Process Optimization of Quinoa and Foxtail Millet Enhanced Khakhra and its Sensory and Nutrional Parameters

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ABSTRACT

The present study was conducted to determine nutritional and sensory quality of the developed khakhra with the incorporation of quinoa and foxtail millet. Khakhra a thin, crispy flatbread has gained popularity as a readytoeat Indian snack, yet its traditional wheatbased recipe offers limited micronutrient diversity. Millets such as foxtail millet (*Setaria italica*) and quinoa (*Chenopodium quinoa*) possess superior protein, mineral, and dietaryfibre profiles. Fresh rosella leaves were processed, dried and converted into small leaves pieces. Wheat flour, gram flour, salt, spices, oil, quinoa and foxtail millet flour were used to prepare khakhra. The khakhra prepared with 10% quinoa, 10% foxtail millet and 5% Dry Rosella leaves was acceptable and proximate analysis was done. Results showed that prepared khakhra protein content (17.9 %) and crude fiber (4.05%) as compared to control khakhra. Incorporation of quinoa and foxtail millet increased nutritional value of khakhra. The prepared khakhra with superior consumer acceptability was acceptable with respect to enhancement of nutritive value without altering organoleptic characteristics

Key words: Wheat, Gram, Snacks, quinoa flour, Foxtail millet flour, Dried rosella Leaves

1. INTRODUCTION

Khakhra is a traditional Indian snack that originated in the western state of Gujarat and is widely consumed in parts of Rajasthan as well. It is a thin, crispy flatbread typically prepared using whole wheat flour, roasted on a flat pan without oil, making it a healthy and convenient ready-to-eat (RTE) option. Khakhra has evolved over time from a home-prepared breakfast item to a commercially available snack in various flavors such as methi, jeera, masala, garlic, and more. Its long shelf life, ease of packaging, and transportability have contributed to its growing popularity among health-conscious consumers in both domestic and international markets (Bartwal et al., 2020; Kamble et al., 2020).

However, the conventional wheat-based khakhra, while low in fat and high in convenience, lacks certain micronutrients and dietary diversity. To address this limitation, the inclusion of nutritionally superior grains such as millets offers a promising avenue for value addition. Millets like foxtail millet (Setaria italica) and quinoa (Chenopodium quinoa) are increasingly recognized as climate-resilient, drought-tolerant crops rich in dietary fiber, essential amino acids, minerals (such as iron, calcium, magnesium) and vitamins. Their low glycemic index and high protein content make them particularly suitable for individuals managing diabetes, cardiovascular risks, and malnutrition (Sravanthi et al., 2023; Singh et al., 2017; Sezgin & Sanlier, 2019).

In addition to cereals, functional ingredients like Roselle (*Hibiscus sabdariffa L.*) add not only unique flavor and color but also enhance the antioxidant potential of the product due to their high anthocyanin and vitamin C content. Roselle has long been used in traditional medicine and is recognized for its ability to scavenge free radicals and protect against oxidative stress (Islam et al., 2021; Villani et al., 2009).

The increasing focus on sustainable agriculture and health-conscious eating has led the Government of India and the United Nations to actively promote millet consumption. The declaration of 2023 as the *International Year of Millets* by the Government of India and FAO has catalyzed public interest, policy support, and product innovation around millet-based food systems (Yadav et al., 2024). Incorporating millets into mainstream food products like khakhra can bridge the gap between traditional nutrition and modern lifestyle needs.

Hence, the objective of the present study was to develop and evaluate millet-based khakhra using composite flour of quinoa and foxtail millet in different proportions and assess their sensory acceptability. The aim was to create a functional, shelf-stable, and nutrient-rich khakhra that aligns with consumer demand for healthy, flavourful, and culturally significant snack options.

2. MATERIALS AND METHODS

2.1 Materials

The primary ingredients used for khakhra formulation included whole wheat flour, Bengal gram flour, quinoa flour, foxtail millet flour, and dried Roselle (Hibiscus sabdariffa L.) leaves. All ingredients were procured from local organic food suppliers in Parbhani, Maharashtra, ensuring food-grade quality. The dried roselle leaves were ground to a fine leaves piece before blending into the flour. Standard kitchen ingredients such as salt, turmeric, chili powder, and refined oil were also used for seasoning.

The equipment used included a laboratory-grade digital weighing balance, dough kneader, rolling board and pin, flat roasting pan (tava) etc.

2.2 Formulation of Khakhra

To enhance the nutritional and functional quality of traditional khakhra, the study involved partial replacement of whole wheat flour with a composite blend of foxtail millet and quinoa flour at different proportions (10%, 20%, and 30%). A constant 30% Bengal gram flour was maintained across all samples to improve the protein and fiber content. Dried roselle powder was added at a fixed 5 g per 100 g of the flour mixture for all samples. The details of the formulations are given in Table 2.1.

