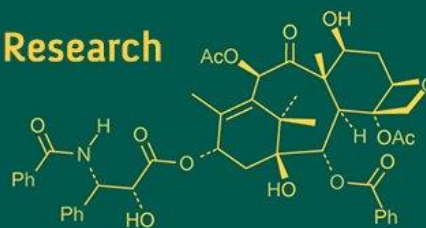


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Developing flour blends with diverse millet types for improved nutritional and functional qualities

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Abstract

A sustainable substitute for water-intensive crops like wheat and rice, millets are a class of small-seeded cereal grains known for their ability to withstand arid and semi-arid areas. With an emphasis on improving their nutritional profiles and functional qualities for culinary applications, this study investigates the creation of millet flour blends using brown top millet, buckwheat millet, and amaranth millet. To satisfy consumer requests for gluten-free and health-promoting products, the study attempts to optimize these mixes using response surface methods, striking a balance between nutritional advantages and sensory attributes. Four millet flour blend formulations were developed and tested in chakli and crackers, two typical Indian snacks. Moderate substitution levels of millet flour improved product quality without sacrificing consumer acceptability, according to sensory evaluation. For both snack products, the T₁ formulation—which has equal amounts of the three millets—produced the greatest sensory scores, demonstrating the complementary impacts of each grain on flavor and texture. The results highlight how millet-based formulations can support sustainable farming methods and improve food security and health. By addressing both nutritional demands and environmental sustainability, this research encourages the incorporation of millets into mainstream food systems.

Keywords: Millets, snacks, chakli, crackers, baked products

1. Introduction

A class of small-seeded cereal grains known as millets has been grown for thousands of years, mostly in arid and semi-arid parts of Asia and Africa. Because they can withstand difficult environmental conditions, they have been cultivated since ancient times and have been staple crops for many civilizations. Millets are highly prized for their capacity to withstand drought, low soil fertility, and harsh temperatures, which makes them a dependable crop in areas where water scarcity and climate variability are common. Because of their agronomic resilience, millets are positioned as a sustainable and eco-friendly crop choice that can lessen dependency on water-intensive cereals like wheat and rice and promote food security in ecosystems that are at risk.

Millets have a better nutritional profile than many traditional cereals, in addition to being climate-adaptable. They are abundant in dietary fiber, which supports healthy digestion and helps control blood sugar levels. Important elements, including calcium, iron, and zinc, which are necessary for healthy bones, oxygen transport, immunological function, and general metabolic activities, are also found in considerable levels in millets. The potential for millets to promote health is further enhanced by the presence of bioactive substances, such as phenolic acids and antioxidants. These substances help reduce oxidative stress and inflammation, which are linked to long-term conditions like obesity, diabetes, and heart problems.

The demand from consumers for functional, nutrient-rich, and gluten-free food products has led to an upsurge in research on the use of millets and pseudocereals in food formulation. Most traditional baked items and snacks are made using refined wheat flour, which has great technological features but often lacks dietary fiber, essential amino acids, and minerals. However, millets and pseudocereals are renowned for their exceptional nutritional composition, which includes high levels of dietary fiber, antioxidants, minerals, and balanced protein profiles. They are therefore suitable alternatives for producing health-promoting food items (Kumar *et al.*, 2017; Bunkar *et al.*, 2021) ^[13, 3].

The applicability of millet flours for a variety of food applications is largely determined by their functional characteristics. Processing efficiency and product quality in baked goods, snacks, and traditional foods are influenced by factors such as water absorption capacity, dough rheology, pasting behavior, and thermal stability. However, due to variations in fiber content, protein structure, and starch composition, these functional characteristics varied greatly among millet species. Additionally, dough handling, texture, and sensory qualities are all greatly impacted by the ratio in which various millet flours are combined. To balance nutritional increase with desired functional and sensory qualities, millet-based flour blends must be systematically formulated and optimized. Composite flour technology has been a successful tactic for enhancing the functional and sensory qualities of food products while combining the nutritional benefits of several grains. According to a number of studies, adding millet and pseudocereal flours to baked goods and snacks improves the nutritional content, dietary fiber, and protein quality without appreciably lowering acceptability (Singla *et al.*, 2024) [23]. For example, at optimal substitution levels, millet-based biscuits, cookies, and extruded snacks have demonstrated superior physicochemical and sensory qualities (Rajkumar, 2018) [18]. Due to their widespread popularity and responsiveness to composite flour formulations, traditional Indian snack goods like chakli and crackers have also been recognized as appropriate carriers for millet integration (Kavali & Shobha, 2020) [11].

