32] This underscores the role of foxnut in influencing the cookies' visual appeal, with a discernible trend towards lighter coloration accompanying an escalating substitution level of foxnut flour. The optimal appearance of the cookies was achieved when incorporating the minimal amount of foxnut (S10).

3.4.2. Flavor

The maximum score observed for flavor was 8.9 and the minimum score was 5.1 (Table 7.2), with actual, predicted, and adjusted R^2 values of 0.8981, 0.7942, and 0.8225, respectively. Both actual and predicted R^2 values were in agreement with the adjusted R^2. Developed model was significant at $P<0.05$ hence both the variables (water chestnut and foxnut content) had significant influence on the flavor of the samples.

Response surfaces depicting the influence of chestnut and foxnut on flavor have been presented in Figure 2. Interesting, all model terms pertaining to flavor also demonstrated significant relevance. Notably, as the foxnut content ranged from 2.9% to 17.1%, the flavor of the cookies exhibited improvement, peaking at around 5%, and subsequently declining as the foxnut content approached 17.1%. The most favorable flavor in the cookies was achieved in the case of S12 sample. Pawar et al., observed the increased mean scores, particularly in terms of taste, that was notably pronounced up to 87-90% incorporation of amaranth flour and foxnut flour into the composite cookies.[34] This reinforces the significance of foxnut's role in enhancing the overall flavor of baked goods, mirroring the findings observed in this study.

3.4.3. Chewability

The maximum score observed for flavor was 7.8 and the minimum score was 4.0 (Table 7.3), with actual, predicted, and adjusted R^2 values of 0.9769, 0.8989, and 0.9603, respectively. Both actual and predicted R^2 values were in agreement with the adjusted R^2. Developed model was significant at $P<0.05$ hence both the variables (water chestnut and foxnut content) had significant influence on the chewability of the samples. Response surfaces, illustrating the impact of chestnut and foxnut on the chewability of the cookies, have been presented in Figure 3. Notably, as the foxnut content increased, the cookies became progressively more challenging to chew. This trend was corroborated to the increased hardness of the cookies, with the escalation in the substitution level of foxnut flour. The optimum chewability of the cookies was achieved with the lowest incorporation level of foxnut, specifically, (S10). Mishra et al., reported that the biscuits developed using the Makhana powder had rigid texture as compared to the biscuits that had potato powder base.[5] This might be due to the scarcity of gluten content in makhana powder which while absorbing water it imparts an elastic texture to the dough.

Conclusion

The present study demonstrated the feasibility of the generation of gluten-free cookies (with up to the mark nutritive and sensory attributes) for fasting purposes by complete replacement of wheat flour by water chestnut and foxnut flour. Replacement of hydrogenated fat with peanut paste during creaming controlled the excess oiliness in the baked cookies. It was observed that water chestnut flour could be incorporated up to 60% level in the cookies without affecting flavor and texture of the cookies. Foxnut powder could be incorporated up to 5% level as with an increase in the foxnut ratio of the cookie the hardness of the cookies kept increasing. Peanut paste was incorporated during creaming with sugar up to 35% without affecting the texture and appearance significantly. Further, nutritional assessments unveiled a substantial increase in protein with the addition of foxnut flour alongside water chestnut flour. Conversely, fat content and moisture content witnessed a significant decrease and ash content elevated as compared to control. Totably, gluten-free cookies outperformed the control in terms of nutritional attributes. Sensory evaluation, encompassing parameters such as appearance, flavor, and chewability, favored the gluten-free samples, with superior scores in terms of appearance and flavor. However, the control sample had a better score for chewability. Sample S12, developed using 60 parts water chestnut flour and 5 parts foxnut powder, garnered the highest overall acceptability score, underscoring its desirability.

List of tables

Table 1. Formulation of cookies based on the chestnut and foxnut composition (as per RSM design).

Table 2. Summarization of the chemical attributes of the raw materials used for the cookie preparation.

Table 3. Summarization of the physical attributes (weight, diameter, thickness) of various cookie samples generated.

