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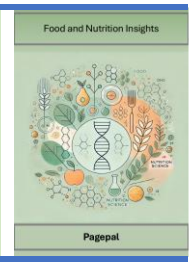

Exploring the Storage Effect on Nutritional, Physicochemical, and Sensory Characteristics of Rice Based Composite Snacks Fortified with *Foeniculum vulgare* and *Amaranthus spp.* Leaf Powders

Faisal Fayyaz[1], Sharafat Ali[2], Aneeza Fatima[3*], Hafiza Ammara shabbir[3], Mamoona Arshad[3], Qurat Ulain[4] and Iraj Fatima[5*]

[1]Department of Food Science and Technology, The Islamia University of Bahawalpur, Pakistan.
[2]Department of Food Science and Technology, UAF-Constituent College Burewala, Pakistan.
[3]National Institute of Food Science and Technology, University of Agriculture, Faisalabad, Pakistan.
[4]Department of Botany, University of Agriculture, Faisalabad, Pakistan.
[5]Department of Nutritional Sciences, Government College Women University Faisalabad, Pakistan.

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Abstract

Rice is a staple food for more than half of the global population. Despite its widespread use as a main source of energy, it can serve as an efficient matrix for adding plant materials with proven health effects. The study assessed nutritional, physical, instrumental color, and sensory properties of rice composite snacks with the addition of 0%, 1%, 2%, 3%, 4%, 5%, 6%, and 7% (Foeniculum vulgare and Amaranthus spp.) during 0, 30, 60, and 90 days of storage. The nutritional composition was determined according to the standard AOAC methods, the color parameters by HunterLab ColorFlex colorimeter, physical parameters by using standard calipers and spread ratio, while sensory evaluation was done on a 9-point hedonic scale. The results revealed that ice snacks with the addition of Foeniculum vulgare and Amaranthus spp. have statistically significantly higher levels of crude protein, crude fiber, ash, and fat contents than the control ($p < 0.05$). The addition of powders increased thickness and weight of snacks but decreased the diameter and spread ratio due to their water binding properties. The instrumental color measurement showed that there was a gradual reduction in the L and b* values of the samples, meaning that color became darker. There were some notable differences among the sensory parameters of the snack in terms of color, texture, and flavor intensity, in which the 7% enrichment of Foeniculum vulgare and Amaranthus spp received lower ratings, but the 4% enrichment of Foeniculum vulgare and Amaranthus spp (T_4) showed the highest acceptability (8.18 on day 0 and 7.71 after 90 days).*

1. Introduction

Diet plans in subcontinent countries are mostly concentrated on cereal-based products. They are deficient in micronutrients and merely fulfill the daily requirement of many essential nutrients (Migliozzi *et al*., 2015). Thus, deficient individuals suffer from several public health problems related to nutrient or combined nutrient deficiencies (Neufeld *et al*., 2017). Rice is a cereal popularly consumed across the globe, with the total domestic consumption of around 48,67,15,000 MT for the calendar and market year 2018. Around the world today, 103 countries consume rice (Shantini *et al*., 2021). Apart from this, rice has a constant consumption pattern in most of the countries, that offer a low risk of excess consumption. Micronutrient fortification through staple foods like rice is directly linked to energy intake (Saha & Roy, 2020).

Rice fortification is an effective and economical strategy to increase micronutrient intake in countries where rice is a

Corresponding Author: Aneeza Fatima & Iraj Fatima Email: aneezaf238@gmail.com & irajfatima@gcwuf.edu.pk

staple food (Liu *et al*., 2025). A successful fortification technology should deliver substantial micronutrient content, high bioavailability, stability during storage, and retention of sensory attributes (Saha *et al*., 2020). As a staple food, rice serves as the primary energy source for approximately 2/3 of the global population. Unprocessed rice is rich in dietary fiber, vitamins, minerals, sterols, phenols, oryzanols, and other nutrients, most of which are removed during the polishing process, resulting in low protein content, an imbalanced amino acid profile, and substantial nutrient loss (Steiger *et al*., 2014; Iqbal *et al*., 2026). The transformation from whole rice grains to polished white rice results in considerable nutrient loss due to processing and washing steps.

Populations that rely heavily on polished rice are more susceptible to malnutrition and micronutrient deficiencies, particularly in regions where alternative staple foods are limited (Ganachari *et al*., 2022). With improvements in living standards, consumer preferences have shifted from meeting basic dietary needs toward healthier and more nutritious staple foods (Akbar & Ayub, 2018). Compared with brown rice, white rice contains 33% less dietary fiber, 11.76% less protein, 72.23% less folic acid, 41.60% less ash, and 65.23% less fat when the milling degree reaches 8% (Monks *et al*., 2013). During polishing, approximately 75-90% of vitamins, particularly vitamins B_1, B_6, E, and B_3, are removed (Steiger *et al*., 2014). Approximately 64% of nutrients and numerous bioactive compounds are concentrated in the rice germ and bran layers, which are largely removed during milling (Ma *et al*., 2020).

Rice is commonly washed several times before cooking; however, washing causes considerable losses of water-soluble vitamins and minerals, thereby reducing its nutritional value. Repeated washing, prolonged soaking, and higher water temperatures further increase nutrient losses (Susan *et al*., 2017). Cooking also contributes to nutrient depletion. Vitamin B1 losses reached 52.5% during processing and 62.5% during cooking, while vitamin B2 losses were 33.3% and 66.7%, respectively.

To overcome the nutritional limitations of conventional rice and satisfy the increasing demand for healthier foods, nutrient fortification has emerged as an effective strategy (Thivani *et al*., 2016). Rice fortification involves the intentional addition of essential micronutrients to improve the nutritional quality of rice (Uchechukwu-Agua *et al*., 2015). Fortification is considered a practical and cost-effective approach for reducing micronutrient deficiencies without requiring major changes in dietary habits (Urooj *et al*., 2026a; Urooj *et al*., 2026b). The increasing consumption of high-moisture rice-based products such as instant rice, rice noodles, and rice cakes has attracted widespread attention (Perignon *et al*., 2016). Microbial spoilage, starch retrogradation, and the absence of robust quality control systems shorten shelf life and impair quality consistency, constituting a major bottleneck for the market expansion of high-moisture rice-based products (Shen *et al*., 2014). Many countries have taken the required measures to ensure rice food security by appropriately controlling distribution and storage all year round (Ahmad *et al*., 2017).