Response surface methodology (RSM), an advanced experimental design methodology, provides an efficient way to optimize flour mix compositions. RSM makes it easier to investigate several factors simultaneously, enabling the identification of blend ratios that optimize nutritional benefits while preserving or enhancing the functional qualities required for processing and customer acceptability. By using such optimization, millet flour mixes customized for certain food products may be created, guaranteeing that the nutritional benefits of millets are given without sacrificing product quality.

The acceptance of newly produced food products is determined in large part by sensory evaluation. According to earlier studies, adding millets to snack goods affects characteristics including texture, flavor, and appearance; therefore, the right amount of formulation is necessary to strike a balance between nutritional improvement and customer preference (Singson, 2012; Kumar, 2022) [24, 14]. Moderate replacement levels produce the highest sensory scores, according to studies on millet-based chakli and baked goods, highlighting the need of formulation optimization.

The invention and optimization of flour blends using various millet varieties—specifically, brown top millet (*Brachiaria ramosa*), buckwheat millet (*Fagopyrum esculentum*), and amaranth millet (*Amaranthus cruentus*)—are the main goals of this study. These millets, which offer a wide range of advantageous chemicals, were chosen due to their unique nutritional profiles and local accessibility. The goal of this research is to create optimum blends that may be tailored to a variety of culinary applications by methodically assessing the physicochemical, nutritional, and rheological properties of different blend formulations. The ultimate objective is to assist sustainable agriculture, enhance dietary quality, and encourage the use of millets in food systems through

creative flour mix development that satisfies industrial and consumer demands.

2. Materials and Methods

2.1 Identification and procurement of ingredients for the formulation of millet flour mix

The essential ingredients required to create millet flour blends were carefully selected based on their nutritional and functional characteristics. Whole grains of specific millets and pseudocereals, like browntop millet, buckwheat, and amaranth, were bought from approved suppliers and regional agricultural markets to ensure quality and authenticity. Dust, stones, and broken seeds were removed from the grains before processing. Based on preliminary experiments and evidence from the literature, four different formulations of millet flour blends were created by varying the proportions of the selected grains in order to achieve an optimal balance of nutritional composition and functional attributes. The blends were created with the goal of increasing the amount of protein, dietary fiber, and minerals while preserving the processing qualities needed for product development. Before being used again in the production of products, all created flour mixes were kept in regulated, airtight containers.

2.2 Value-added product development and organoleptic assessment.

Millet-based composite flours were used to add value to popular Indian cuisines. Millet flour blends were used to create value-added products to assess their viability for functional food applications. To create nutritionally enriched mixes, four distinct formulations of millet flour blends were first created by adjusting the ratios of particular millets and pseudocereals. The generated formulations were then added to standard recipes by using the millet flour mix in place of base flour at varying percentages. Chakli and crackers were chosen for product development based on appropriateness and product acceptability because they are popular snack foods that can be substituted for flour. Standardized processing procedures were used to create the products, and the effects of varying millet flour incorporation levels on product quality were assessed.

To ascertain their acceptability, the produced products underwent organoleptic (sensory) examination. A 9-point hedonic scale was used for the sensory evaluation, with 1 denoting "dislike extremely" and 9 denoting "like extremely." A semi-trained panel evaluated key attributes, including appearance, color, texture, taste, fragrance, and overall acceptability. The samples were coded and presented at random to avoid bias. The results of the sensory assessment were used to evaluate the most pleasant formulation and the potential of millet-based flour blends in the production of baked goods with added value.

3. Results and Discussion

3.1 Development of millet flour mix treatments

3.1.1 Selection of recipe

A standard recipe is one that regularly provides a high-quality product using the same amount and proportion of ingredients. The first list of ingredients and the second explanation of how to combine them are the two main components of a recipe. To prepare popular items such as crackers mix, chakli mix, dhokla mix, upma mix, and idli mix, the brown millet flour, buckwheat millet flour, and

amaranth millet flour were mixed with various components in varying quantities.

3.1.2 Standardization of Mix and Product Preparation

Millet flour mix treatments were developed to evaluate the effects of different quantities of millets and pseudocereals on product quality. Four different millet flour blend formulas were initially developed by varying the ratios of browntop millet, buckwheat, and amaranth flours to produce nutritionally balanced composite mixtures. These formulae were carefully blended and labeled as separate therapies to ensure uniformity. The developed millet flour blends were then added to traditional recipes at certain substitution percentages to create value-added products like chakli and crackers. The products were created in controlled environments to assess how each formulation affected functional characteristics and overall product quality. Comparing the suitability of different millet flour ratios for the production of snack products was made possible by this rigorous approach.