Table 4. Summarization of the chemical attributes of the raw materials used for the cookie preparation.

Table 5. Summarization of the sensorial assessment of the developed cookie samples.

Table 6. Regression coefficients of different responses for gluten free cookie.

Table 7. Analysis of variance for the response variables.

Table 7.1. Appearance **Table 7.2**. Flavor **Table 7.3.** Chewability

List of figures

Figure 1. Response surface demonstrating the effect of foxnut and chestnut on the appearance of cookie samples.

Figure 2. Response surface demonstrating the effect of foxnut and chestnut on flavour of cookie samples.

Figure 3. Response surface demonstrating the effect of foxnut and chestnut on chewability of cookie samples.

References

1. Rajput, J. D., & Singh, S. P. (2023). Water Chestnut (Trapa natans L.): Functional characteristics, nutritional properties and applications in food industry: A review. *The Journal of Phytopharmacology*, *12*(2), 119–126. https://doi.org/10.31254/phyto.2023.12209
2. Ismail, B., Haffar, I., Baalbaki, R., & Henry, C. J. (2008). Physico-chemical characteristics and sensory quality of two date varieties under commercial and industrial storage conditions. *Lebensmittel-Wissenschaft & Technologie*, *41*(5), 896–904.
3. Parekh, J., & Chanda, S. (2007). In vitro antimicrobial activity of Trapa natans L. fruit rind extracted in different solvents. *African Journal of Biotechnology*, *6*(6).
4. Kaur, K., Kaur, G., & Singh, A. (2023). Water chestnut starch: extraction, chemical composition, properties, modifications, and application concerns. *Sustainable Food Technology*, *1*(2), 228-262.
5. Mishra, A., Devi, M., & Jha, P. (2014). Development of gluten free biscuits utilizing fruits and starchy vegetable powders. *Journal of Food Science and Technology*, *52*(7), 4423–4431. https://doi.org/10.1007/s13197-014-1521-5
6. Bao, H., Ding, H. H., Charles, A. P. R., Hui, D., Rakshit, S., Nahashon, S., & Wu, Y. (2023). Application of yellow mustard mucilage in encapsulation of essential oils and polyphenols using spray drying. Food Hydrocolloids, 143, 108815.https://doi.org/10.1016/j.foodhyd.2023.108815
7. Kr, D. (2023). *A Comprehensive Review on Nutraceutical Properties of Euryale ferox Salisb Review Article*. Retrieved August 8, 2023, from https://www.opensciencepublications.com/wp-content/uploads/JPSR-2349-2805-9-221.pdf
8. KUMAR, L., SINGH, A. K., & Bhatt, B. P. (2016). Nutritional status of recently developed makhana (gorgon nut) variety-Swarna Vaidehi. *Journal of AgriSearch*, *3*(4), 199-205. DOI: 10.21921/jas.v3i4.6701.

9. Arya, S. S., Salve, A. R., & Chauhan, S. (2015). Peanuts as functional food: a review. *Journal ofFood Science and Technology*, *53*(1), 31–41. https://doi.org/10.1007/s13197-015-2007-9.

10. Julakanti, S., Charles, A. P. R., Syed, R., Bullock, F., & Wu, Y. (2023). Hempseed polysaccharide (Cannabis sativa L.): Physicochemical characterization and comparison with flaxseed polysaccharide. Food Hydrocolloids, 143, 108900.https://doi.org/10.1016/j.foodhyd.2023.108900

11. Šoronja-Simović, D., Pajin, B., Šubarić, D., Dokić, L., Šereš, Z., & Nikolić, I. (2017). Quality, sensory and nutritional characteristics of cookies fortified with chestnut flour. *Journal of food processing and preservation*, *41*(1), e12887. https://doi.org/10.1111/jfpp.12887

12. Pranav, V., & Meena, C. S. (2018). Ghee residue: processing and utilization in food and non-food applications. *Indian Dairyman*, *70*(10), 96-100.

