Research Article

Development of Gluten-Free Rice Flour-Based Muffins Enriched With Flaxseed and Cinnamon Powder

Komal Fatima[1], Majid Suhail Hashmi[1], Muhammad Asim Irshad[2], Ayaz Ahmad[*1], Ayesha Riaz[1] and Sahib Alam[1]

[1]Department of Food Science and Technology, Faculty of Nutrition Sciences, The University of Agriculture Peshawar, Pakistan; [2]Food and Nutrition division, Nuclear Research Institute of Food and Agriculture Tarnab, Peshawar, Pakistan.

Abstract | This study investigates the formulation and quality assessment of gluten-free muffins made from rice flour, enriched with flaxseed and cinnamon powder, and preserved through irradiation. Five formulations were developed: T_0 (control, all-purpose flour), T_1 (100% rice flour), T_2 (90% rice flour + 10% flaxseed), T_3 (98% rice flour + 2% cinnamon), and T_4 (90% rice flour + 8% flaxseed + 2% cinnamon). The muffins were packed in zip-lock bags and irradiated at 4 kGy for 4 hours. Physiochemical parameters such as moisture content, protein, fat, fiber, ash content, water activity, free fatty acids, peroxide value, total phenolic content, and microbial count were evaluated over a 28-day storage period. Sensory attributes, including taste, color, texture, and overall acceptability, were also assessed. The results showed significant improvements in nutritional quality with T_4 exhibiting the highest protein (6.40a±0.33%), fiber (3.22a±0.16%), and fat content (8.43a±0.43%). Moisture retention declined over storage, and sensory attributes showed a gradual decrease. However, T_2 and T_4 demonstrated lower microbial growth, indicating enhanced preservation. The study suggests that flaxseed and cinnamon significantly improve the nutritional value and storage stability of gluten-free muffins.

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***Correspondence** | Ayaz Ahmad, Department of Food Science and Technology, Faculty of Nutrition Sciences, The University of Agriculture Peshawar, Pakistan. **Email:** ayaz@aup.edu.pk

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Keywords | Gluten-free, Rice flour, Flaxseed, Cinnamon, Muffins, Sensory evaluation, Shelf-life, Irradiation.

Introduction

Celiac disease and gluten intolerance are increasingly prevalent autoimmune and gastrointestinal conditions that necessitate the development of nutritionally optimized gluten-free (GF) food products. According to the World Gastroenterology Organization (2021), the global incidence of celiac disease is rising, underscoring the critical demand for safe and health-promoting GF alternatives. Although rice flour is a widely accepted base in GF formulations due to its hypoallergenic properties, it is inherently deficient in essential macronutrients such as protein and dietary fiber. This limitation warrants the incorporation of bioactive-rich functional ingredients to enhance the nutritional profile and technological functionality of GF baked goods.

Flaxseed (*Linum usitatissimum*) is a well-established functional ingredient, recognized for its high content of α-linolenic acid (omega-3 fatty acids), lignans, and dietary fiber (Goyal *et al*., 2014). Its regular consumption has been associated with improved cardiovascular health, modulation of inflammatory pathways, and enhanced gastrointestinal function. Technologically, flaxseed's mucilage a natural hydrocolloid contributes to improved water retention and textural integrity in GF matrices, mitigating the common quality defects in gluten-free baking (Singletary, 2019).

Cinnamon (*Cinnamomum verum*) is another functional additive with significant antioxidant, antimicrobial, and anti-inflammatory properties (Ranasinghe *et al*., 2013). It has been shown to inhibit lipid peroxidation and microbial growth, thereby enhancing the oxidative stability and microbiological shelf life of food products (Shan *et al*., 2004). These attributes position cinnamon as a promising natural preservative in clean-label formulations. Flaxseed is rich in alpha-linolenic acid, dietary fiber, and lignans, which offer antioxidant and anti-inflammatory effects. Cinnamon, particularly *Cinnamomum verum*, contributes natural antioxidants and exhibits strong antimicrobial properties, which enhance food preservation without synthetic additives.