Rice storability is the ability to maintain the quality properties of rice during its storage and distribution (Kim *et al*., 2017). This is required to maintain a consistent supply of rice, especially in the case of natural disasters that might lead to a dramatic reduction in rice yields. Many factors such as the temperature and duration of storage, moisture content, and relative humidity play key roles in the storability of rice (Kim *et al*., 2022). Good temperature management is the most essential and yet the most easily regulated factor that can retard deterioration of rice quality. Globally, snack foods are conveniently prepared and tasty; they make an important component of the diet in most cultures (Arif *et al*., 2026). However, snack foods, particularly those based on starches, do not contain necessary nutrients and thus may cause obesity, stunted growth, decreased work ability, and impaired mental and social development. It is important to increase the amount of protein and improve its quality in snack food diets to reduce protein malnutrition in developing countries. Some snacks' high energy and low nutritional density may lead to overeating and obesity, as well as increased risk of developing metabolic diseases (Urooj *et al*., 2026c). Snacks mean a small meal or food eaten between regular meals. Snacks are consumed because of pleasure and taste rather than any nutrient content. Snacks have a crispy texture and are easily edible, hence gaining popularity among different cultures. Ready-to-eat snacks are accepted by many people because of their convenience, no preparation time, appeal, packaging, and distribution. Since snacks are liked by all age groups, especially children and adolescents, there is an interest in improving the nutritional profile of this product (Trilokia, 2022). It is difficult to maintain a balance between enhancing the nutritional profile of snacks and sensory attributes. Therefore, the main objective of the current research was to formulate rice-based composite snacks enriched with different levels (0-7%) of leaf powders of *Foeniculum vulgare* and *Amaranthus spp.* and to evaluate the nutritional, physical, instrumental color, and sensory characteristics of these snacks. The objectives of the study were to study the effect of storage for 90 days on the nutritional, physicochemical, color, and sensory properties of the formulated snacks and identify the formulation providing the best balance of nutritional enrichment, quality of the product, storage stability, and consumer acceptance.

2. Materials and Methods

2.1 Raw materials

Rice was procured from the local market of Metro Mart, Multan, Pakistan. The rice was manually cleaned to remove extraneous materials and subsequently milled into fine flour. The prepared rice flour was stored in airtight containers until further processing. Fresh fennel (*Foeniculum vulgare*) and amaranthus (*Amaranthus* spp.) leaves were procured from the local vegetable market and processed at the Food Processing Centre. The two leafy vegetables were used in equal proportions for preparation; other ingredients required for snack preparation, including butter, sesame seeds, salt, sugar, baking powder, baking soda, and water, were obtained from the local market.

2.2 Preparation of *Foeniculum vulgare* and *Amaranthus* spp. leaf powders

Fresh fennel and amaranthus leaves were sorted, graded, and washed thoroughly under running tap water to eliminate adhering dirt. To remove potential agricultural contaminants, the leaves were soaked and washed in a saline solution (2 teaspoons of salt dissolved in 2 L of tap water) and rinsed thrice with clean water. Excess water was drained using a strainer, after which the leaves were dried separately in a combi-master oven fan dryer at 70 °C for 2 h. The dried leaves were milled using an electric blender and passed through a 0.05 mm sieve to obtain a uniform fine powder. The resulting powders were stored in airtight, labeled zip-lock plastic bags at ambient conditions until incorporation into the snack's formulations (Olusanya *et al*., 2023).

2.3 Formulation of rice composite snacks

Rice composite snacks were formulated by incorporating powders at different levels into a standardized rice flour-based formulation, with detailed treatment formulations as presented in Table 1.

Table 1. Formulation of rice snacks with different levels of *Foeniculum vulgare* and *Amaranthus spp.* leaf powders

Treatments	RF (%)	SS (%)	FLP (%)	ALP (%)
T_0	100	0	0	0
T_1	89	10	0.5	0.5
T_2	88	10	1.0	1.0
T_3	87	10	1.5	1.5
T_4	86	10	2.0	2.0
T_5	85	10	2.5	2.5
T_6	84	10	3.0	3.0
T_7	83	10	3.5	3.5

RF = Rice Flour; SS = Sesame seeds ; FLP = Fennel leaf powder ; ALP = Amaranthus leaf powder

2.4 Preparation of rice composite snacks

Formulation and preparation of rice composite snack foods were carried out following the formulation method as proposed by Ren *et al*. (2021) with suitable modifications. Dry ingredients consisting of fixed proportions of rice flour, FLP, ALP, sesame seeds (SS), baking powder, baking soda, sugar, and salt were accurately weighed for each experiment and kept in airtight high-density polyethylene containers. Cold butter, which did not contain any added salt and was kept at 10 °C, was chopped up and mixed well to achieve a consistent crumb-like texture of the dry mixture. Deionized water was then slowly added and mixed well to form a homogeneous dough mass, then wrapped up and allowed to rest at 5 °C for 10 min in order to relax the starch structure, and sheeted to a thickness of 2.0 mm and cut into pieces of standard size 36 × 36 mm. These dough pieces were arranged in non-stick baking trays and baked at 250 °C in a deck oven for 6 min. After baking, the products were cooled on racks made of elevated wire mesh at room temperature (25 ± 2°C) for 1 hour to allow the steam to evaporate internally without causing sogginess due to condensation, after which they were sealed in laminated aluminum foil pouches.

2.5 Storage of rice composite snacks

The prepared snacks from each treatment were packed in aluminum laminate pouches and stored under ambient conditions for 90 days. Samples were collected at predetermined storage intervals of 0, 30, 60, and 90 days to evaluate changes in their physicochemical, functional, bioactive, sensory, and microbiological characteristics. Samples were analyzed according to the respective analytical procedures at each storage interval.

2.6 Nutritional analysis

Composition of rice-based snacks was analyzed using standard procedures of AOAC (2019), as followed by Urooj and Asif (2026). Moisture content was analyzed using the air oven drying method at 105 ± 1 °C until the attainment of constant weight (AOAC Method 925.10). Ash content was measured by incinerating the samples in the muffle furnace at 550 °C until constant ash weight was attained (AOAC Method 923.03). Crude protein content was analyzed using the micro Kjeldahl method (AOAC Method 979.09), and the total nitrogen was multiplied by 6.25 (conversion factors for rice to estimate crude protein content). Crude fat content was analyzed using the Soxhlet extraction method with petroleum ether (AOAC Method 920.39), whereas crude fiber content was analyzed using the acid-alkali digestion method (AOAC Method 962.09). Available carbohydrates were estimated by difference:

Carbohydrate (%) = 100 − [Moisture (%) + Ash (%) + Crude protein (%) + Crude fat (%) + Crude fiber (%)]

Total energy was calculated using the Atwater conversion factors (4 kcal g^{-1} for protein, 4 kcal g^{-1} for carbohydrates, and 9 kcal g^{-1} for fat) as described by Roberts & Flaherman (2022).

