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Formulation and Quality Evaluation of Gluten-Free Muffins Enriched with Foxtail Millet and Flaxseed Flour

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ABSTRACT

The present study was undertaken to develop and evaluate gluten-free muffins enriched with foxtail millet flour and flaxseed flour, aiming to improve the nutritional quality and functional properties of conventional bakery products. Gluten-free formulations are increasingly important due to rising cases of celiac disease, gluten intolerance, and growing consumer demand for healthier bakery alternatives. In this study, six formulations (T_0–T_5) were prepared by partial substitution of rice flour with foxtail millet flour (0–55%) while maintaining a constant level of flaxseed flour (5%) in all treatments except the control (T_0). The developed muffins were analyzed for proximate composition, physical properties, sensory characteristics, microbiological quality, and storage stability. The proximate analysis of raw materials showed that foxtail millet flour and flaxseed flour were rich sources of protein, dietary fiber, fat, and minerals compared to rice flour, indicating their potential for nutritional enhancement. Physical analysis revealed that muffin weight, height, volume, and specific volume increased with the incorporation of millet and flaxseed flour up to an optimum level, with T_4 (50% rice flour, 45% foxtail millet flour, and 5% flaxseed flour) showing the best structural quality and aeration. Sensory evaluation using a nine-point hedonic scale indicated that all formulations were acceptable, but T_4 obtained the highest overall acceptability score due to superior colour, taste, texture, aroma, and mouthfeel. Microbiological analysis confirmed that freshly baked muffins were free from microbial contamination, while during storage a gradual increase in microbial load was observed; however, it remained within acceptable safety limits up to six days of ambient storage. The storage study of the optimized formulation (T_4) demonstrated a gradual decrease in moisture content and sensory scores over time, while proximate composition remained relatively stable. Despite minor quality deterioration during storage, the muffins maintained acceptable sensory and microbial quality throughout the storage period.

Keyword- Gluten Free Muffins, Foxtail Millet Flour, Flaxseed Flour

1. Introduction

The demand for gluten-free food products has increased significantly worldwide due to the rising incidence of celiac disease, gluten intolerance, and wheat allergy.

Gluten is a complex protein found in wheat, barley, and rye that provides viscoelastic properties essential for the structure and texture of bakery products. However, for individuals suffering from gluten-related disorders, consumption of gluten-containing foods leads to adverse health effects such as intestinal damage, malabsorption, and nutritional deficiencies. As a result, there is a growing need for the development of gluten-free bakery products that are not only safe for consumption but also nutritionally balanced and organoleptically acceptable (Arendt & Dal Bello, 2008; Thompson, 2009).

Bakery products, particularly muffins, are widely consumed across all age groups due to their convenience, soft texture, and palatability. However, conventional muffins are primarily prepared using wheat flour, which limits their suitability for gluten-free diets. The absence of gluten in alternative formulations often results in poor dough structure, reduced volume, crumbly texture, and lower sensory acceptability. Therefore, selection of suitable gluten-free raw materials and optimization of their proportions is essential to overcome these technological challenges (Arendt & Dal Bello, 2008).

In recent years, millets have gained considerable attention as functional and sustainable food ingredients. Foxtail millet (Setaria italica) is one of the oldest cultivated millets and is recognized for its high nutritional value, including significant amounts of dietary fiber, protein, iron, calcium, and antioxidant compounds. It has a low glycemic index, making it suitable for diabetic and health-conscious consumers. The incorporation of foxtail millet flour in bakery formulations can enhance nutritional quality and improve functional properties such as water absorption and crumb structure (Taylor & Emmambux, 2008; Zhou *et al.,* 2014).

Flaxseed (Linum usitatissimum) is another important functional ingredient widely used in food product development. It is a rich source of alpha-linolenic acid (omega-3 fatty acids), dietary fiber, high-quality protein, lignans, and essential minerals. Flaxseed is known to provide several health benefits, including improved cardiovascular health, anti-inflammatory effects, and digestive regulation. In bakery applications, flaxseed flour also contributes to moisture retention, texture improvement, and extended shelf life due to its hydrocolloid properties (Morris, 2007; Ullah *et al.,* 2015).