Contemporary food industry trends increasingly favor clean-label products, driven by consumer preference for minimally processed foods free from synthetic additives (Bigliardi and Galati, 2013). Conventional preservatives such as sodium benzoate and potassium sorbate, though effective, have raised health concerns including allergenicity and gastrointestinal distress (Sharma, 2015). In contrast, natural preservative systems based on flaxseed and cinnamon offer multifunctional benefits improving nutritional quality, extending shelf life, and ensuring consumer safety thereby aligning with both regulatory and market demands.

The objective of this study was to develop gluten-free muffins enriched with flaxseed and cinnamon to improve their nutritional and functional properties while extending shelf life without synthetic preservatives. Additionally, the study evaluated the effectiveness of gamma irradiation as a preservation technique to ensure microbial safety and quality retention over an extended storage period.

Materials and Methods

Procurement of ingredients

All ingredients, including rice flour, all-purpose flour, flaxseed, cinnamon powder, sugar, eggs, vegetable oil, milk, and baking soda, were sourced from local markets in Peshawar. Flaxseed was ground into fine powder before incorporation into the muffin formulations to ensure uniform distribution.

Formulation and preparation of muffins

Five treatments were formulated as T_0: Control (100% all-purpose flour), T_1: 100% rice flour, T_2: 90% rice flour + 10% flaxseed, T_3: 98% rice flour + 2% cinnamon, and T_4: 90% rice flour + 8% flaxseed + 2% cinnamon. The dry ingredients (flour, flaxseed, cinnamon, and baking soda) were sieved to ensure uniform particle size and then mixed. Separately, eggs, sugar, vegetable oil, and milk were whisked until a homogeneous mixture was achieved. The wet ingredients were gradually incorporated into the dry mixture, and the batter was mixed thoroughly to maintain consistency. The muffin batter was poured into pre-greased molds and baked at 180°C for 25 minutes in a preheated oven. Once baked, muffins were cooled at room temperature before being packed for further analysis.

Packaging and storage

The muffins were packed in air-sealed zip-lock bags and stored at room temperature for 28 days. The packaging was done to minimize moisture loss and oxidative degradation during storage.

Irradiation process

The packed muffins were subjected to gamma irradiation at a dose of 4 kGy for 4 hours using a Cobalt-60 gamma radiation source at the Nuclear Institute of Food and Agriculture (NIFA), Peshawar. Irradiation was performed to assess its impact on shelf-life extension and microbial stability.

Analytical tests

A series of analytical tests were conducted at 0, 14, and 28 days of storage to assess the quality and stability of the muffins. All the samples of Gluten free muffins enriched with flaxseed and cinnamon were subjected to evaluate physico-chemical analysis (proximate analysis, texture analysis, water activity, Free fatty acid, Peroxide Value, total phenolic content, and Total viable count (TVC) was assessed using the standard plate count method on nutrient agar, incubated at 37 ˚C for 24–48 hours, following AOAC (2012) protocols. and sensory evaluation (color, taste, texture and overall acceptability) by 9 points Hedonic scale (Larmond, 1977).

Sensory analysis

All the samples were studied for 28 days with every 14-day interval. Sensory evaluation of gluten-free muffins was conducted using a 9-point hedonic scale, where 1 = dislike extremely and 9 = like extremely.

Stastical analysis

Data were analyzed using a completely randomized design (CRD) (Steel *et al*., 1997). Statistical comparisons were performed using analysis of variance (ANOVA) followed by the Lest Significant Difference (LSD) test to determine significant differences ($p < 0.05$). The software used for statistical analysis was SPSS version 25.0 (IBM Corp., Armonk, NY, USA).