Table 2.1: Standardized Recipe for Khakhra (per 100 g)

Sr. No	Ingredients	T0	T1	T2	T3
1	Whole Wheat Flour (g)	70	60	50	40
2	Gram Flour (g)	30	30	30	30
3	Quinoa Flour (g)	0	5	10	15
4	Foxtail Millet Flour (g)	0	5	10	15
5	Dried Roselle Leaves (g)	5	5	5	5
6	Salt (g)	2	2	2	2
7	Chili & Turmeric Powder (g)	2	2	2	2
8	Refined Oil (ml)	15	15	15	15

Treatment codes:

- **T0**: Control – 70% whole wheat flour, 30%-gram flour
- **T1**: 10% composite millet flour (5% quinoa + 5% foxtail millet)
- **T2**: 20% composite millet flour (10% quinoa + 10% foxtail millet)
- **T3**: 30% composite millet flour (15% quinoa + 15% foxtail millet)

2.3 Preparation of Khakhra

All dry ingredients were weighed accurately and mixed thoroughly. Refined oil was added and blended evenly into the flour mixture. Sufficient water was added to knead the dough until it reached a soft, pliable consistency. The dough was rested for 10 minutes, then divided into small round balls (25–30 g each). Each ball was rolled into a thin circular disc of 8–12 cm in diameter. The discs were roasted on a preheated flat pan (tava) at medium heat for approximately 2 minutes, with gentle pressure applied using a wooden press to ensure uniform crispness and prevent puffing. Roasting was continued until both sides developed a light brown color and crispy texture. The khakhras were cooled to room temperature and packed in HDPE pouches for further evaluation and storage studies.

2.4 Sensory Evaluation

Sensory evaluation of the prepared khakhra samples was conducted using a 9-point hedonic scale, where 1 indicated "dislike extremely" and 9 indicated "like extremely." A panel of 10 members, comprising trained and semi-trained evaluators. The sensory parameters assessed included color, flavor, taste, texture, and overall acceptability. The evaluation was carried out under controlled lighting and noise-free conditions to avoid bias.

Statistical analysis revealed that all samples were significantly acceptable across all sensory parameters, with T2 (20% composite millet flour) receiving the highest overall acceptability score. The addition of millets did not adversely affect the sensory characteristics and even enhanced the nutritional appeal and consumer preference in moderate blends.

3. RESULTS AND DISCUSSION

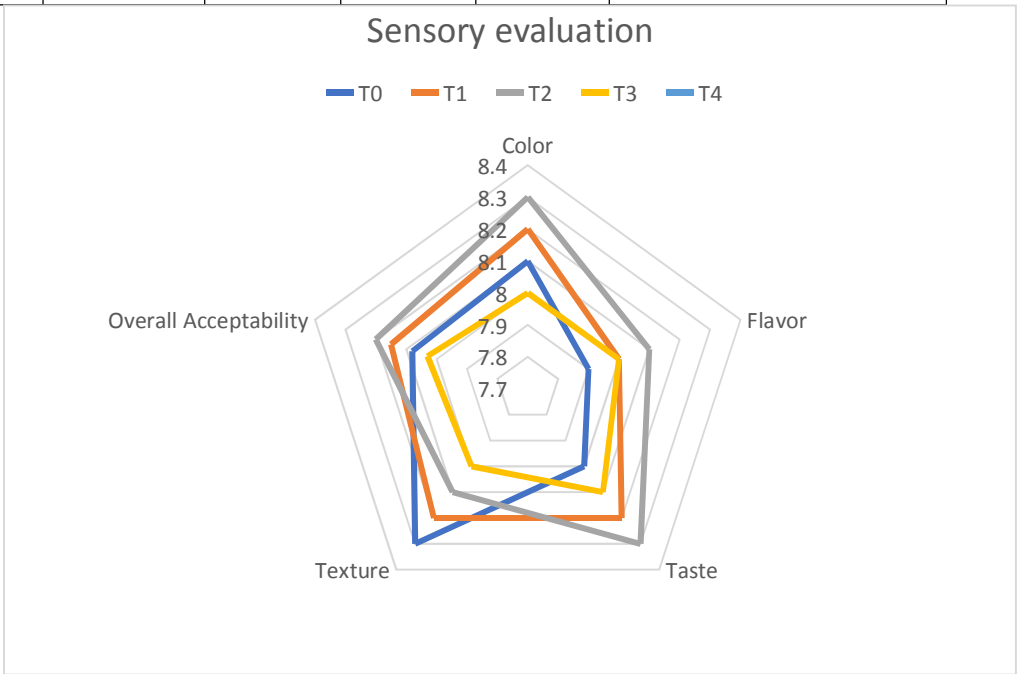
3.1 Sensory Evaluation Results

Sensory evaluation is a critical step in assessing consumer acceptability for new or modified food products. In this study, khakhra samples developed with varying levels of millet incorporation (quinoa and foxtail millet) were evaluated for color, flavor, taste, texture, and overall acceptability using a 9-point hedonic scale. The results of the sensory evaluation are presented in Table 3.1.