3.1.2.1 Development of Crackers Mix

Several experiments were carried out using various ratios of brown top, buckwheat, and amaranth seed flour (33:33:33, 50:25:25, 25:50:25, and 25:25:50) to prepare crackers to create a standardized flour blend. Out of all the treatments, T₁ (33% brown top, 33% buckwheat, and 33% amaranth seed flour) was selected for additional study since it obtained the highest sensory score from the panel. Table 1 displays the flour mix's standardized composition.

Table 1: The developed cracker mix was prepared using the ingredients

Ingredients	T ₁	T ₂	T ₃	T ₄
Brown top millet flour (g)	33.33	50	25	25
Buckwheat millet flour (g)	33.33	25	50	25
Amaranth millet flour (g)	33.33	25	25	50
Oil (shortening)	5	5	5	5
Cumin seed	2	2	2	2
Carom seed	2	2	2	2
Dry fenugreek leaves (tsp.)	2	2	2	2
Chilli powder (tsp.)	1/2	1/2	1/2	1/2
Turmeric powder (tsp.)	1/2	1/2	1/2	1/2
Salt (tsp.)	1	1	1	1
Water (ml)	20	20	20	20

3.1.2.2 Development of Chakli Mix

The standardized evaluation of the instant chakli mix revealed notable variations across the different flour combinations. Chakli made with varying proportions of brown top, buckwheat, and amaranth seed flour (33:33:33, 50:25:25, 25:50:25, and 25:25:50) was evaluated using

sensory analysis. When compared to the other treatments, treatment T₁ (33% brown top, 33% buckwheat, and 33% amaranth seed flour) had the best overall acceptance as well as superior taste, texture, and flavor scores, according to the mean sensory scores. Due to minor variations in texture and flavor, treatments employing uneven millet flours had relatively poorer acceptability. T₁ was selected as the standard formulation for additional research since it was thought to be the best combination. Table 2 provides a full composition.

Table 2: The developed cracker mix was prepared using the ingredients

Ingredients	T ₁	T ₂	T ₃	T ₄
Brown top millet flour (g)	33.33	50	25	25
Buckwheat millet flour (g)	33.33	25	50	25
Amaranth millet flour (g)	33.33	25	25	50
Butter (shortening)	3	3	3	3
Cumin seed	3	3	3	3
Sesame seeds (tsp.)	1	1	1	1
Chilli powder (tsp.)	1/2	1/2	1/2	1/2
Turmeric powder (tsp.)	1/2	1/2	1/2	1/2
Salt (tsp.)	1	1	1	1
Water (ml)	25	25	25	25

3.2 Sensory evaluation of the developed baked product

The organoleptic evaluation was carried out at MPUAT University in Udaipur, Department of Food Science and Nutrition. A five-point hedonic rating scale was utilized for organoleptic evaluation, and five distinct panelists were chosen based on the results of the sensitivity threshold test. Two diverse recipes—baked crackers and chakli—were shortlisted. These dishes were evaluated for color, texture, flavor, and general acceptance. Any product's acceptability is mostly determined by taste, which has the biggest influence on the product's market success and acceptability. Sensory analysis is an essential tool for assessing food products' acceptability based on consumer perception. Four millet-mix-based product formulations (T₁, T₂, T₃, and T₄) were developed and their sensory attributes evaluated in this study. Several factors were assessed, including appearance, color, flavor, texture, taste, and general acceptability. Panelists evaluated each item using a 9-point hedonic scale, ranging from "1-Dislike extremely" to "9-Like extremely." This approach offers a quick and efficient way to assess various formulations and determine which is the best product. Based on overall customer choice, the optimal formulation among T₁, T₂, T₃, and T₄ is determined with the use of the sensory scores.

3.2.1 Crackers

Table 3: Mean $\pm$ SD score of Sensory analysis of crackers prepared with millet blend

S. No	Sensory attributes of Crackers Mean $\pm$ SD						
	Treatment	Appearance	Color	Flavor	Texture	Taste	Overall acceptability
1.	T ₁	8.18 $\pm$ 0.83	8.54 $\pm$ 0.52	8.45 $\pm$ 0.52	8.63 $\pm$ 0.50	7.81 $\pm$ 0.75	8.09 $\pm$ 0.83
2.	T ₂	6.81 $\pm$ 0.60	6.63 $\pm$ 0.50	7.36 $\pm$ 0.50	7.18 $\pm$ 0.60	7.27 $\pm$ 0.46	7.54 $\pm$ 0.52
3.	T ₃	7.81 $\pm$ 0.60	7.72 $\pm$ 0.46	8.00 $\pm$ 0.63	7.81 $\pm$ 1.07	7.27 $\pm$ 1.00	7.90 $\pm$ 1.04
4.	T ₄	6.27 $\pm$ 0.90	6 $\pm$ 0.77	7.09 $\pm$ 1.04	6.18 $\pm$ 1.16	6.45 $\pm$ 1.03	7.27 $\pm$ 0.90