Results and Discussion

Proximate composition and free fatty acids (%)

The proximate analysis of gluten-free muffins showed significant variations across treatments (Figure 1). The protein content was highest in T_4 (6.40± 0.13%), attributed to flaxseed's high protein content (Goyal *et al*., 2014). Similarly, fiber content increased significantly in T_4 (3.22± 0.09%), as flaxseed is an excellent source of dietary fiber, contributing to improved gastrointestinal health (Singletary, 2019). Fat content was also highest in T_4 (8.43± 0.16%) due to the presence of flaxseed's omega-3 fatty acids, essential for cardiovascular health (Kajla *et al*., 2015).

Moisture content decreased over the storage period, with T_4 retaining more moisture compared to T_0, likely due to flaxseed's water-binding capacity. Ash content, indicating the mineral content, was highest in T_4 (1.83±0.09%), further supporting the enhanced nutritional benefits of flaxseed and cinnamon (Jayaprakasha *et al*., 2006). The statistical analysis showed that these compositional changes were significant ($p<0.05$), aligning with previous studies on flaxseed-fortified baked products (Grasso *et al*., 2019).

Free fatty acid (FFA) content is an important indicator of lipid hydrolysis and fat degradation in food products. The results (Figure 1) showed a significant ($p<0.05$) increase in FFA levels over storage in all formulations. However, the increase was lowest in T_4 (1.21 ± 0.06%), suggesting that flaxseed and cinnamon contributed to lipid stability. The lower FFA content in T_4 may be due to the antioxidant properties of cinnamon, which help prevent fat oxidation (Ranasinghe *et al*., 2013).

The breakdown of fats leads to an increase in FFA content, which can negatively impact the flavor and shelf life of muffins. The results are consistent with previous studies that indicate antioxidants help maintain lipid quality in bakery products (Jayaprakasha *et al*., 2006).

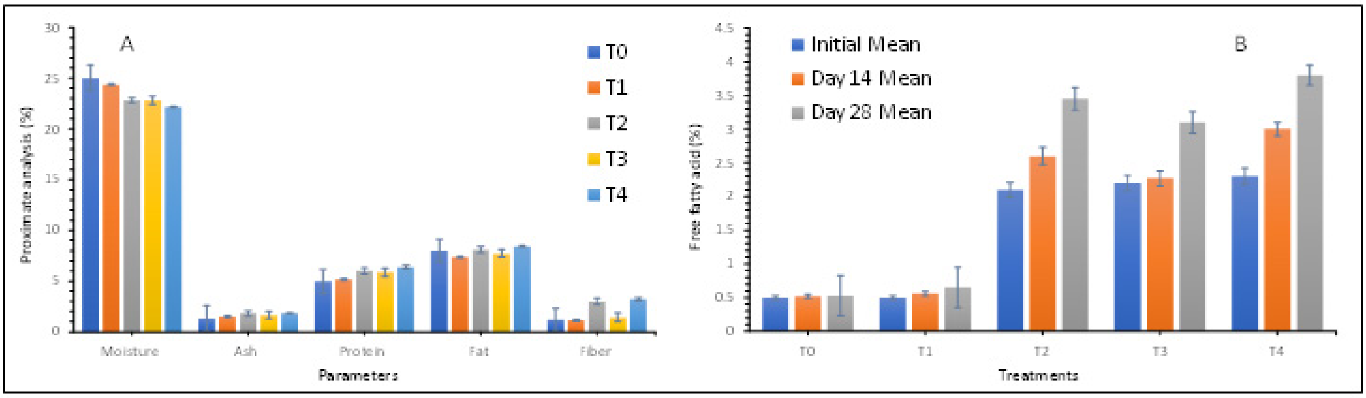

Figure 1: *Proximate analysis (%) of gluten free muffins (b) free fatty acid (%) analysis of gluten-free muffins during 28 days storage life. values are mean ± sd (n = 3). different letters indicate significant differences (p < 0.05) based on tukey's hsd test. the bars show standard deviation among three replicate values. where t_0 muffin with 100% all-purpose flour, t_1 muffin with 100% rice flour only, t_2 muffin with 90% rice flour and 10% flaxseed, t_3 muffin with 98% rice flour and 2% cinnamon powder and lastly t_4 muffin with 90% rice flour, 8% flaxseed and 2% cinnamon powder.*