13. Vashisht, P., Chaudhary, V., Sharma, S., Devi, H., & Singh, T. P. (2023). Whey Kefir: A Sustainable Solution to Reduce Waste and Improve Health. *ACS Food Science & Technology*, *3*(9), 1403-1410.

14. De Lima Brito, I., De Souza, E. L., Félex, S. S. S., Madruga, M. S., Yamashita, F., & Magnani, M. (2014). Nutritional and sensory characteristics of gluten-free quinoa (Chenopodium quinoa Willd)-based cookies development using an experimental mixture design. *Journal of Food Science and Technology*, *52*(9), 5866–5873. https://doi.org/10.1007/s13197-014-1659-1

15. Jisha, S., & Padmaja, G. (2009). Whey Protein Concentrate Fortified Baked Goods from Cassava-Based Composite Flours: Nutritional and Functional Properties. *Food and Bioprocess Technology*, *4*(1), 92–101. https://doi.org/10.1007/s11947-008-0175-6

16. Păucean, A., Man, S., Muste, S., & Pop, A. (2016). Development of Gluten Free Cookies From Rice And Coconut Flour Blends. *Bulletin of University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca*, *73*(2), 163. https://doi.org/10.15835/buasvmcn-fst:12311

17. Susman, I. E., Schimbator, M., Culetu, A., & Popa, M. E. (2021). Formulation of Gluten-Free Cookies with Enhanced Quality and Nutritional Value. *Bulletin of*

University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca, *78*(1), 113. https://doi.org/10.15835/buasvmcn-fst:2020.0046.

18. Giri, N. A., & Sakhale, B. K. (2021). Effects of incorporation of orange-fleshed sweet potato flour on physicochemical, nutritional, functional, microbial, and sensory characteristics of gluten-free cookies. *Journal of Food Processing and Preservation*, *45*(4). https://doi.org/10.1111/jfpp.15324
19. Suriya, M., Rajput, R., Reddy, C. K., Haripriya, S., & Bashir, M. (2017). Functional and physicochemical characteristics of cookies prepared from Amorphophallus paeoniifolius flour. *Journal of Food Science and Technology*, *54*(7), 2156–2165. https://doi.org/10.1007/s13197-017-2656-y
20. Gül, H., Hayit, F., Acun, S., & Tekeli, S. G. (2018). Improvement of Quality Characteristics of Gluten-Free Cookies with the Addition of Xanthan Gum. *Conference Proceedings "Agriculture for Life, Life for Agriculture," 1*(1), 529–535. https://doi.org/10.2478/alife-2018-0083
21. Mohta, S., Rajput, M. S., Ahuja, V., & Makharia, G. (2021). Emergence of Celiac disease and Gluten-related disorders in Asia. *Journal of Neurogastroenterology and Motility*, *27*(3), 337–346. https://doi.org/10.5056/jnm20140
22. Caio, G., Volta, U., Sapone, A., Leffler, D. A., De Giorgio, R., Catassi, C., & Fasano, A. (2019). Celiac disease: a comprehensive current review. *BMC Medicine*, *17*(1).
23. Dr. Latimer, George W, Jr. (ed.), *Official Methods of Analysis of AOAC INTERNATIONAL*, 22 (New York, 2023; online edn, AOAC Publications, 4 Jan. 2023) https://doi.org/10.1093/9780197610145.001.0001.
24. AACC Approved Methods of Analysis, 11th Ed. Method 10-50.05. Baking Quality of Cookie Flour. 02-03.02. Cereals & Grains Association, St. Paul, MN, U.S.A. http://dx.doi.org/10.1094/AACCIntMethod-10-05.05.
25. Pawar, S., & Singh, S. P. (2022). Functional bread fortified with foxnut flour and amaranth flour. *Pharm Innov J*, *11*, 528-35.
26. Shafi, M., Baba, W. N., Masoodi, F., & Bazaz, R. (2016). Wheat-water chestnut flour blends: effect of baking on antioxidant properties of cookies. *Journal of*