Despite these nutritional advantages, the incorporation of millet and flaxseed flour into gluten-free bakery products presents technological challenges. The absence of gluten affects gas retention and structure formation during baking, leading to dense and less aerated products. Therefore, balancing functional ingredients with appropriate base flour such as rice flour is crucial for achieving desirable product quality. Rice flour is commonly used in gluten-free formulations due to its neutral taste, easy digestibility, and hypoallergenic nature, although it lacks strong nutritional and structural properties (Rai *et al*., 2018).

The development of gluten-free muffins enriched with foxtail millet and flaxseed flour provides an opportunity to combine nutritional enhancement with product diversification. Such formulations not only cater to the dietary needs of gluten-sensitive individuals but also promote the utilization of underutilized millets and oilseeds, contributing to sustainable food systems and value-added product development (Verma et al., 2020; Ullah *et al.,* 2015).

In this context, the present study focuses on the formulation and quality evaluation of gluten-free muffins by partial substitution of rice flour with foxtail millet flour and flaxseed flour. The study evaluates proximate composition, physical properties, sensory attributes, microbiological quality, and storage stability of the developed muffins. Furthermore, it aims to identify the most acceptable formulation based on comprehensive quality assessment, thereby contributing to the development of nutritionally improved gluten-free bakery products.

3. MATERIALS AND METHODS

3. 1. Materials

The raw materials used for the preparation of gluten-free muffins included rice flour, foxtail millet flour, and flaxseed flour. Rice flour served as the primary gluten-free base ingredient. Foxtail millet flour was selected due to its high nutritional value and functional properties, while flaxseed flour was incorporated as a source of dietary fiber, omega-3 fatty acids, and proteins. Other ingredients such as sugar, eggs, milk, vegetable oil, baking powder, and vanilla essence were used to improve taste, texture, and structural quality. All ingredients were procured from local markets and stored under hygienic conditions until use.

3.2. Preparation of Flours

Foxtail millet grains and flaxseeds were cleaned to remove impurities and milled into fine flour using a laboratory grinder. The flours were sieved through a 60-mesh sieve to obtain uniform particle size and stored in airtight containers at room temperature until further use.

3.3. Formulation of Gluten-Free Muffins

Six different formulations (T_0–T_5) were prepared by partial substitution of rice flour with foxtail millet flour and flaxseed flour.

- T_0 served as the control (100% rice flour).
- T_1–T_5 contained increasing levels of foxtail millet flour (15–55%) with a constant 5% flaxseed flour.

Table 3.1 Formulation of Gluten-Free Muffins

Ingredients (g)	T_0	T_1	T_2	T_3	T_4	T_5
Rice Flour	100	80	70	60	50	40
Foxtail Millet Flour	0	15	25	35	45	55
Flaxseed Flour	0	5	5	5	5	5

Sugar	40	40	40	40	40	40
Egg	50	50	50	50	50	50
Milk	60	60	60	60	60	60
Vegetable Oil	30	30	30	30	30	30
Baking Powder	3	3	3	3	3	3
Vanilla Essence	1	1	1	1	1	1

3.4. Preparation of Muffins

The muffins were prepared using the standard creaming method. Dry ingredients were first mixed thoroughly in a bowl, followed by addition of wet ingredients to form a uniform batter. The batter was poured into greased muffin moulds and baked in a preheated oven at 180°C for 20–25 minutes. After baking, muffins were cooled at room temperature and stored in airtight containers for further analysis.

3.5. Physical Analysis

Physical parameters such as weight, height, volume, and specific volume were evaluated.

- Weight was measured using a digital balance.
- Height was measured using a Vernier caliper.
- Volume was determined by rapeseed displacement method (AACC, 2010).
- Specific volume was calculated as volume/weight ratio.

3.6. Proximate Analysis

Proximate composition of raw materials and muffins was determined using AOAC (2019) methods:

- Moisture: Oven drying method (105°C)
- Protein: Kjeldahl method
- Fat: Soxhlet extraction method
- Crude fiber: Acid-alkali digestion method
- Ash: Muffle furnace method (550°C)
- Carbohydrates: Calculated by difference

3.7. Sensory Evaluation

Sensory evaluation was conducted using a 9-point hedonic scale by 10–15 semi-trained panelists. Attributes evaluated included colour, aroma, texture, taste, mouthfeel, and overall acceptability.