Links Researchers

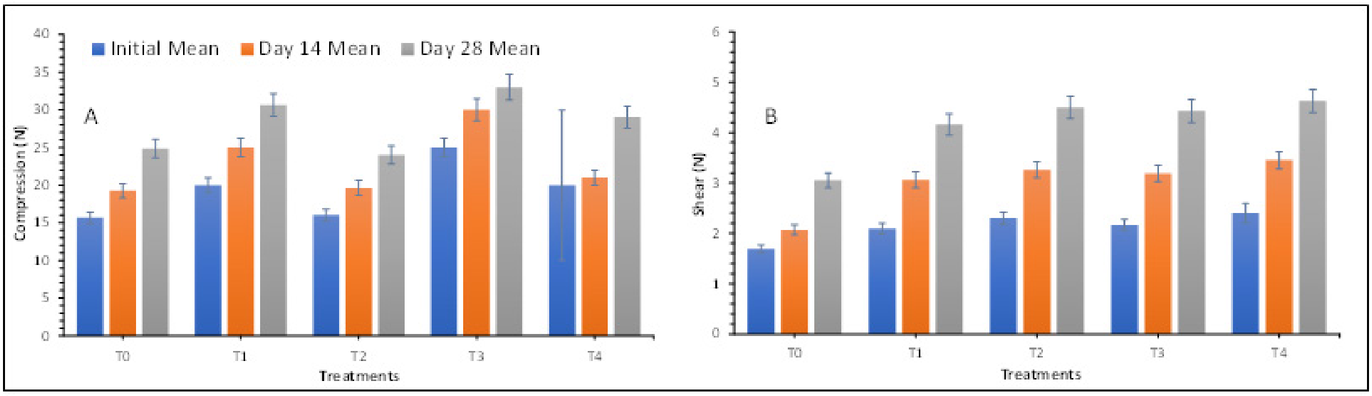

Figure 2: *Texture analysis (compression) n of gluten free muffins (b) texture analysis (shear) n of gluten free muffins during 28 days storage life. values are mean ± sd (n = 3). different letters indicate significant differences (p < 0.05) based on tukey's hsd test. the bars show standard deviation among three replicate values. where t_0 muffin with 100% all-purpose flour, t_1 muffin with 100% rice flour only, t_2 muffin with 90% rice flour and 10% flaxseed, t_3 muffin with 98% rice flour and 2% cinnamon powder and lastly t_4 muffin with 90% rice flour, 8% flaxseed and 2% cinnamon powder.texture analysis (n)*