Energy (kcal/100 g) = [(% carbohydrate × 4) + (% crude protein × 4) + (% crude fat × 9)]

2.7 Physical characteristics

Evaluation of physical properties was done based on thickness, diameter, weight, and spread ratio using standard procedures (Asif *et al*., 2023, 2024b) with slight alterations. Snack thickness was determined by piling three units of snacks vertically, recording their overall heights by means of a digital Vernier caliper (Mitutoyo 500-196-30, Mitutoyo Corp., Kawasaki, Japan; precision: ±0.02 mm), and dividing their overall values by three. The diameter of the snack was measured by arranging three units next to one another and measuring their overall length with a digital caliper; they were then turned 90° to obtain the second diameter measurement, which resulted in an average diameter of each unit. Both thickness and diameter of the sample were measured in triplicate in mm. The weight of each snack was measured with a top pan digital balance that was calibrated (±0.001g accuracy) and expressed in grams (g) for three replicates. The spread ratio was determined through the formula:

$$\text{Spread ratio} = \frac{\text{Mean diameter (mm)}}{\text{Mean thickness (mm)}}$$

2.8 Color

Color characteristics of composite snacks were determined instrumentally using a HunterLab ColorFlex colorimeter following established instrumental colorimetry procedures (Fatima *et al*., 2025)

2.9 Sensory evaluation

Sensory analysis of rice composite snacks was performed using the standardized sensory analysis procedure (Asif *et al*., 2024a; Asif *et al*., 2025b). The sensory panel was composed of 20 semi-trained testers (10 males and 10 females, aged 20-35 years) having no allergies to the ingredients used in the experiment, selected from the institute. The samples of the snacks coded with three digits were served to them on white, odorless disposable plates under uniform fluorescent lights. The sensory analysis was done in individual sensory booths at room temperature (25 ± 2 °C). Appearance, aroma, taste, and acceptability were rated on a standardized 9-point hedonic scale (1 -dislike extremely to 9 - like extremely).

2.10 Statistical analysis

All the experimental trials were conducted in triplicate, and results were reported as mean ± standard deviation (SD) (Butt *et al*., 2026). The statistical analysis was conducted in Statistical Software Statistix 8.1 (Analytical Software, Tallahassee, FL, USA) to evaluate the main effects of the formulation of treatments and storage period, and their interaction. The statistically significant differences between treatment means were distinguished through Tukey's Honestly Significant Difference (HSD) test at the $p < 0.05$ level (Zahid *et al*., 2025).

3. Results and Discussions

3.1 Proximate composition

Moisture content of the rice snacks varied considerably among treatments and showed a general increase during the storage period (Table 2). At 0 days, the moisture content was varied from 3.51% in T_0 and T_4 to 4.34% in T_3 and T_7. After 90 days of storage, the moisture content varied between 4.10% in T_7 and 4.42% in T_0, with all the treatments being within the acceptable range of moisture content of less than 5% as required for crispiness of cereal snacks. From the results of the study, there was an increase in moisture content of all the treatments after storage, which can be attributed to the hygroscopicity of the snacks, as well as absorption of moisture in the storage environment. Besides, the variability among different treatments was attributed to differences in the water-holding ability of the

Table 2. Effect of leaf powders (*Amaranthus spp.* and *Foeniculum vulgare*) and storage duration on the proximate composition and energy value of rice snacks