Table 3.1: Sensory Evaluation Scores of Khakhra Samples

Sample	Color	Flavor	Taste	Texture	Overall Acceptability
T0	8.1	7.9	8.0	8.3	8.08
T1	8.2	8.0	8.2	8.2	8.15
T2	8.3	8.1	8.4	8.0	8.20

T3	8.0	8.0	7.9	8.2	8.03



Among all the khakhra formulations, sample T2 (with 20% millet incorporation) received the highest color score of 8.3, likely due to the appealing natural pigmentation imparted by foxtail millet, quinoa, and especially the roselle leaf powder, which contributed a subtle reddish hue and enhanced visual appeal. In contrast, sample T3 (30% millet) showed a slight decline in color rating (8.0), possibly due to a denser texture that affected even surface browning. Flavor-wise, all samples scored above 8.0, with T2 again leading at 8.1. This suggests that millet incorporation up to 20% enhanced the flavor profile, while T3 showed no further improvement, implying a sensory threshold beyond which flavor benefits plateau or diminish. Taste scores followed a similar trend T2 scored highest (8.4), indicating that the balanced inclusion of quinoa and foxtail millet positively influenced the palatability by imparting a mildly nutty and sweet flavor that blended well with the wheat–gram base. Interestingly, the control sample T0 (without millets) received the highest texture score (8.3), likely due to the absence of coarse millet fibers, which contribute a slightly firmer bite. Nevertheless, all millet-based samples maintained acceptable texture scores above 8.0, suggesting that crispness and crunch were largely retained. In terms of overall acceptability, T_2 once again emerged as the most preferred sample with a score of 8.20, followed by T1 (8.15) and T_0 (8.08). The lowest overall score was recorded for T_3 (8.03), indicating that while still acceptable, excessive millet substitution may slightly reduce consumer likability, possibly due to minor changes in taste and mouthfeel.

The 20% millet-substituted formulation (T_2), incorporating 10% quinoa and 10% foxtail millet, emerged as the most preferred variant across all evaluated sensory parameters. This formulation exhibited a well-balanced sensory profile, receiving the highest scores for taste, color, and overall acceptability, while maintaining favorable ratings for flavor and texture. The sensory superiority of T_2 can be attributed to the synergistic effect of quinoa and foxtail millet, which not only enhanced the nutritional value but also contributed positively to the flavor and palatability of the khakhra. Additionally, the inclusion of dried roselle leaf provided visual appeal and antioxidant benefits without overpowering the traditional taste. Importantly, the crisp texture a defining characteristic of khakhra was retained even with millet incorporation, ensuring product familiarity and consumer acceptance. These observations are consistent with findings reported by Solanke et al. (2018) and Divakar et al. (2020), who noted improved sensory quality and consumer acceptability in khakhra formulations with moderate levels of millet substitution.

3.2 **Proximate Evaluation Results**

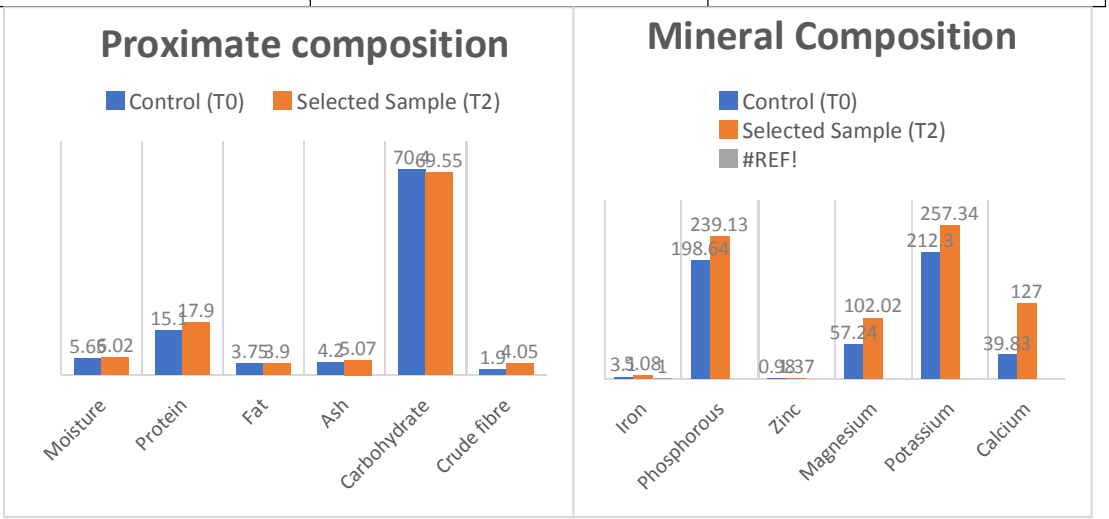
The nutritional composition and mineral contents of control sample (T_0) and selected sample (T_2) khakhras are presented in Table 3.2.