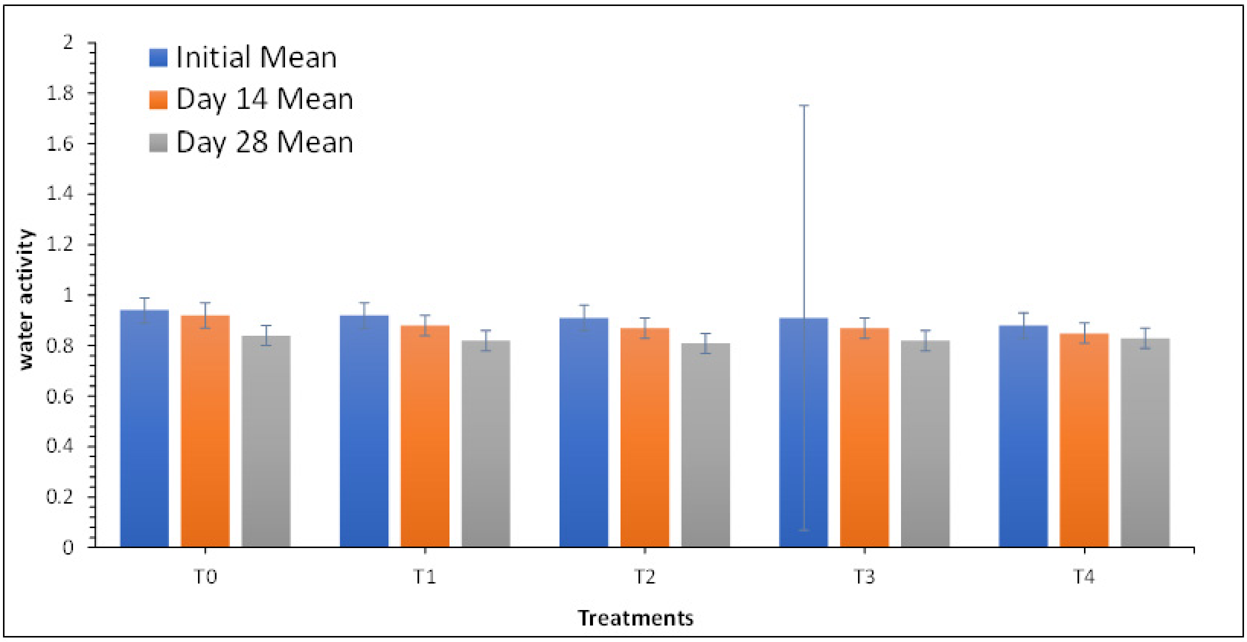

Figure 3: *Water activity of gluten free muffins during 28 days storage life. values are mean ± sd (n = 3). different letters indicate significant differences (p < 0.05) based on tukey's hsd test. the bars show standard deviation among three replicate values. where t_0 muffin with 100% all-purpose flour, t_1 muffin with 100% rice flour only, t_2 muffin with 90% rice flour and 10% flaxseed, t_3 muffin with 98% rice flour and 2% cinnamon powder and lastly t_4 muffin with 90% rice flour, 8% flaxseed and 2% cinnamon powder.*

Texture hardness increased significantly over storage in all treatments (Figure 2), with the smallest increase observed in T_4 (Initial: 1.85 ± 0.07 N, Day 28: 2.65 ± 0.10 N). This suggests flaxseed and cinnamon delayed staling and preserved crumb softness. Flaxseed's mucilage content has been reported to improve texture retention in gluten-free products (Muhammad and Dewettinck, 2017). Springiness and cohesiveness were also better retained in T_4 (Figure 2), aligning with previous research on flaxseed's mucilage improving texture in gluten-free products (Grasso *et al.*, 2019).

Water activity (Aw)

Water activity (*Aw*) significantly (p<0.05) decreased in all formulations, with T_2 and T_4 recording the lowest values (Figure 3). Lower aw values are associated with improved microbial stability and extended shelf life (Suthar and Das, 2004).