All the values are (Mean $\pm$ SD) of three observations

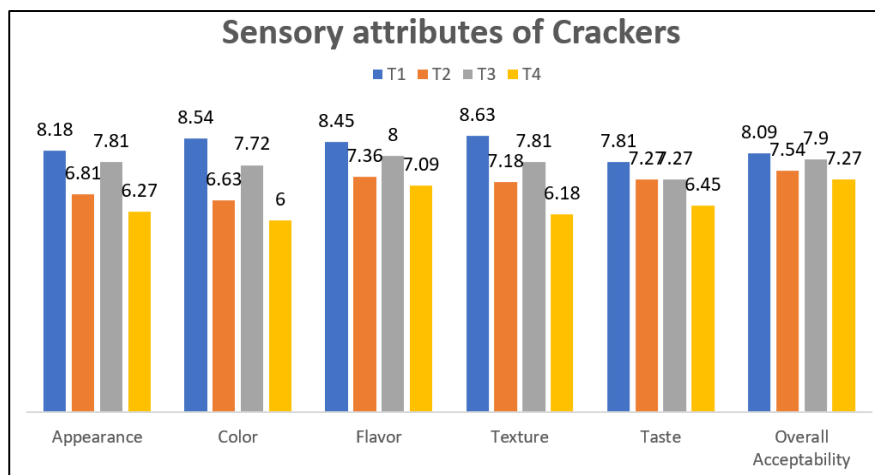


Fig 1: Sensory characteristics of crackers made with millet blend

The T₁ formulation received the greatest overall acceptance score (8.09 ± 0.83), along with the best scores for appearance (8.18 ± 0.83), color (8.54 ± 0.52), flavor (8.45 ± 0.52), and texture (8.63 ± 0.50). This suggests that the proportion of millet flour used in T₁ provided the best possible balance between nutritional value and sensory quality. The desirable texture and flavor could be attributed to the synergistic benefits of amaranth, buckwheat, and browntop millet. Browntop millet adds fiber that influences texture, buckwheat adds flavor with its unique nutty taste, and amaranth enhances protein structure.

Additionally, the T₃ formulation demonstrated comparatively high acceptability (7.90 ± 1.04), with good scores across most characteristics, suggesting that acceptable sensory qualities can be maintained at moderate millet inclusion levels. On the other hand, T₂ and T₄ treatments showed relatively lower sensory scores, especially in terms of texture, color, and appearance. The lowest ratings were seen in T₄, where the product structure

may have been adversely influenced by larger amounts of millet replacement, resulting in darker color, increased hardness, and a subtle bitterness, particularly from buckwheat components.

These results align with earlier studies on baked products made from millet. According to Gull *et al.* (2015) [6], a moderate amount of millet flour added to crackers and baked goods increased their sensory acceptability, but higher substitution levels reduced customer preference because of flavor and texture alterations. In a similar vein, Banu and Aprodu (2022) [2] noted that while excessive inclusion might have a detrimental effect on product quality, optimal amounts of pseudocereal incorporation improve sensory qualities. According to Kumar *et al.* (2022) [14], because millet-based snacks have a better balance between functional and sensory qualities, they reach optimum acceptability at modest substitution levels.

3.2.1 Chakli

Table 3: Mean $\pm$ SD score of Sensory analysis of chakli prepared with millet blend

S. No	Sensory attributes of Chakli Mean $\pm$ SD						
	Treatment	Appearance	Color	Flavor	Texture	Taste	Overall acceptability
1.	T ₁	8.36 ± 0.92	7.90 ± 0.94	8 ± 0.63	8.36 ± 0.80	7.81 ± 0.98	8.27 ± 0.78
2.	T ₂	7.27 ± 0.64	7.36 ± 0.80	7.45 ± 1.03	8 ± 0.77	7.36 ± 0.50	7.72 ± 0.78
3.	T ₃	6.81 ± 0.75	6.90 ± 0.94	7.36 ± 0.50	6.90 ± 1.13	7.09 ± 0.83	7.36 ± 0.50
4.	T ₄	6.09 ± 0.70	6.63 ± 0.67	6.81 ± 0.87	6.45 ± 0.50	6.45 ± 0.68	6.81 ± 0.40