Food Science and Technology, *53*(12), 4278–4288. https://doi.org/10.1007/s13197-016-2423-5

27. Ahmed, J., Al-Attar, H., & Arfat, Y. A. (2016). Effect of particle size on compositional, functional, pasting and rheological properties of commercial water chestnut flour. *Food Hydrocolloids*, *52*, 888-895.
28. Bala, A., Gul, K., & Riar, C. S. (2015). Functional and sensory properties of cookies prepared from wheat flour supplemented with cassava and water chestnut flours. *Cogent Food & Agriculture*, *1*(1), 1019815.
29. Jana, B. R., Srivastava, A., & Idris, M. (2019). New makhana (Euryale ferox Salisb.) processed products for health benefit. *Journal of Pharmacognosy and Phytochemistry*, *8*(2), 1662-1666.
30. Charles, A. P. R., Mu, R., Jin, T. Z., Li, D., Pan, Z., Rakshit, S., ... & Wu, Y. (2022). Application of yellow mustard mucilage and starch in nanoencapsulation of thymol and carvacrol by emulsion electrospray. *Carbohydrate polymers*, *298*, 120148. https://doi.org/10.1016/j.carbpol.2022.120148
31. Yellavila, S. B., Agbenorhevi, J. K., Asibuo, J. Y., & Sampson, G. O. (2015). Proximate composition, minerals content and functional properties of five lima bean accessions.
32. Kumar, S., Singh, I., Kumar, N., & Singh, C. (2015). Application and effect of addition of popped makhana flour on the properties and qualities of cookies. *International Journal of Processing and Post Harvest Technology*, *6*(1), 80–86. https://doi.org/10.15740/has/ijppht/6.1/80-86
33. Rathnakumar, K., Kalaivendan, R. G. T., Eazhumalai, G., Charles, A. P. R., Verma, P., Rustagi, S., ... & Pandiselvam, R. (2023). Applications of ultrasonication on food enzyme inactivation-Recent review report (2017-2022). Ultrasonics Sonochemistry, 106407. https://doi.org/10.1016/j.ultsonch.2023.106407
34. Pawar, S., Wagh, N., & Jagdale, N. R. G. (2023). Development and Physio-Chemical Analysis of Amaranth and Foxnut Flour-Based Nutrient-Rich Cookies. *International Journal of Advanced Research in Science, Communication and Technology*, 277–284. https://doi.org/10.48175/ijarsct-7978.

35. Elleuch, M., Bedigian, D., Roiseux, O., Besbes, S., Blecker, C., & Attia, H. (2011). Dietary fibre and fibre-rich by-products of food processing: Characterisation, technological functionality and commercial applications: A review. *Food chemistry*, *124*(2), 411-421.

36. Wardlaw, G. M., & Kessel, M. W. (2002). *Perspectives in nutrition*. McGraw-Hill.

37. Charles, A. P. R., Jin, T. Z., Mu, R., & Wu, Y. (2021). Electrohydrodynamic processing of natural polymers for active food packaging: A comprehensive review. *Comprehensive reviews in food science and food safety*, *20*(6), 6027-6056.https://doi.org/10.1111/1541-4337.12827

38. Correia, P., & Beirão-da-Costa, M. L. (2012). Effect of drying temperatures on starch-related functional and thermal properties of chestnut flours. *Food and Bioproducts Processing*, *90*(2), 284-294.

Table 1. Formulation of cookies based on the chestnut and foxnut composition (as per the RSM design).

Sample	Chestnut flour (%)	Foxnut flour (%)
Control	0	0
S1	55	10
S2	47.9	10
S3	55	10
S4	50	15
S5	55	10
S6	50	5
S7	55	10
S8	62.1	10
S9	60	15
S10	55	2.9
S11	55	17.1
S12	60	5
S13	55	10

Table 2. Summarization of the chemical attributes of the raw materials used for the cookie preparation.