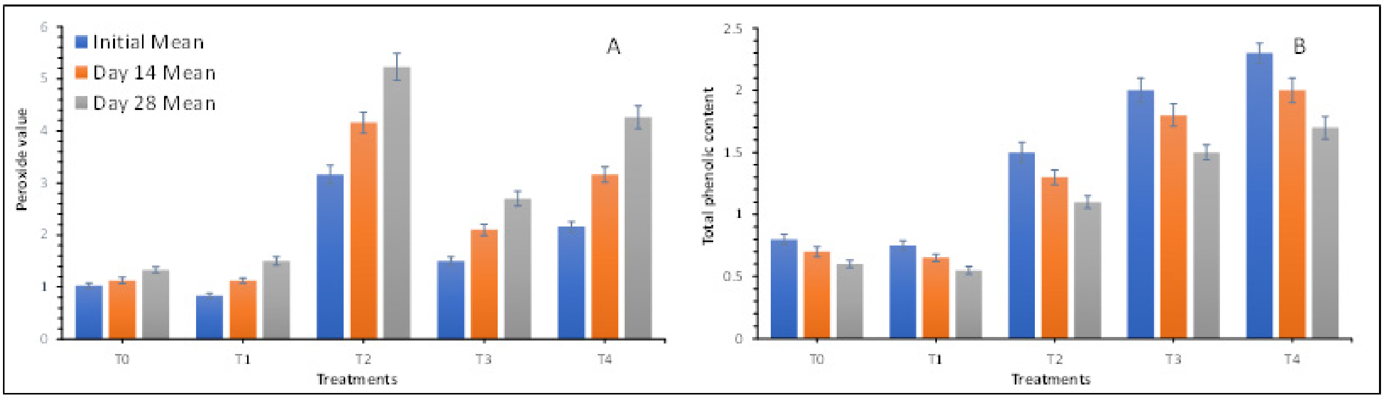

Figure 4: *Pov analysis of gluten free muffins (b) tpc analysis (mg gae/g) of gluten free muffins during 28 days storage life. values are mean ± sd (n = 3). different letters indicate significant differences (p < 0.05) based on tukey's hsd test. the bars show standard deviation among three replicate values. where t_0 muffin with 100% all-purpose flour, t_1 muffin with 100% rice flour only, t_2 muffin with 90% rice flour and 10% flaxseed, t_3 muffin with 98% rice flour and 2% cinnamon powder and lastly t_4 muffin with 90% rice flour, 8% flaxseed and 2% cinnamon powder.*