T	S	Moisture (%)	Ash (%)	Crude fat (%)	Crude protein (%)	Crude fiber (%)	Carbohydrates (%)	Energy (kcal/100 g)
T_0	0	3.51±0.04^{g}	0.94±0.02^{h}	9.27±0.05^{c}	9.76±0.04^{g}	1.58±0.03^{g}	74.72±0.16^{ab}	421.86±1.15^{a}
	30	3.84±0.05^{ef}	0.82 ± 0.03^{i}	9.16±0.06^{de}	9.64±0.05^{gh}	1.55±0.03^{gh}	74.85±0.19^{ab}	420.83±1.10^{ab}
	60	4.23±0.04^{bc}	0.71±0.01^{j}	9.07±0.04^{e}	9.51±0.04^{h}	1.48±0.03^{hi}	74.96±0.20^{ab}	419.79±1.35^{bc}
	90	4.42±0.06^{a}	0.63±0.03^{k}	8.66±0.07^{g}	9.24±0.07^{i}	1.39 ± 0.02^{i}	75.57 ± 0.22^{a}	417.44±1.15^{de}
T_1	0	3.78±0.03^{f}	1.42± 0.03^{f}	9.32±0.05^{bc}	10.05±0.05^{f}	1.76± 0.03^{f}	73.91 ± 0.16^{c}	419.94±1.20^{bc}
	30	3.81±0.04^{ef}	1.31± 0.02^{g}	9.22±0.05^{cd}	9.93±0.06^{fg}	1.72± 0.03^{f}	74.00± 0.13^{c}	418.92± 1.05^{c}
	60	4.15 ± 0.05^{cd}	1.20 ± 0.03^{h}	9.08 ± 0.04^{e}	9.68 ± 0.04^{gh}	1.64 ± 0.03^{fg}	74.29 ± 0.19^{bc}	417.57±1.40^{de}
	90	4.37±0.04^{ab}	1.12± 0.02^{h}	8.81± 0.06^{f}	9.54± 0.05^{h}	1.53±0.04^{gh}	74.67± 0.22^{ab}	416.37± 1.11^{ef}
T_2	0	4.09±0.04^{cd}	1.52± 0.03^{e}	9.38± 0.05^{b}	10.31±0.06^{e}	1.88± 0.05^{e}	73.48± 0.15^{cd}	419.57±1.15^{bc}
	30	3.76 ±0.03^{f}	1.44±0.02^{ef}	9.27±0.04^{c}	10.20±0.05^{ef}	1.83± 0.03^{e}	73.55± 0.18^{cd}	418.47±1.30^{cd}
	60	4.07±0.05^{cd}	1.35±0.03^{fg}	9.13±0.05^{de}	10.06±0.07^{f}	1.67± 0.02^{f}	73.7 ± 0.20^{cd}	417.54±1.04^{de}
	90	4.33 ± 0.04^{ab}	1.27 ± 0.02^{g}	8.87 ± 0.06^{f}	9.91 ± 0.04^{fg}	1.56 ± 0.03^{g}	73.96 ± 0.17^{c}	416.19 ± 1.25^{ef}
T_3	0	4.34 ± 0.05^{ab}	1.65 ± 0.03^{d}	9.43 ± 0.04^{b}	10.55 ± 0.05^{d}	2.01 ± 0.03^{d}	72.98 ± 0.16^{de}	418.99 ± 1.20^{c}
	30	3.71 ± 0.03^{fg}	1.57 ± 0.02^{de}	9.32 ± 0.05^{bc}	10.40 ± 0.07^{de}	1.97 ± 0.04^{d}	73.09 ± 0.15^{de}	417.72 ± 1.10^{de}
	60	4.02 ± 0.04^{d}	1.45 ± 0.03^{ef}	9.18 ± 0.04^{d}	10.27 ± 0.05^{e}	1.92 ± 0.02^{de}	73.21 ± 0.19^{d}	416.43 ± 1.20^{ef}
	90	4.28 ± 0.05^{b}	1.36 ± 0.02^{fg}	8.92 ± 0.05^{ef}	10.14 ± 0.07^{ef}	1.74 ± 0.03^{f}	73.61 ± 0.22^{cd}	415.43 ± 1.15^{fg}
T_4	0	3.51 ± 0.04^{g}	1.76 ± 0.04^{c}	9.48 ± 0.04^{ab}	10.75 ± 0.05^{c}	2.12 ± 0.04^{c}	72.61 ± 0.18^{e}	418.61 ± 1.24^{cd}
	30	3.68 ± 0.03^{fg}	1.67 ± 0.02^{cd}	9.36 ± 0.04^{b}	10.63 ± 0.05^{cd}	2.08 ± 0.03^{c}	72.68 ± 0.16^{e}	417.24 ± 1.16^{de}
	60	3.99 ± 0.04^{de}	1.59 ± 0.03^{d}	9.23 ± 0.05^{cd}	10.44 ± 0.06^{d}	2.02 ± 0.02^{cd}	72.79 ± 0.17^{de}	415.87 ± 1.40^{ef}
	90	4.22 ± 0.05^{bc}	1.51 ± 0.02^{e}	8.97 ± 0.06^{ef}	10.27 ± 0.05^{e}	1.85 ± 0.03^{e}	73.24 ± 0.20^{d}	414.83 ± 1.05^{fg}
T_5	0	3.78 ± 0.03^{f}	1.87 ± 0.03^{b}	9.54 ± 0.04^{ab}	10.97 ± 0.06^{b}	2.21 ± 0.03^{b}	72.09 ± 0.14^{fg}	417.31 ± 1.21^{de}
	30	3.60 ± 0.04^{g}	1.78 ± 0.02^{bc}	9.44 ± 0.05^{b}	10.81 ± 0.07^{bc}	2.15 ± 0.03^{bc}	72.27 ± 0.17^{f}	417.30 ± 1.10^{de}
	60	3.94 ± 0.05^{de}	1.69 ± 0.02^{cd}	9.28 ± 0.04^{c}	10.66 ± 0.05^{c}	2.09 ± 0.04^{c}	72.40 ± 0.18^{ef}	415.69 ± 1.30^{f}
	90	4.17 ± 0.04^{cd}	1.61 ± 0.02^{d}	9.08 ± 0.05^{e}	10.51 ± 0.06^{cd}	1.93 ± 0.02^{d}	72.76 ± 0.21^{e}	414.96 ± 1.15^{fg}
T_6	0	4.09 ± 0.04^{cd}	1.95 ± 0.03^{ab}	9.60 ± 0.05^{a}	11.15 ± 0.07^{a}	2.35 ± 0.04^{a}	71.84 ± 0.16^{g}	418.29 ± 1.25^{cd}
	30	3.53 ± 0.03^{g}	1.86 ± 0.02^{b}	9.48 ± 0.04^{ab}	11.01 ± 0.05^{ab}	2.25 ± 0.03^{ab}	72.03 ± 0.15^{fg}	416.60 ± 1.12^{e}
	60	3.87 ± 0.05^{e}	1.78 ± 0.03^{bc}	9.34 ± 0.05^{bc}	10.86 ± 0.05^{b}	2.18 ± 0.02^{b}	72.14 ± 0.19^{f}	414.78 ± 1.35^{fg}
	90	4.13 ± 0.04^{cd}	1.70 ± 0.02^{cd}	9.19 ± 0.04^{d}	10.72 ± 0.06^{c}	2.11 ± 0.03^{bc}	72.20 ± 0.18^{f}	414.55 ± 1.23^{g}
T_7	0	4.34 ± 0.05^{ab}	2.06 ± 0.05^{a}	9.67 ± 0.05^{a}	11.34 ± 0.08^{a}	2.48 ± 0.04^{a}	71.46 ± 0.14^{h}	418.16 ± 1.30^{cd}
	30	3.46 ± 0.03^{g}	1.97 ± 0.03^{a}	9.57 ± 0.04^{a}	11.20 ± 0.06^{a}	2.39 ± 0.03^{a}	71.48 ± 0.17^{h}	416.84 ± 1.15^{de}
	60	3.80 ± 0.04^{ef}	1.88 ± 0.02^{b}	9.43 ± 0.05^{b}	11.06 ± 0.08^{ab}	2.33 ± 0.03^{ab}	71.57 ± 0.19^{h}	415.35 ± 1.25^{fg}
	90	4.10±0.05^{cd}	1.80±0.03^{bc}	9.26±0.06^{c}	10.92 ± 0.05^{b}	2.20 ± 0.04^{b}	71.80 ± 0.20^{g}	414.21 ± 1.13^{g}

T = Treatments; S = Storage (days)

dietary fiber in the snacks from the incorporation of Amaranthus leaf powder (ALP), fennel leaf powder (FLP), and sesame seeds (SS). The above results concur with the findings by Thakur (2022) and Sharma (2014).

The inclusion of ALP, FLP, and SS in the rice snack formulations caused an increase in the ash content, as illustrated in Table 2. On day 0, the ash content increased steadily from 0.94% in the control (T_0) to 2.06% in T_7. In 90-day, storage, T_7 possessed the highest ash content (1.80%), while the lowest was found in T_0 (0.63%). Although a slight decrease occurred after storage in all the treatments, a significantly high ash content was obtained in the fortified snacks due to the high mineral content of the amaranth leaves, fennel leaves, and sesame seeds compared to that of rice flour. This result is in agreement with the studies of Choton (2021) and Asadi and Khan (2021) that revealed increases in the ash content in snacks formulated using mineral-rich leafy vegetables and other plants.

Crude protein content in the snack formulations varied significantly between formulations, ranging from 9.76% to 11.34% on day 0 (Table 2). The highest crude protein content occurred in T_7 (11.34%), whereas T_0 recorded the least (9.76%). This trend in crude protein content occurred in a proportional relationship to the increasing concentrations of ALP, FLP, and sesame seeds due to their high contribution of amino acids and proteins in comparison to base rice flour. Similar trends in increasing amounts of crude protein content were noted by Dachana *et al.* (2010) and Nurhanan *et al.* (2021) in moringa-enriched cookies and spinach crackers. Results of the storage study demonstrated

Table 3. Effect of leaf powders (*Amaranthus spp.* and *Foeniculum vulgare*) and sesame seed supplementation on the physical properties and storage stability of rice snacks