Components	Water chestnut flour (%)	Foxnut (%)	Groundnut (%)
Moisture	5.71 ± 0.22^{a}	12.80 ± 0.91^{b}	5.71 ± 0.37^{a}
Ash	1.82 ± 0.61^{a}	0.62 ± 0.02^{b}	1.72 ± 0.20^{a}
Fat	0.81 ± 0.09^{a}	0.50 ± 0.06^{a}	43.20 ± 0.86^{b}
Protein	6.01 ± 0.89^{a}	9.70 ± 0.71^{b}	22.70 ± 0.73^{c}

Note: Level of significance used was 5%.

Table 3. Summarization of the physical attributes (weight, diameter, thickness) of various cookie samples generated.

Sample	Weight (g)	Diameter (mm)	Thickness (mm)
Control	11.10 ± 0.43	50.28 ± 0.37	8.37 ± 0.56
S1	13.25 ± 0.21	52.20 ± 0.20	8.70 ± 0.37
S2	12.14 ± 0.35	51.90 ± 0.20	8.50 ± 0.63
S3	13.51 ± 0.25	52.80 ± 0.10	8.70 ± 0.21
S4	13.99 ± 0.23	51.60 ± 0.30	8.00 ± 0.35
S5	13.00 ± 0.41	52.30 ± 0.20	8.90 ± 0.43
S6	13.42 ± 0.32	53.40 ± 0.10	9.10 ± 0.15
S7	13.36 ± 0.27	52.50 ± 0.40	8.80 ± 0.09
S8	14.42 ± 0.51	51.60 ± 0.30	8.25 ± 0.27
S9	14.76 ± 0.31	49.00 ± 0.40	8.20 ± 0.24
S10	13.17 ± 0.37	56.10 ± 0.40	9.60 ± 0.17
S11	14.51 ± 0.63	49.60 ± 0.20	7.80 ± 0.07
S12	12.47 ± 0.41	55.20 ± 0.30	9.50 ± 0.37
S13	13.29 ± 0.29	52.00 ± 0.30	8.60 ± 0.40

Table 4. Summarization of the chemical attributes of the raw materials used for the cookie preparation.

Cookie samples	Moisture (%)	Ash (%)	Fat (%)	Protein (%)
Control	4.16 ± 0.35	1.84 ± 0.33	26.5 ± 0.25	5.20 ± 0.17
S1	3.70 ± 0.27	3.72 ± 0.30	17.92 ± 0.67	8.41 ± 0.23
S2	3.81 ± 0.29	3.65 ± 0.27	17.83 ± 0.78	7.50 ± 0.42
S3	3.67 ± 0.39	3.76 ± 0.07	17.92 ± 0.71	8.50 ± 0.32
S4	3.61 ± 0.31	3.93 ± 0.78	17.66 ± 0.33	8.83 ± 0.49
S5	3.73 ± 0.41	3.74 ± 0.35	17.95 ± 0.52	8.45 ± 0.32
S6	3.78 ± 0.47	3.54 ± 0.46	18.20 ± 0.11	7.13 ± 0.24
S7	3.69 ± 0.25	3.73 ± 0.34	17.97 ± 0.83	8.39 ± 0.64
S8	3.56 ± 0.13	3.87 ± 0.62	18.63 ± 0.21	8.94 ± 0.34
S9	3.52 ± 0.06	3.90 ± 0.31	18.46 ± 0.43	8.97 ± 0.36
S10	3.83 ± 0.09	3.32 ± 0.29	18.28 ± 0.38	7.20 ± 0.58
S11	3.50 ± 0.29	3.98 ± 0.81	17.51 ± 0.13	7.01 ± 0.58
S12	3.84 ± 0.40	3.51 ± 0.45	18.52 ± 0.09	6.92 ± 0.23
S13	3.68 ± 0.43	3.72 ± 0.56	18.05 ± 0.77	8.41 ± 0.51

Table 5. Summarization of the sensorial assessment of the developed cookie samples.