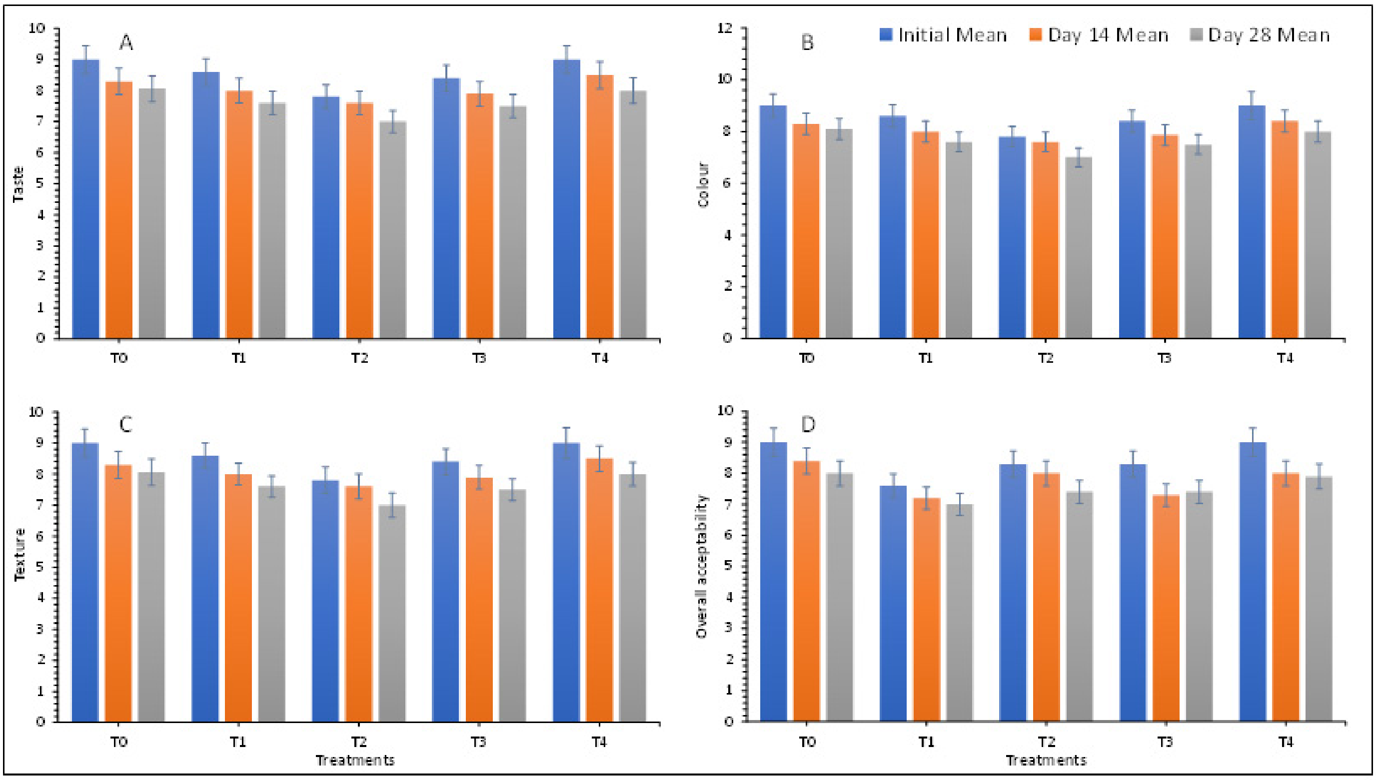

Figure 5: *Sensory analysis (a) taste (b) colour (c) texture and (d) overall acceptability of gluten free muffins during 28 days storage life. different letters indicate significant differences at p < 0.05 using tukey's hsd test. the bars show standard deviation among three replicate values. where t_0 muffin with 100% all-purpose flour, t_1 muffin with 100% rice flour only, t_2 muffin with 90% rice flour and 10% flaxseed, t_3 muffin with 98% rice flour and 2% cinnamon powder and lastly t_4 muffin with 90% rice flour, 8% flaxseed and 2% cinnamon powder.*

The presence of flaxseed and cinnamon contributed to the decreased water activity, as flaxseed's fiber content helps bind water, reducing its availability for microbial growth (Kajla *et al*., 2015). Cinnamon's antimicrobial properties further enhance product stability (Ranasinghe *et al*., 2013).

Peroxide value and total phenolic content

Peroxide value (POV) is a key indicator of lipid oxidation, which directly affects the shelf life and sensory attributes of bakery products. Higher POV levels indicate oxidative rancidity, leading to undesirable flavors and reduced product quality. The results (Figure 4) showed a significant (p<0.05) increase in POV across all formulations over storage, with T_4 (1.43 ± 0.05 meq/kg) having the lowest increase. This suggests that flaxseed and cinnamon contributed to oxidative stability by reducing lipid peroxidation (Ranasinghe *et al*., 2013).

The lower POV in T_4 may be attributed to the antioxidant properties of cinnamon, which contains bioactive compounds such as cinnamaldehyde that inhibit oxidation (Jayaprakasha *et al*., 2006). Flaxseed, rich in omega-3 fatty acids, also plays a role in enhancing lipid stability by forming a protective matrix around fats, preventing excessive oxidation (Kajla *et al*., 2015).

TPC values were significantly higher ($p<0.05$) in T_4 (23.4 ± 0.7 mg GAE/g) compared to other treatments, confirming the role of flaxseed and cinnamon as polyphenol-rich ingredients (Figure 4). Jayaprakasha *et al*. (2006) highlighted the antioxidant benefits of these ingredients, which support oxidative stability over storage. Cinnamon is well-known for its rich polyphenolic content, particularly cinnamaldehyde and proanthocyanidins, which contribute to its strong antioxidant properties (Ranasinghe *et al*., 2013). Flaxseed also contains lignans and flavonoids that enhance the overall phenolic profile, improving the muffins' resistance to oxidative degradation (Kajla *et al*., 2015).