Treatments	Storage (days)	Thickness (mm)	Diameter (mm)	Weight (g)	Spread ratio
T_0	0	3.48 ± 0.03^{g}	54.68 ± 0.15^{a}	3.48 ± 0.02^{f}	15.71 ± 0.12^{a}
	30	3.51 ± 0.02^{fg}	54.57 ± 0.12^{ab}	3.46 ± 0.03^{fg}	15.55 ± 0.10^{ab}
	60	3.55 ± 0.03^{ef}	54.45 ± 0.14^{bc}	3.43 ± 0.02^{gh}	15.34 ± 0.12^{bc}
	90	3.59 ± 0.02^{de}	54.32 ± 0.11^{cd}	3.40 ± 0.03^{h}	15.13 ± 0.08^{cd}
T_1	0	3.53 ± 0.02^{fg}	54.59 ± 0.16^{ab}	3.51 ± 0.02^{e}	15.47 ± 0.12^{ab}
	30	3.56 ± 0.04^{ef}	54.48 ± 0.13^{b}	3.49 ± 0.03^{ef}	15.30 ± 0.13^{bc}
	60	3.60 ± 0.02^{de}	54.36 ± 0.15^{c}	3.46 ± 0.02^{fg}	15.10 ± 0.13^{cd}
	90	3.64 ± 0.03^{cd}	54.23 ± 0.12^{d}	3.43 ± 0.03^{gh}	14.90 ± 0.11^{de}
T_2	0	3.59 ± 0.03^{de}	54.53 ± 0.14^{ab}	3.54 ± 0.02^{d}	15.19 ± 0.15^{bc}
	30	3.62 ± 0.03^{cd}	54.42 ± 0.11^{bc}	3.52 ± 0.03^{de}	15.03 ± 0.09^{cd}
	60	3.66 ± 0.03^{c}	54.30 ± 0.13^{cd}	3.49 ± 0.02^{ef}	14.84 ± 0.11^{de}
	90	3.70 ± 0.02^{bc}	54.17 ± 0.15^{de}	3.46 ± 0.02^{fg}	14.64 ± 0.10^{ef}
T3	0	3.63 ± 0.03^{cd}	54.45 ± 0.12^{bc}	3.56 ± 0.04^{cd}	15.00 ± 0.11^{cd}
	30	3.66 ± 0.03^{c}	54.34 ± 0.17^{c}	3.54 ± 0.02^{d}	14.85 ± 0.13^{de}
	60	3.70 ± 0.02^{bc}	54.22 ± 0.13^{d}	3.51 ± 0.03^{e}	14.65 ± 0.10^{ef}
	90	3.74 ± 0.03^{b}	54.09 ± 0.14^{e}	3.48 ± 0.03^{f}	14.46 ± 0.12^{fg}
T4	0	3.69 ± 0.03^{bc}	54.34 ± 0.15^{c}	3.60 ± 0.02^{bc}	14.73 ± 0.12^{ef}
	30	3.72 ± 0.02^{b}	54.23 ± 0.14^{d}	3.58 ± 0.03^{c}	14.58 ± 0.10^{f}
	60	3.76 ± 0.03^{ab}	54.11 ± 0.16^{de}	3.55 ± 0.02^{d}	14.39 ± 0.11^{fg}
	90	3.80 ± 0.02^{a}	53.98 ± 0.12^{ef}	3.52 ± 0.03^{de}	14.21 ± 0.09^{gh}
T5	0	3.75 ± 0.03^{b}	54.27 ± 0.13^{cd}	3.62 ± 0.02^{b}	14.47 ± 0.10^{fg}
	30	3.78 ± 0.02^{ab}	54.16 ± 0.15^{de}	3.60 ± 0.02^{bc}	14.33 ± 0.11^{g}
	60	3.82 ± 0.03^{a}	54.04 ± 0.17^{ef}	3.57 ± 0.03^{c}	14.15 ± 0.11^{gh}
	90	3.86 ± 0.02^{a}	53.91 ± 0.14^{f}	3.54 ± 0.02^{d}	13.97 ± 0.13^{h}
T6	0	3.81 ± 0.03^{ab}	54.19 ± 0.12^{d}	3.64 ± 0.02^{ab}	14.22 ± 0.11^{gh}
	30	3.84 ± 0.02^{a}	54.08 ± 0.14^{e}	3.62 ± 0.03^{b}	14.08 ± 0.10^{h}
	60	3.88 ± 0.03^{a}	53.96 ± 0.13^{ef}	3.59 ± 0.02^{c}	13.91 ± 0.12^{h}
	90	3.92 ± 0.02^{a}	53.83 ± 0.11^{fg}	3.56 ± 0.05^{cd}	13.73 ± 0.12^{i}
T7	0	3.88 ± 0.03^{a}	54.11 ± 0.17^{de}	3.67 ± 0.03^{a}	13.95 ± 0.13^{h}
	30	3.91 ± 0.02^{a}	54.00 ± 0.12^{ef}	3.65 ± 0.02^{a}	13.81 ± 0.11^{hi}
	60	3.95 ± 0.03^{a}	53.88 ± 0.14^{fg}	3.62 ± 0.03^{b}	13.64 ± 0.11^{ij}
	90	3.99 ± 0.02^{a}	53.75 ± 0.13^{g}	3.59 ± 0.02^{c}	13.47 ± 0.14^{j}

that the crude protein content remained stable after 90 days of storage, showing reduced values to 9.24% in T_0 and 10.92% in T_7, representing good nutrient retention and protein stability.

% of crude fat showed a significant increase from 9.27% in T_0 to 9.67% in T_7 at day 0, reflecting the contribution of lipids from the sesame seeds and leaf powder fractions. The outcomes observed agree with results from studies conducted by Yadav *et al*. (2022) and Thakur (2022), which showed a high amount of fat in bakery products with moringa leaf powder and pumpkin seeds. During the storage period, a continuous decrease in crude fat was noted in all samples over 90 days, with an increase to 8.66% in T_0 and 9.26% in T_7 on day 90. These changes can be attributed to autoxidation, hydrolysis of lipids, and the formation of oxidation products. However, T_7 remained the highest level of fats over the 90 days.

The results clearly show a noticeable increase in the amount of crude fiber as the level of supplementation of ALP, FLP, and SS increased (Table 2). On Day 0, crude fiber was recorded to be between 1.58% for T_0 and 2.48% for T_7. The high levels of fiber content in the snack formulations are due to structural polysaccharides in plant cells such as cellulose, hemicellulose, and lignin found in the cell walls of the green leaves and sesame coat. These results are consistent with those by Thakur (2022) where increased levels of fiber were observed in bakery products made with amaranth leaves. At Day 90 of storage, T_7 had higher levels of crude fiber (2.20%) than T_0 (1.39%).