Sample	Appearance	Flavor	Chewability	Overall acceptability
S1	4.2	6.5	5.5	5.4
S2	6.2	7.9	6	6.7
S3	4.1	6.6	5	5.2
S4	2.7	5.7	4.5	4.3
S5	4	6.8	5.2	5.3
S6	6.4	8.7	7.7	7.6
S7	4.2	6.5	5	5.2

S8	7.1	6.3	7.5	6.9
S9	3.2	6	4.7	4.6
S10	7.9	6.5	7.8	7.4
S11	2.5	5.1	4	3.9
S12	6.5	8.9	7.6	7.8
S13	4	6.5	5.1	5.2

Table 6. Regression coefficients of different responses for gluten free cookie.

Factor	**Coefficient**		
	Appearance	**Flavor**	**Chewability**
Intercept	4.00	6.61	5.00
A – chestnut	0.2341	226.87	0.0655
B – foxnut	-1.83	225.19	-1.43
AB	0.1000	0.0404	0.0750
A^2	1.02	160.75	1.05
B^2	0.2938	-159.99	0.3250
R^2	0.9177	0.8981	0.9769
Adjusted R^2	0.9043	0.8225	0.9603
Predicted R^2	0.8996	0.7942	0.8989
Press	22.10	17.39	4.12

Table 7. Analysis of variance for the response variable.

Table 7.1. Appearance

Source	**Sum of squares**	**DF**	**Mean square**	**F-value**	**P-value**	
Model	17.13	2	8.56	4.18	0.0480	Significant
A-Chestnut	0.1908	1	0.1908	0.0931	0.7666	

B-Foxnut	16.73	1	16.73	8.16	0.0171	
AB	1.15	1	1.15	79.22	< 0.0001	
A^2	0.0010	1	0.0010	0.0682	0.8014	
B^2	0.0000	1	0.0000	0.0031	0.9569	
Residual	20.50	10	2.05			
Lack of Fit	13.27	5	2.65	1.84	0.2606	Not significant
Pure Error	7.23	5	1.45			
Total	37.63	12				

Table 7.2. Flavour

Source	**Sum of Squares**	**DF**	**Mean square**	**F-value**	**P-value**	
Model	19.05	5	3.81	44.78	<0.0001	Significant
A-Chestnut	5.72	1	5.72	67.20	< 0.0001	
B-Foxnut	5.66	1	5.66	66.50	< 0.0001	

AB	0.0016	1	0.0016	0.0186	0.8953	
A²	5.78	1	5.78	67.89	< 0.0001	
B²	5.72	1	5.72	67.26	< 0.0001	
Residual	7.95	7	1.14			
Lack of Fit	2.83	2	1.41	1.38	0.3337	Not Significant
Pure Error	5.13	5	1.03			
Total	17.54	12				

Table 7.3. Chewability

Source	**Sum of squares**	**DF**	**Mean square**	**F-value**	**P-value**	
Model	18.01	5	3.60	4.28	0.0421	Significant
A-Chestnut	0.0901	1	0.0901	0.1070	0.7532	
B-Foxnut	9.28	1	9.28	11.02	0.0128	
AB	0.5375	1	0.5375	0.6380	0.4507	
A²	7.38	1	7.38	8.76	0.0211	
B²	0.7473	1	0.7473	0.8870	0.3776	
Residual	5.90	7	0.8425			

Lack of Fit	0.6053	2	0.3027	0.2860	0.7628	Not significant
Pure Error	5.29	5	1.06			
Total	23.91	12				