3.8. Storage Study

The optimized muffin sample (T_4) was packed in polyethylene pouches and stored at ambient temperature (27 ± 2°C). Analysis was conducted at 0, 2, 4, and 6 days for:

- Proximate composition
- Sensory quality

- Microbial load

4. RESULTS AND DISCUSSION

4.1 Proximate Composition of Raw Materials

Table 4.1 Proximate Composition of Raw Materials (%)

Parameter (%)	Rice Flour	Foxtail Millet Flour	Flaxseed Flour
Moisture	11.20 ± 0.15	10.35 ± 0.12	6.85 ± 0.10
Protein	6.80 ± 0.18	12.30 ± 0.25	20.50 ± 0.30
Fat	0.60 ± 0.05	4.20 ± 0.08	36.80 ± 0.45
Crude Fiber	0.40 ± 0.03	8.10 ± 0.15	24.60 ± 0.32
Ash	0.50 ± 0.02	2.85 ± 0.07	3.75 ± 0.09
Carbohydrates	80.50 ± 0.40	62.20 ± 0.35	7.50 ± 0.28

The proximate composition of raw materials showed significant nutritional variation. Rice flour contained the highest carbohydrate content (80.50%), confirming its role as a primary energy source in gluten-free bakery systems. However, it showed the lowest levels of protein, fat, fiber, and ash, indicating poor micronutrient density.

Foxtail millet flour exhibited a balanced nutritional profile with higher protein (12.30%), fiber (8.10%), and ash content (2.85%) compared to rice flour. This highlights its functional importance in improving nutritional and structural properties of gluten-free products.

Flaxseed flour demonstrated superior nutritional richness with exceptionally high fat (36.80%) and fiber (24.60%) content, along with high protein (20.50%). The lipid fraction is rich in omega-3 fatty acids, making flaxseed a valuable functional ingredient for health-oriented bakery formulations.

Overall, the results confirm that both foxtail millet and flaxseed flour are nutritionally superior to rice flour and can significantly enhance the quality of gluten-free muffins.

4.2 Proximate Composition of Gluten-Free Muffins

Table 4.2 Proximate Composition of Muffins (%)

Parameter (%)	T_0	T_1	T_2	T_3	T_4	T_5
Moisture	24.85	24.30	23.95	23.60	23.20	22.85
Protein	7.20	8.45	9.35	10.25	11.10	12.05
Fat	10.25	10.85	11.20	11.75	12.10	12.65
Crude Fiber	0.85	2.10	3.15	4.30	5.45	6.60
Ash	1.05	1.35	1.60	1.85	2.10	2.35
Carbohydrates	55.80	52.95	50.75	48.25	46.05	43.50

A clear improvement in nutritional composition was observed with increasing substitution of foxtail millet and flaxseed flour. Protein content increased significantly from 7.20% (T_0) to 12.05% (T_5), indicating successful protein enrichment.

Fat content also increased due to the lipid-rich nature of flaxseed flour, contributing essential unsaturated fatty acids. Crude fiber showed a remarkable rise, confirming the functional food potential of the developed muffins.

A gradual decrease in carbohydrate content was observed, which is attributed to partial replacement of rice flour with nutrient-dense ingredients. Moisture content decreased slightly due to higher water-binding capacity of fiber-rich flours.

4.3 Physical Properties of Muffins

Table 4.3 Physical Characteristics

Treatment	Weight (g)	Height (cm)	Volume (cm^3)	Specific Volume
T_0	52.10	4.20	120.5	2.31
T_1	53.00	4.35	125.8	2.37
T_2	54.20	4.55	132.4	2.44
T_3	55.10	4.70	138.6	2.52
T_4	56.00	4.85	145.2	2.59
T_5	56.50	4.60	140.0	2.48

Physical properties improved with increasing substitution levels up to T_4. This is due to better water absorption and batter aeration caused by millet and flaxseed flour.

The highest volume and specific volume were observed in T_4, indicating optimal gas retention and structural stability. However, a decline in T_5 suggests that excessive fiber weakens batter structure and reduces expansion due to lack of gluten network.

4.4 Storage Study – Moisture Content

Table 4.4 Moisture Content (%)

Treatment	Day 0	Day 2	Day 4	Day 6
T_0	24.85	24.42	24.01	23.60
T_1	24.30	23.95	23.55	23.10
T_2	23.95	23.60	23.18	22.75
T_3	23.60	23.25	22.85	22.40
T_4	23.20	22.94	22.58	22.11
T_5	22.85	22.55	22.15	21.70

Moisture content decreased progressively in all treatments during storage due to evaporation and moisture migration. Samples with higher fiber content showed slightly better moisture retention due to water-binding properties of flaxseed mucilage.