As shown in Table 2, there was an observed reduction in the total available carbohydrate content of the snacks as the

Table 4. Effect of leaf powders (*Amaranthus spp.* and *Foeniculum vulgare*) and sesame seed supplementation on the color coordinates and storage stability of rice snacks

Treatments	Storage (days)	L* value (Lightness)	a* value (Redness/Greenness)	b* value (Yellowness/Blueness)
T_0	0	61.42 ± 0.05^a	2.04 ± 0.06^a	9.05 ± 0.06^a
	30	60.97 ± 0.06^a	2.21 ± 0.03^a	8.96 ± 0.04^a
	60	60.49 ± 0.04^a	2.38 ± 0.06^a	8.74 ± 0.05b
	90	60.17 ± 0.07^a	2.51 ± 0.02^a	8.46 ± 0.07^a
T_1	0	60.94 ± 0.08^b	1.31 ± 0.03^b	8.91 ± 0.04^b
	30	60.31 ± 0.05^b	1.84 ± 0.03^b	8.78 ± 0.05^b
	60	59.96 ± 0.06^b	2.05 ± 0.02a	8.55 ± 0.05^b
	90	59.65 ± 0.05^b	2.18 ± 0.03^b	8.40 ± 0.04^a
T_2	0	60.48 ± 0.06^c	0.69 ± 0.05^d	8.77 ± 0.06^c
	30	60.16 ± 0.06^b	1.47 ± 0.04^c	8.64 ± 0.03^c
	60	59.75 ± 0.06^b	1.59 ± 0.03^d	8.49 ± 0.03^b
	90	59.52 ± 0.09^b	1.70 ± 0.06^d	8.33 ± 0.06^a
T_3	0	60.03 ± 0.05^d	0.24 ± 0.02^e	8.63 ± 0.06^d
	30	59.71 ± 0.06^c	1.15 ± 0.02^c	8.55 ± 0.05^c
	60	59.27 ± 0.04^c	1.21 ± 0.06^e	8.40 ± 0.04^b
	90	58.92 ± 0.06^c	1.36 ± 0.03^e	8.27 ± 0.05^a
T_4	0	59.56 ± 0.06^e	0.55 ± 0.03^d	8.49 ± 0.07^e
	30	59.23 ± 0.07^d	0.67 ± 0.06^d	8.37 ± 0.07^d
	60	58.91 ± 0.06^d	0.77 ± 0.06^f	8.18 ± 0.03^c
	90	58.63 ± 0.05^c	0.90 ± 0.02^f	8.17 ± 0.04^a
T_5	0	59.08 ± 0.06^f	0.99 ± 0.03^c	8.35 ± 0.06^f
	30	58.76 ± 0.05^e	1.06 ± 0.03^e	8.28 ± 0.05^d
	60	58.45 ± 0.05^e	1.19 ± 0.05^e	8.14 ± 0.03^c
	90	58.17 ± 0.08^d	1.31 ± 0.05^e	8.05 ± 0.04^a
T_6	0	58.64 ± 0.04^g	1.20 ± 0.05^b	8.20 ± 0.06^g
	30	58.32 ± 0.07^f	1.31 ± 0.05^c	8.11 ± 0.03^e
	60	57.93 ± 0.05^f	1.45 ± 0.02^d	7.89 ± 0.06^d
	90	57.65 ± 0.06^e	1.60 ± 0.03^d	7.65 ± 0.03^b
T_7	0	58.18 ± 0.05^h	1.39 ± 0.03^b	8.06 ± 0.06^h
	30	57.86 ± 0.07^g	1.70 ± 0.06^b	7.94 ± 0.05^f
	60	57.54 ± 0.04^g	1.84 ± 0.05^c	7.76 ± 0.06^e
	90	57.28 ± 0.06^f	1.97 ± 0.05^c	7.57 ± 0.05^b

level of supplementation was increased, decreasing from 74.72% in T_0 to 71.46% in T_7 on day 0. The above reduction in available carbohydrate content is due to the replacement of carbohydrate rich rice flour with protein, fiber, fat and minerals rich food sources (ALP, FLP, and SS). This trend is like that recorded by Ikuomola *et al*. (2017) and Martinez-Saez *et al*. (2017) on the reduction in available carbohydrates in fiber fortified composite bakery products. On day 90, the calculated carbohydrate values increased proportionally to some extent (75.57% in T_0 and 71.80% in T_7). Similarly, there was a moderate reduction in the calculated energy content with increasing levels of supplementation. Energy values decreased from 421.86 kcal/100g in T_0 to 418.16 kcal/100g in T_7 on day 0 and then decreased further to 417.44 kcal/100g in T_0 and 414.21 kcal/100g in T_7 on day 90. The low caloric value of snacks is consistent with their high dietary fiber and low carbohydrate content.

3.2 Physical properties

Significant changes ($p < 0.05$) in the dimensions of the rice snacks were observed across different formulation treatments and throughout the storage duration (Table 3). The progressive increment in the proportion of the use of ALP, FLP, and SS from T_0 to T_7 was associated with the increase in thickness and unit weight, accompanied by a decrease in diameter and spread ratio. At day 0, thickness for snacks increased from 3.48 mm for T_0 to 3.88 mm for T_7, while diameter for snacks was reduced from 54.68 mm for T_0 to 54.11 mm for T_7. Such dimensions are mainly caused by the high dietary fiber content of leaf powder and sesame seeds and the ability to retain moisture, which enhanced the viscosity of the dough, making it impossible

Table 5. Effect of leaf powders (*Amaranthus spp.* and *Foeniculum vulgare*) and sesame seed supplementation on the sensory attributes and storage stability of rice snacks