The control sample (T_0) and test (T_2) samples moisture content were 5.65% and 6.02% respectively. The protein content in the control sample (T_0) found to be 45.10% and in the (T_2) sample content was 17.9%. The protein content of the in the selected sample (T_2) was higher than that of the control sample (T_0). The control sample (T_0) and the (T_2) sample showing fat contents of 3.75% and 3.90% respectively. The content of the carbohydrate found in the (T_2) sample i.e. 70.40% as well as in the control sample (T_0) 69.55%. Khakhra made from millet increases the amount of protein and decreases the carbohydrates contents.

Table 3.2: Nutritional composition of khakhras (per 100 g)

Parameters (%)	**Control (T_0)**	**Selected Sample (T_2)**
Moisture	5.65±0.10	6.02±0.20
Protein	15.10±0.20	17.9±0.40
Fat	3.75±0.25	3.90±10
Ash	4.20±0.30	5.07±0.05
Carbohydrate	70.40±.53	69.55±0.25
Crude fibre	1.9±0.30	4.05 ± 0.60
Calcium	39.83±3.87	127.26±1.44
Iron	3.10±0.03	5.08±0.02
Phosphorous	198.64± 1.01	239.13± 1.20
Zinc	0.98± 0.2	1.37± 0.04
Magnesium	57.24± 0.88	102.02± 0.96
Potassium	212.30 ± 1.07	257.34± 1.51

Calcium	39.83±3.87	127.26±1.44



The (T_2) sample crude fiber content was higher than that of the control sample (T_0), having 4.05% and 1.9%. The control sample (T_0) had the ash content of 4.20% and (T_2) sample of 5.07%. When comparing the control sample, the selected sample we found that a higher ash content, suggesting that it had better amount of minerals. According to the data the sample (T_2) had a high amount of carbohydrates and protein. These results are similar to result given by Patil et al. (2020).

The Mineral content in control sample (T_0) mineral contents of calcium 39.83 mg/100g, while 127.26 mg/100g found in selected sample (T_2). The content of iron in the control sample (T_0) was 3.10 mg/100g while 5.08 mg/100g found in selected sample (T_2). The content of phosphorus in the control sample (T_0) was 198.64 mg/100g while 239.13 mg/100g found in selected sample (T_2). The content of zinc in the control sample (T_0) was 0.98 mg/100g while 1.37 mg/100g found in selected sample (T_2). The content of Magnesium in the control sample (T_0) was 57.24 mg/100g while 102.02 mg/100g found in selected sample (T_2). The content of potassium in the control sample (T_0) was 212.30 mg/100g while 257.34 mg/100g found in selected sample (T_2). Increasing the mineral content of khakhra made from foxtail millet, quinoa and dry rosella leaves. The similar results were obtained by Surekha and Naik (2014).

CONCLUSION

The present study successfully analyzed the nutritional and sensory evaluation of millet-based khakhra using a composite blend of quinoa and foxtail millet flours. Among the formulations tested, the 20% millet-substituted variant (T_2: 10% quinoa + 10% foxtail millet)

was found to be the most acceptable in terms of color, taste, flavor, texture and overall acceptability. This formulation not only maintained the traditional crispy texture of khakhra but also offered improved sensory appeal and potential nutritional benefits due to the inclusion of high-protein and high-fiber millets along with antioxidant-rich roselle leaves.

Millets being nutritionally superior, climate compliant crops can be utilized in development of value added ready to eat products such as khakhras. In this study incorporation of quinoa and foxtail millets influenced the nutritional composition. Moreover, a food rich in protein, fiber, minerals and less in fat is a choice of health-conscious people. However, it is necessary to popularize these traditional ready-to-eat products among all sectors of the population and also as a functional food.

The findings suggest that moderate substitution of wheat flour with nutrient-dense millets can enhance the functional value of traditional Indian snacks without compromising consumer preferences. Such value-added products align with current dietary trends promoting health, sustainability, and the revival of underutilized crops like millets. Therefore, millet-based khakhra, especially the T_2 formulation, holds significant potential as a ready-to-eat functional food suitable for modern consumers seeking taste, nutrition, and convenience. Future studies may focus on detailed nutritional profiling, shelf-life analysis, and market-level consumer acceptance to further validate its commercial viability.

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