4.5 Protein Stability During Storage

Table 4.5 Protein Content (%)

Treatment	Day 0	Day 6
T_0	7.20	7.12
T_5	12.05	11.97

Protein content showed only a slight decrease during storage, indicating good stability of protein under ambient conditions. Minor reductions may be due to moisture loss and biochemical interactions but are not nutritionally significant.

4.6 Fat, Ash and Carbohydrates (Storage Behavior)

Table 4.6 Summary of Changes (Day 0–6)

Parameter	Trend	Observation
Fat	Slight decrease	Minor lipid oxidation
Ash	Stable	No mineral loss
Carbohydrates	Slight increase	Due to moisture loss

Fat content showed minimal reduction due to slight oxidation, whereas ash content remained stable throughout storage. Carbohydrate increase is attributed to moisture loss since carbohydrate is calculated by difference, not actual formation.

SEM Micrograph of Gluten-Free Muffins Enriched with Foxtail Millet and Flaxseed Flour

SEM analysis demonstrated that the incorporation of foxtail millet flour and flaxseed flour significantly influenced the microstructure of gluten-free muffins. Moderate substitution levels (T_2 and T_3) produced a well-organized porous network with uniform air cell distribution and a cohesive matrix, indicating improved structural quality and desirable textural properties. The presence of flaxseed flour enhanced matrix continuity through its mucilage-forming capability, which acted as a natural hydrocolloid and improved batter stability. However, excessive replacement of rice flour with foxtail millet flour (T_4 and T_5) led to matrix disruption, particle aggregation, and irregular pore formation, adversely affecting crumb integrity. Therefore, formulations containing 25–35% foxtail millet flour and 5% flaxseed flour (T_2–T_3) exhibited the most favorable microstructural characteristics for the development of high-quality gluten-free muffins.

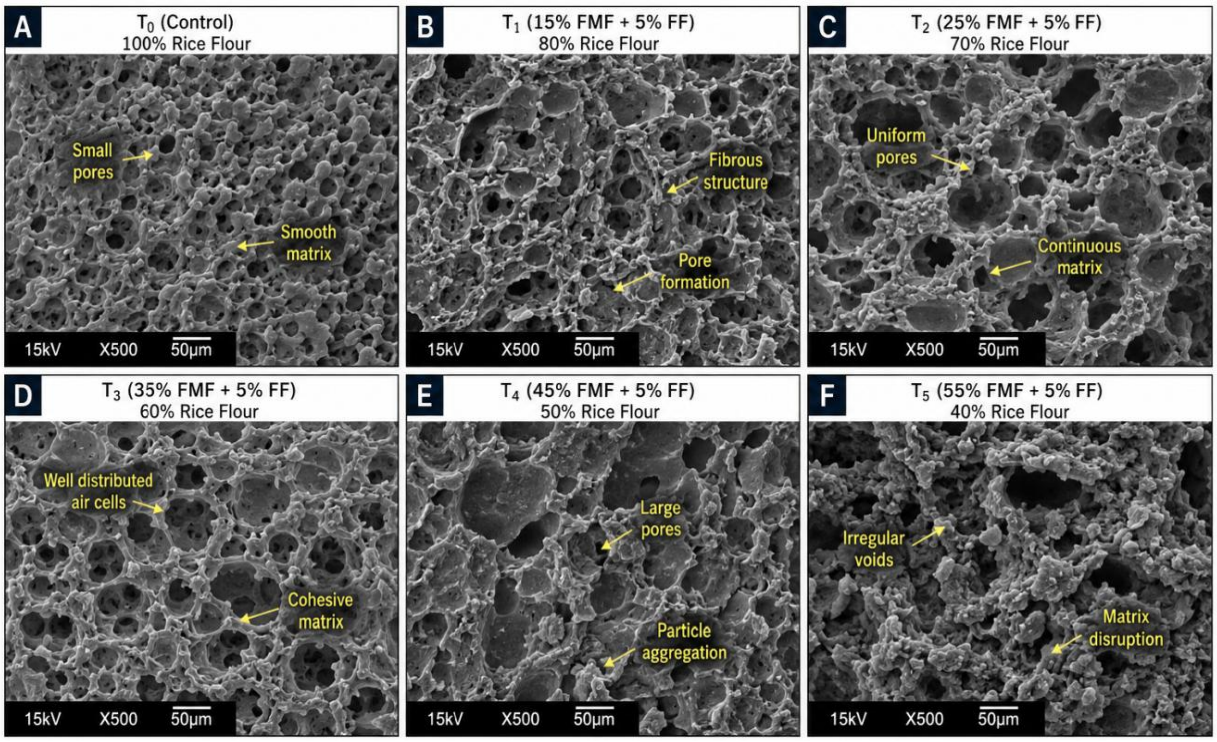
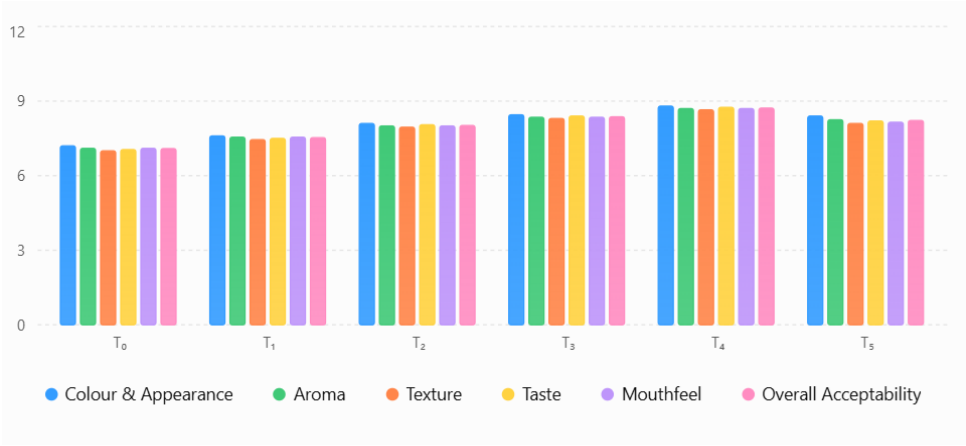