Figures

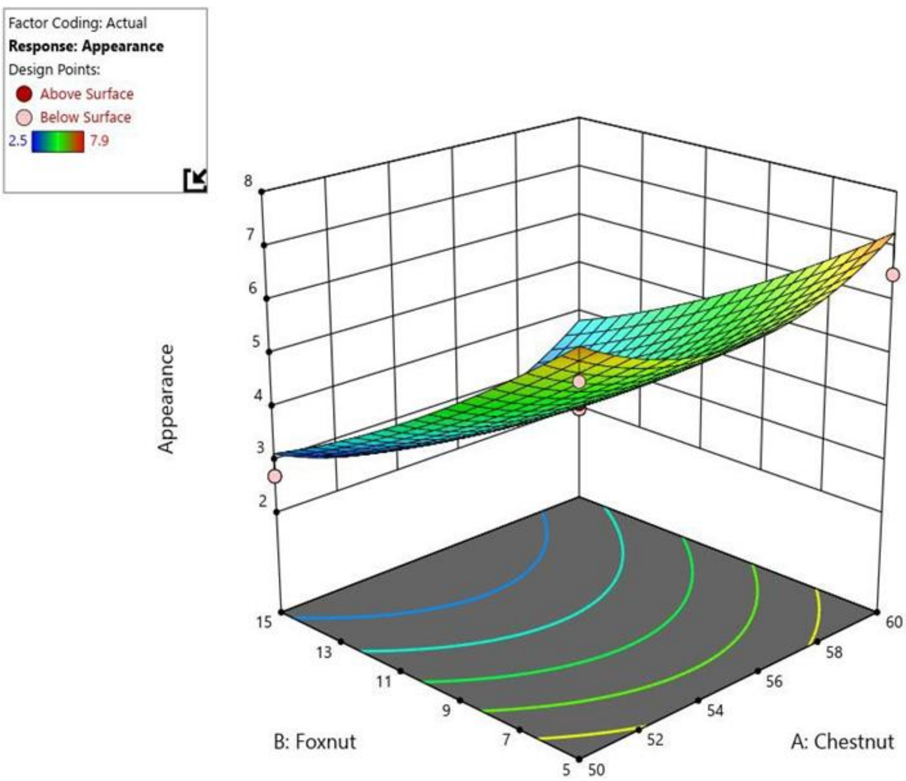

Figure 1. Response surface demonstrating the effect of foxnut and chestnut on appearance of cookie samples.