Treatments	Storage (days)	Appearance	Aroma	Taste	Overall acceptability
T_0	0	7.82 ± 0.05^b	7.76± 0.08^c	7.80± 0.07^c	7.80 ± 0.06^b
	30	7.70 ± 0.05^b	7.65± 0.05^c	7.68± 0.04^c	7.66 ± 0.07^c
	60	7.58 ± 0.06^b	7.52± 0.07^c	7.55± 0.04^c	7.54 ± 0.08^c
	90	7.46 ± 0.07^b	7.40±0.05^b	7.42± 0.04^c	7.42 ± 0.05^b
T_1	0	7.94 ± 0.05^b	7.84±0.06^b	7.91±0.05a	7.88 ± 0.03^b
	30	7.81 ± 0.06^b	7.73±0.05^b	7.79±0.05^b	7.75 ± 0.05^b
	60	7.69 ± 0.06^b	7.61±0.07^b	7.66±0.05^b	7.63 ± 0.06^b
	90	7.53 ± 0.06^b	7.47±0.04^b	7.51±0.06^b	7.50 ± 0.05^b
T_2	0	7.88 ± 0.04^b	7.90±0.08^b	7.95±0.08^b	7.91 ± 0.07^b
	30	7.76 ± 0.05^b	7.78±0.04^b	7.83±0.06^b	7.78 ± 0.06^b
	60	7.63 ± 0.04^b	7.64±0.06^b	7.70±0.04^b	7.64 ± 0.08^b
	90	7.49 ± 0.05^b	7.50±0.07^b	7.56±0.04^b	7.49 ± 0.06^b
T_3	0	7.91 ± 0.06^b	7.87±0.05^b	7.88±0.08^b	7.83 ± 0.07^b
	30	7.80 ± 0.08^b	7.76±0.07^b	7.77±0.06^b	7.81 ± 0.08^b
	60	7.66 ± 0.04^b	7.62±0.05^b	7.63±0.04^b	7.67 ± 0.05^b
	90	7.51 ± 0.06^b	7.48±0.05^b	7.49±0.07^b	7.51 ± 0.05^b
T_4	0	8.20 ± 0.05^a	8.14±0.06^a	8.22±0.05^a	8.18 ± 0.07^a
	30	8.06 ± 0.04^a	8.00±0.08^a	8.08±0.07^a	8.04 ± 0.05^a
	60	7.91 ± 0.04^a	7.86±0.07^a	7.94±0.07^a	7.92 ± 0.07^a
	90	7.73 ± 0.07^a	7.70±0.04^a	7.75± 0.05^a	7.71 ± 0.04^a
T_5	0	7.98 ± 0.07^b	7.95±0.06^b	7.99±0.05^b	7.96 ± 0.04^b
	30	7.84 ± 0.05^b	7.82±0.05^b	7.85±0.07^b	7.82 ± 0.07^b
	60	7.68 ± 0.08^b	7.67±0.06^b	7.70±0.04^b	7.62 ± 0.07^b
	90	7.54 ± 0.07^b	7.53±0.06^b	7.55±0.07^b	7.53 ± 0.06^b
T_6	0	7.89 ± 0.06^b	7.86±0.06^b	7.91±0.04^b	7.88 ± 0.04^b
	30	7.76 ± 0.04^b	7.74±0.07^b	7.78±0.05^b	7.75 ± 0.06^b
	60	7.62 ±0.08^b	7.60±0.05^b	7.64±0.06^b	7.61 ± 0.07^b
	90	7.48 ± 0.05^b	7.46±0.04^b	7.49±0.05^b	7.46 ± 0.05^b
T_7	0	7.70 ± 0.08^c	7.72±0.07^c	7.66±0.07^d	7.68 ± 0.07^c
	30	7.62 ± 0.07^c	7.59±0.05^c	7.54±0.08^d	7.66 ± 0.06^c
	60	7.49 ± 0.07^c	7.46±0.08^c	7.41±0.05^d	7.50 ± 0.04^c
	90	7.36 ± 0.05^c	7.33±0.06^c	7.28±0.07^d	7.37 ± 0.07^b

for the dough to expand laterally during the baking process. Snack thickness showed an increasing trend through 90 days of storage for all the treatments, reaching 3.59 mm for T_0 and 3.99 mm for T_7, while diameter had been slightly reduced to 54.32 mm for T_0 and 53.75 mm for T_7, showing that the compact structure provided by ALP and FLP was retained during the storage period. Such results agree with those observed by Korese *et al*. (2021) and Hussien (2016) in functional baked products with alternative flour.

Spread ratio showed a significant inverse relationship with the level of ALP, FLP, and SS fortification, declining from 15.71 in T_0 to 13.95 in T_7 at day 0 (Table 3). The reduced spread ratio in the composite snacks is closely related to the quick rate of water absorption by plant fibers and proteins, which makes the spread of dough during the process difficult. Over 90 days of storage, the spread ratio declined further to 15.13 in T_0 and 13.47 in T_7. Reductions in spread ratios in similar amounts have been observed in baked foods supplemented with moringa leaf powder and plant composite flour mixes (Chopra *et al*., 2018). Individual snack weight was found to be increasing steadily with an increase in the concentration of leaf powder and sesame seeds, from 3.48 g in T_0 to 3.67 g in T_7 on day 0. It was made possible because of the high bulk density and water retention ability of the high fiber-containing foods. During storage, there were some reductions in weight due to mass losses (reducing to 3.40 g in T_0 and 3.59 g in T_7 on day 90); however, the fortified snacks were always having higher weights than the control, indicating the presence of the functional ingredients (Adeola & Ohizua, 2018; Yadav *et al*., 2022).

3.3 Color characteristics

The significant difference ($p < 0.05$) between the two samples in respect of lightness (L*), redness (a*), and yellowness (b*) showed that the maximum lightness (L*), redness (a*), and yellowness (b*) values appeared in control sample (T_0) while minimum values in terms of these parameters were recorded in the highest supplemented formulation (T_7) on day 0 (Table 4). Lightness (L*) reduced from 61.42 in T_0 to 58.18 in T_7, redness (a*) reduced from 2.04 to 1.39, and yellowness (b*) reduced from 9.05 to 8.06. The gradual reduction in lightness (L*), redness (a*), and yellowness (b*) can be justified by the replacement of light-colored rice flour with green leaf powders (ALP and FLP) which contain various pigments and phytochemicals like natural chlorophyll pigments, polyphenols, as finding is in line with Galla *et al*. (2017) and Nurhanan *et al*. (2021).

The lightness (L*) of all formulations was observed to drop across the 90-day storage period to 60.17 in T_0 and 57.28 in T_7, while the yellowness (b*) reduced to 8.46 in T_0 and 7.57 in T_7. These observations could be explained by the degradation of the pigments and oxidative non-enzymatic browning reaction in the matrix of the cereal leaves (Li *et al*., 2017). a* of the snacks increased across the storage period in all formulations from 2.04 to 2.51 in T_0 and from 1.39 to 1.97 in T_7 after 90 days. This increment of a* was because of degradation of chlorophyll pigments and formation of brown melanoidin compounds through Maillard reactions and lipids-protein oxidations reactions (Shen *et al*., 2018; Choton, 2021). However, the snacks with added nutrients remained relatively darker with greenish olive color compared to the control, indicating that the influence of color of ALP and FLP was constant during storage periods (Paciulli *et al*., 2020).

3.4 Sensory acceptability

The sensory properties of the rice snacks fortified with ALP, FLP, and SS for 90 days of ambient storage are shown in Table 5. In the initial assessment of appearance (day 0), the ratings varied between 7.70 and 8.20. The highest acceptability rating was obtained for formulation T4 (8.20 ± 0.05) and was significantly ($p < 0.05$) higher than other formulations, including the control sample (T_0, 7.82 ± 0.05), whereas the highest amount of fortification resulted in the lowest rating (T_7, 7.70 ± 0.08). High appearance rating of formulation T_4 revealed that addition of moderate amounts of ALP and FLP contributed to the appearance of green color; on the contrary, the excessive amount of powders led to dark green color. These tendencies have been confirmed in earlier studies by Galla *et al*. (2017) and Nurhanan *et al*. (2021). Appearance ratings steadily decreased during 90 days of storage, decreasing to 7.73 ± 0.07 for T_4, 7.46 ± 0.07 for T_0, and 7.36 ± 0.05 for T_7, owing mainly to non-enzymatic browning, surface moisture equilibrium, and pigment oxidation. The aroma acceptability ratings varied between 7.72 and 8.14 on day 0 (Table 5). The highest aroma score (8.14 ± 0.06, $p < 0.05$) was measured for treatment T_4 compared with the rest treatments, including the control (T_0, 7.76 ± 0.08) and T_7 (7.72 ± 0.07). This high score for T_4 treatment revealed that there is a harmonious, nutty-herbal aroma provided by FLP and sesame seeds, which was pleasant to complement cereals. On the contrary, treatment T_7 has a strong grassy, vegetable-like off-odor, which can be explained by an excessive amount of leaf powder added. Over the course of 90 days of storage, aroma scores were reduced to 7.70 ± 0.04 for T_4, 7.40 ± 0.05 for T_0, and 7.33 ± 0.06 for T_7, showing the gradual volatilization of low molecular weight aroma compounds and minor lipid oxidation of unsaturated fatty acids from seeds and leaf lipids (Horgue *et al*., 2022).