Total viable count (TVC)

TVC was significantly lower in T_2 and T_4 (Day 28: 1.9 ± 0.2 log CFU/g for T_4), indicating enhanced microbial stability (Table 1). Cinnamon's antimicrobial effects have been widely reported, reducing bacterial and fungal contamination (Ranasinghe *et al*., 2013). Total viable count (TVC) is a key indicator of microbial load in food products and is used to assess their microbial stability and safety during storage. Higher TVC values indicate increased microbial contamination, which can negatively impact shelf life and food safety (Ranasinghe *et al*., 2013). The presence of antimicrobial ingredients such as cinnamon, combined with irradiation, plays a crucial role in controlling microbial growth.

Sensory analysis

Sensory evaluation of gluten-free muffins was conducted using a 9-point hedonic scale, where 1 = dislike extremely and 9 = like extremely. Sensory attributes assessed included taste, color, texture, and overall acceptability (Figures 5). The taste scores decreased over storage, but T_4 maintained the highest acceptability (Day 0: 8.5 ± 0.3; Day 28: 7.9 ± 0.2), followed closely by T_0 and T_1. The incorporation of cinnamon contributed aromatic sweetness, while flaxseed added a subtle nuttiness, improving flavor complexity. For color, T_4 and T_0 achieved the highest ratings (8.4 ± 0.2), attributed to the warm brown hue imparted by cinnamon and flaxseed. In contrast, T_2 received the lowest color scores (7.4 ± 0.3), likely due to flaxseed's darker appearance dominating the visual appeal.

Table 1: *Total viable count (CFU/g) of muffins*

Treatment	CFU/g
T_0	10000
T_1	17000
T_2	200
T_3	20000
T_4	700

Texture ratings were best in T_4 and T_0 (8.5 ± 0.2), indicating enhanced softness and chewiness, retained over storage. Flaxseed mucilage likely played a key role in moisture retention and crumb integrity, reducing textural degradation. In terms of overall acceptability, T_4 (8.3 ± 0.2) and T_1 (8.4 ± 0.2) were most favored, combining improved sensory traits with better shelf stability. These findings suggest that flaxseed and cinnamon act synergistically to improve the organoleptic properties of gluten-free muffins, even over extended storage.

Conclusions and Recommendations

This study successfully developed a gluten-free muffin formulation using rice flour enriched with flaxseed and cinnamon, enhanced through gamma irradiation for shelf stability. The T_4 treatment (90% rice flour, 8% flaxseed, 2% cinnamon) demonstrated superior nutritional content higher protein, fiber, and antioxidant levels and better sensory scores than the control and other treatments. Additionally, flaxseed and cinnamon contributed to reduced microbial load and oxidative rancidity, thereby extending product shelf life.

These results support the potential of natural functional ingredients and non-thermal preservation techniques in producing clean-label, gluten-free bakery products with improved consumer acceptability and stability during storage.

Novelty Statement

This study uniquely combines rice flour-based gluten-free muffin formulation with natural enrichment using flaxseed and cinnamon, alongside a non-thermal preservation technique through gamma irradiation. It is the first to comprehensively evaluate the synergistic impact of these functional ingredients and irradiation on both the nutritional enhancement and microbial stability of gluten-free baked products during storage. The findings highlight a novel approach to improving the shelf life, nutritional profile, and sensory acceptability of gluten-free muffins, addressing key challenges in gluten-free product development.

Author's Contribution

The study was designed, conducted and written by Komal Fatima. Majid S. Hashmi designed, supervised, and assisted in finalizing the manuscript. Muhammad Asim Irshad supervised and assisted in drafting the manuscript. Ayaz Ahmad assisted in data analysis, proof reading, formatting and preparing the final manuscript. Ayesha Riaz and Sahib Alam assisted in data analysis and finalization of the manuscript.
This work has been carried out as a requirement for M.Sc. (Hons) degree of first author.

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Generative AI or AI assisted technology statement
The authors declare that no Genrative AI was used in the creation of this manuscript.

Conflict of interests
The authors show no conflict of interests.

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