All the values are (Mean $\pm$ SD) of three observations

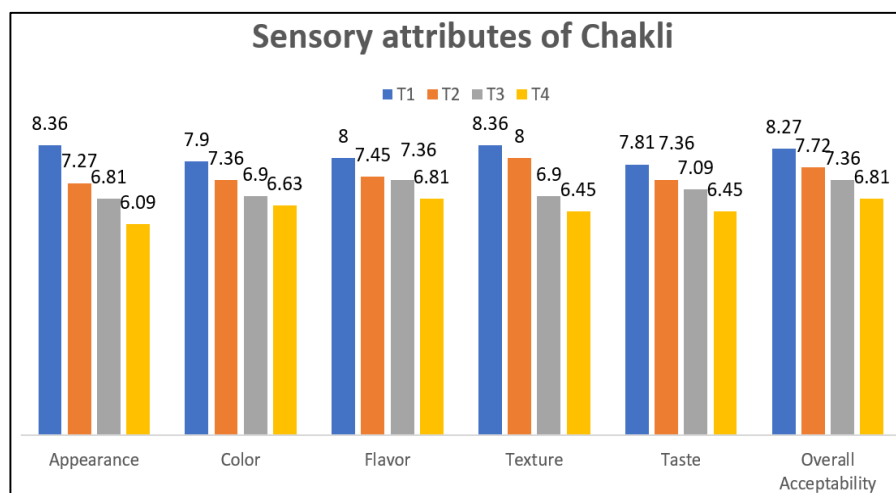


Fig 1: Sensory characteristics of chakli made with millet blend

Compared to the other treatments, T₁ received higher ratings for appearance (8.36±0.92), flavor (8.00±0.63), texture (8.36±0.80), taste (7.81±0.98), and overall acceptance (8.27±0.78). This suggests that T₁'s formulation achieved the best possible balance between millet integration and product quality. The desirable sensory properties could be attributed to the synergistic action of buckwheat, amaranth, and browntop millet. Browntop millet adds fiber that preserves structural integrity without compromising texture, buckwheat enriches flavor with its nutty tone, and amaranth improves protein structure and crispness.

Additionally, the T₂ formulation showed good acceptance (7.72±0.78), especially in texture (8.00±0.77), suggesting that acceptable snack products can be produced with moderate substitution levels of millet flour. However, a minor deterioration in flavor and appearance when compared to T₁ indicates that product attributes start to change as the quantity of millet increases.

T₃ and T₄ had lower sensory scores as a result of further millet inclusion, with T₄ having the lowest overall acceptability (6.81±0.40). The increased fiber content from browntop millet, which can result in a firmer texture, and the phenolic chemicals in buckwheat, which may give it a somewhat bitter flavor and darker color, could be the causes of the decrease in sensory quality at greater substitution levels. Furthermore, adding too much amaranth can change the structure of the dough, resulting in less crispness and a different mouthfeel. These results are consistent with previous research. According to Singson (2012)^[24], millet-based chakli exhibited the maximum acceptability at moderate substitution levels, but higher inclusion led to worse sensory scores because of flavor and texture changes. In a similar vein, Gull *et al.* (2015)^[6] found that while adding millet flour enhances nutritional quality, doing so adversely impacts snack products' sensory qualities. Additionally, Banu and Aprodu (2022)^[2] noted that while larger levels of pseudocereal integration may result in unfavorable sensory qualities, optimal levels improve product quality. Additionally, higher fiber and phenolic content in composite flours can affect color and taste, decreasing consumer acceptance at higher concentrations, according to Kaur *et al.* (2019)^[10].

Conclusion

The study used blends of brown top millet, buckwheat, and amaranth flour to create value-added snack products, particularly crackers and chakli, successfully. An analysis of four formulations showed that adding millet flour had a major impact on sensory characteristics. In terms of look, color, flavor, texture, taste, and overall acceptability, the T₁ formulation scored highest, demonstrating the best possible balance between sensory quality and nutritional gain. While higher T₄ levels resulted in a drop in acceptability due to increased fiber, darker color, and mild bitterness, moderate millet inclusion in T₂ and T₃ still yielded acceptable scores. The study highlights how these millet-based blends can be used to make gluten-free snacks that are nonetheless acceptable to consumers and improve dietary diversity by offering healthier substitutes for conventional snacks.

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