The results of significance ($p < 0.05$) were seen in taste acceptability on day 0 at 7.66-8.22 (Table 5). T_4 showed the best taste acceptability (8.22 ± 0.05), which was superior ($p < 0.05$) to treatment T_5 (7.99 ± 0.05), T_2 (7.95 ± 0.08), the control (T_0; 7.80 ± 0.07), and T_7 (7.66 ± 0.07). This shows that an intermediate level of incorporation of ALP, FLP, and SS achieved an optimal combination of herbal-savory taste and mildly rice taste. Conversely, higher supplementation level (T_7) caused bitterness and astringency, due to polyphenols, tannins, and saponins. The above results agree with results found by Kaur *et al*. (2021) and Fjaeldstad and Fernandes (2020), who found that taste acceptability would be negatively affected by exceeding threshold levels of botanicals. By day 90, taste acceptability had dropped to 7.75 ± 0.05 for T_4 and 7.28 ± 0.07 for T_7.

The overall acceptability was consistent with the individual sensory attributes with the initial values ranging between 7.68 and 8.18 on day 0 (Table 5). The treatment T_4 had the highest value (8.18 ± 0.07) which was statistically higher (p

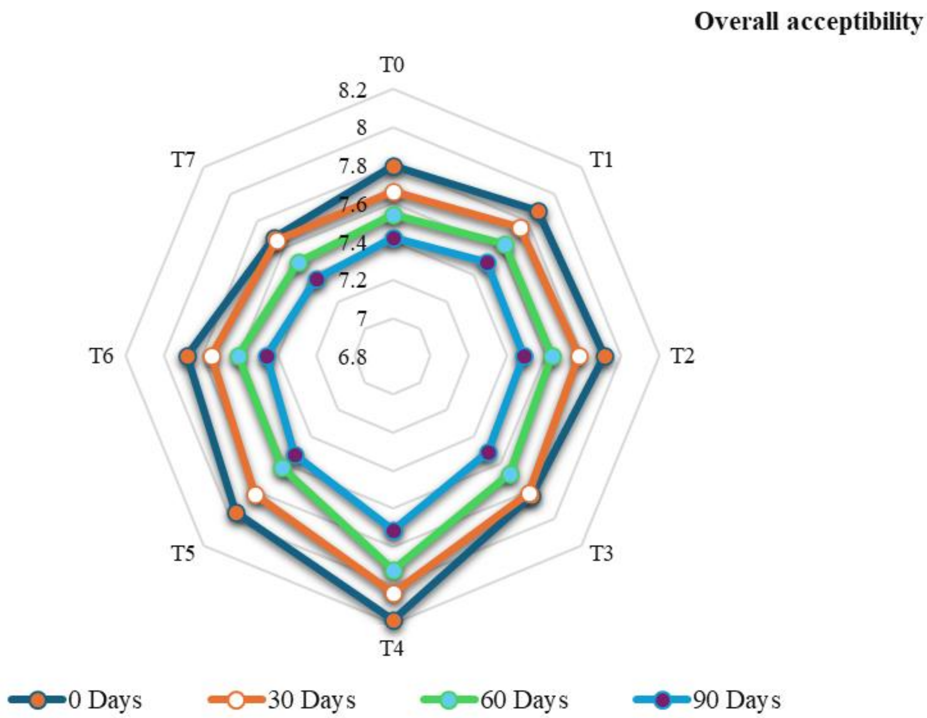

Figure 1. Overall acceptability of rice snacks enriched with *Amaranthus* leaf powder fennel leaf powder and

< 0.05) compared to the control treatment (T_0, 7.80 ± 0.06) and all other treatments that included T_5 (7.96 ± 0.04), T_2 (7.91 ± 0.07) and T_7 (7.68 ± 0.07). This finding suggests that the proper utilization of ALP, FLP and sesame seeds significantly increased the panelist acceptability compared to the control sample without affecting product acceptability, just like what was observed by Aljobair (2022) and Galla *et al*. (2017). During the 90-day storage period, the overall acceptability of all treatments decreased. However, treatment T4 still possessed significantly higher value (7.71 ± 0.04, $p < 0.05$) compared to all other treatments (7.37 ± 0.07 to 7.53 ± 0.06).

Conclusion

In this study, the influence of leaf powder enrichment (*Amaranthus spp.* and *Foeniculum vulgare*) and sesame seed enrichment on the nutritional quality, physicochemical characteristics, color, and sensory qualities of composite rice snacks during 90-day storage period has been evaluated. The addition of ALP and FLP increased the nutritional quality of composite snacks significantly by gradually improving crude protein content (11.34%), crude fiber content (2.48%), crude fat, and ash content in comparison to unenriched snack (T_0), where maximal nutrient levels were reached in 7% enrichment level (T_7). Enrichment also affected physicochemical parameters by increasing unit thickness and weight but reducing diameter and spread ratio of the snacks due to higher water binding capacity of the dietary fiber matrix. Sensory evaluation showed that even though 7% enrichment level had low scores because of the high dark color and herbal flavor, the 4% enrichment level (T_4) had the best scores regarding appearance, aroma, taste, and overall acceptance (8.18 ± 0.07 on day 0 and 7.71 ± 0.04 on day 90). Importantly, all formulations were physically and sensorily stable over the period of 90 days of ambient storage. Leaf powder is indeed a promising functional ingredient that can improve the nutrient content of cereal snacks, and the formulation of 4% composite enrichment is the ideal formulation.

Author Contributions

Faisal Fayyaz: Conceptualization, methodology, formal analysis, investigation, writing – original draft, Sharafat Ali: Supervision, project administration, validation, Aneeza Fatima: Conceptualization, validation, writing – review & editing, Hafiza Ammara Shabbir: Investigation, methodology, validation, Mamoona Arshad: Formal analysis, software, writing – review & editing, Qurat Ulain:

Validation, material acquisition, investigation, Iraj Fatima Formal analysis, visualization, writing – review & editing,

Conflict of Interest

The authors declare that they have no known competing financial or personal interests

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