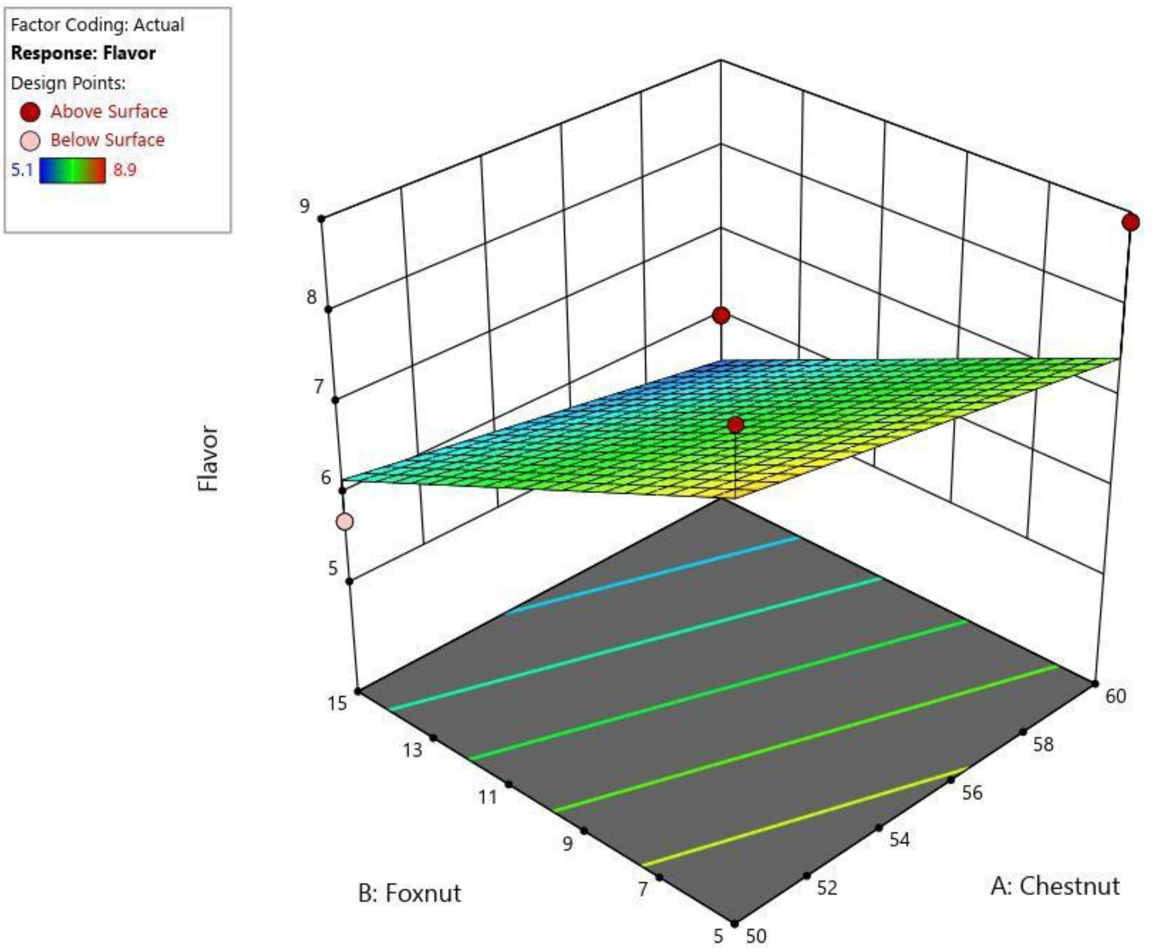

Figure 2. Response surface demonstrating the effect of foxnut and chestnut on flavor of cookie samples.

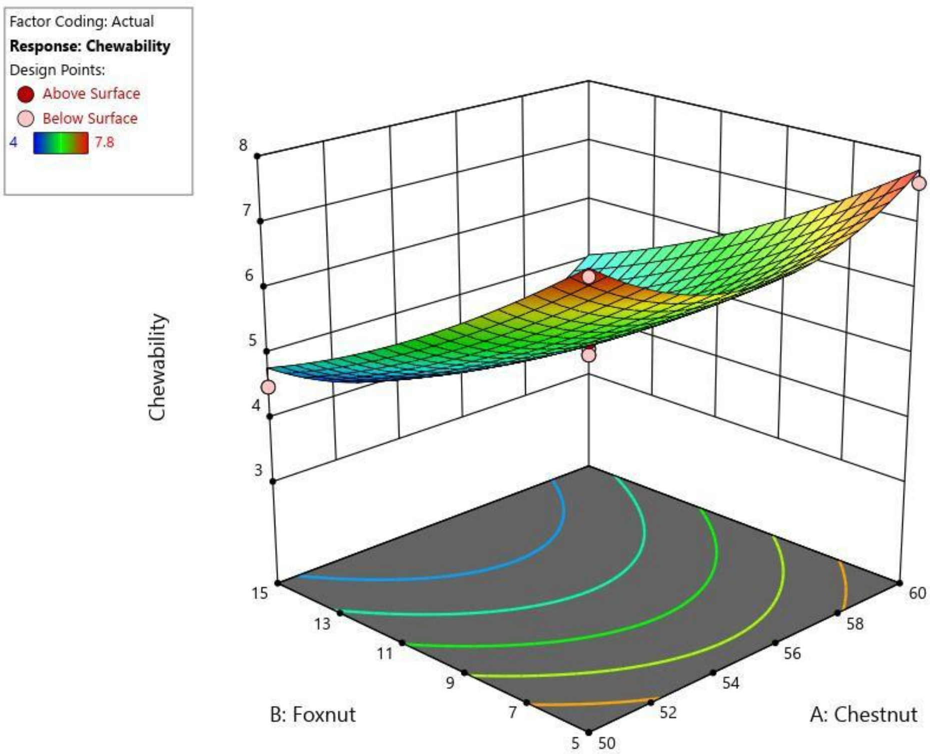

Figure 3. Response Surface showing the effect of foxnut and chestnut on chewability of cookie samples.