Figure 1. SEM micrographs of gluten-free muffins prepared with different levels of foxtail millet flour and flaxseed flour: (A) T_0 – Control (100% Rice Flour), (B) T_1 – 15% Foxtail Millet Flour, (C) T_2 – 25% Foxtail Millet Flour, (D) T_3 – 35% Foxtail Millet Flour, (E) T_4 – 45% Foxtail Millet Flour, and (F) T_5 – 55% Foxtail Millet Flour showing changes in crumb microstructure, pore distribution, and matrix organization.

4.7 Sensory Evaluation



Overall acceptability scores ranged from 7.09 to 8.72, indicating that all formulations were acceptable, but T_4 was the most preferred among panelists. The results suggest that partial replacement of rice flour with foxtail millet flour and addition of flaxseed flour can significantly enhance the sensory quality of gluten-free muffins.

5. Conclusion

The present study on the formulation and quality evaluation of gluten-free muffins enriched with foxtail millet flour and flaxseed flour demonstrated that both ingredients can be successfully utilized to improve the nutritional and functional quality of bakery products. The incorporation of foxtail millet and flaxseed flour significantly enhanced the protein, fiber, fat, and mineral content of the muffins compared to the control prepared with rice flour alone. Physical properties such as weight, height, volume, and specific volume were also positively influenced up to an optimum substitution level, indicating improved batter structure and better product expansion during baking. Sensory evaluation results revealed that all formulations were acceptable, but the treatment containing 50% rice flour, 45% foxtail millet flour, and 5% flaxseed flour (T_4) was found to be the most acceptable in terms of colour, taste, texture, aroma, and overall acceptability. Microbiological analysis confirmed that the developed muffins were safe for consumption, as no contamination was observed immediately after baking and microbial growth remained within permissible limits during storage. The storage study indicated a gradual decline in moisture content and sensory attributes over six days, but the product remained acceptable and stable under ambient conditions. Overall, it can be concluded that foxtail millet and flaxseed flour are suitable functional ingredients for developing nutritionally enriched gluten-free muffins, with T_4 identified as the most optimized formulation in terms of nutritional, physical, sensory, and storage quality characteristics.

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