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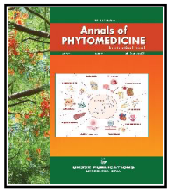

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A comprehensive analysis of sensory excellence, nutritional proficiency, and shelf life in germinated quinoa chikki prepared from superior varieties and optimal cooking techniques

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Abstract

The present study aimed to evaluate the sensory excellence and nutritional proficiency of germinated quinoa (*Chenopodium quinoa* Willd.) Chikki, identifying the best quinoa variety and cooking method. Eighteen treatments were tested using three quinoa varieties (EC 507741, EC 507743, EC 507744) and three cooking methods (salt, dry, microwave roasting) using ingredients in different ratios. The optimal combination, 60% jaggery and 40% dry-roasted germinated quinoa of the EC507743 variety was most accepted by a semi-trained panel using a 9-point Hedonic scale. Dry roasting produced the best appearance, texture, and taste results, surpassing salt and microwave roasting. The selected Chikki was nutritionally rich, containing 9.5% crude protein, 9.0% total dietary fiber, and essential minerals (calcium: 73.6 mg/100 g, potassium: 225.2 mg/100 g, phosphorus: 376.3 mg/100 g), along with 6.5% lysine. Stored in HDPE bags at room temperature for two months, the free fatty acid value remained stable for the first 30 days, with a slight increase in peroxide content from 0.011 meq/kg at 30 days to 0.034 meq/kg at 60 days. The study concluded that the Chikki made with 60% jaggery and 40% dry-roasted germinated quinoa (EC507743) was highly nutritious with the best sensory parameters. Overall, the findings of this research contribute to the selection of an appropriate quinoa variety and cooking method for the production of Chikki that could be used for supplementation to enhance the overall nutritional status of celiac children.

1. Introduction

India boasts a rich culinary tradition with a diverse array of confectionery items celebrated for their unique taste and health benefits. As health consciousness grows, there is a greater emphasis on the nutritional content of food. Among traditional sweets, Chikki is particularly popular across all age groups. It provides essential nutrients while satisfying taste buds, making it a wholesome snack choice (Abhirami and Karpagapandi, 2018). Chikki is made by mixing roasted ground nuts with either sugar or jaggery. Jaggery, a traditional sweetener, is rich in minerals such as iron, calcium, magnesium, and phosphorus. The rising global demand for gluten-free products has led to the development of various quinoa-based foods, including breads, cookies, pasta, and breakfast cereals (Graf *et al.,* 2015).

Quinoa is now commonly incorporated into traditional snacks for its health benefits, due to its high protein content and well-balanced amino acid profile (Iuliano *et al.,* 2019). Sprouting further boosts grain's nutritional value and nutrient availability while decreasing anti-nutrient content, making them abundant in anti-inflammatory, anticarcinogenic and antidiabetic compounds. Rich in beta-glucan, isoflavones, flavonoids, saponins and GABA, these grains can be used in various proportions in bakery products such as bread, cookies and cakes. Sprouted grains provide numerous health benefits, including being low GI, healthy, organic and better tasting (Pathak and Singh, 2022). The present study focused on evaluating the sensory properties as well as self-life of germinated quinoa Chikki and identifying the best quinoa variety and cooking method for its preparation. The gluten-free pseudocereals, *i.e.,* amaranth, quinoa and buckwheat have excellent nutrient profiles, making them ideal for human consumption. Unlike common grains, their proteins are primarily globulins and albumins, with little to no prolamins, the toxic proteins found in celiac disease. This makes them suitable for individuals with gluten intolerance (Verma *et al.,* 2020).

Nutritional variations in quinoa per 100 g of the edible portion reveal protein content ranging from 9.1 to 15.7 g, total fat from 4.0 to 7.6 g and dietary fiber from 8.8 to 14.1 g, depending on the variety (Nowak *et al.,* 2015). Quinoa is also rich in essential micronutrients such as β-carotene (8.0 µg), thiamine (0.36 mg), riboflavin (0.32 mg), niacin (1.52 mg), pantothenic acid (0.77 mg), pyridoxine (49 mg) and total folic acid (184 µg) per 100 g. Pyridoxine and folic acid meet the daily needs of both children and adults, while riboflavin fulfills 80% of children's and 40% of adult's daily requirements. Quinoa's B-complex vitamins, including riboflavin, pyridoxine and folic acid, exceed those

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found in cereals like wheat, barley, oats, rice, rye and corn (Hernandez-Ledesma, 2019).

Beyond its macro-micronutrient profiles, quinoa contains secondary metabolites such as quercetin, triterpenoids, phenolics, betalains and glycine betaine that contribute to health (Navruz-Varli and Sanlier, 2016). Quercetin, widely utilized as a nutraceutical and phytochemical medication for various diseases, is known for its strong antioxidant activity, and shown nephroprotective effects against drugs and various toxic agents (Kilaru *et al.,* 2022). Saponins, a major antinutritional factor in quinoa, can impart a bitter taste, but various processing methods can reduce their content and enhance quinoa's edibility, nutritional value, and sensory properties (Angeli *et al.,* 2020).

Roasting, a common food processing method involving dry heating with hot air, improves digestibility, palatability and nutrient bioavailability by altering the food matrix. It also enhances color, aroma, flavor compounds and antioxidants while cooking, gelatinizing or expanding the food (Bhattacharya, 2014; Sruthi *et al.,* 2021).

2. Materials and Methods

2.1 Procurement of sample

The samples of three newly developed quinoa (*C. quinoa*) genotypes, *i.e.,* EC 507741, EC507743 and EC507744 were obtained from the Department of Plant Breeding and Genetics, Punjab Agricultural University, Ludhiana, and other ingredients (jaggery and ghee) were procured from the local market.

2.2 Processing of quinoa seeds

Quinoa seeds were cleaned with running water to remove saponins and then soaked for 7-8 h at room temperature for hydration. After soaking, the seeds were drained and germinated for 12 to 24 h until sprouts appeared. The germinated seeds were dried in an oven at 40-50°C for 6-8 h. Once dried, the seeds were stored in an airtight container in a cool, dry place to prevent rehydration.

2.3 Roasting of germinated quinoa seeds

To prepare the germinated quinoa seeds for roasting, tempering was first performed. Each 100 g sample of germinated quinoa was mixed with 10 ml of water and left to temper for 45 min to ensure even moisture distribution. After tempering, the quinoa was roasted using three different methods.

2.3.1 Salt roasting

This method involved preheating salt in a pan to 200°C. Once the salt reached the desired temperature, the tempered quinoa seeds were added and roasted for 30-40 sec.

2.3.2 Dry roasting

This method involved preheating a pan to 200°C, and then dry roasting the tempered quinoa for 45 sec, with continuous stirring to avoid burning and to ensure even heat distribution.

2.3.3 Microwave roasting

This method involved placing the tempered quinoa in a microwave-safe dish and microwaving it for 120 sec. During this process, the quinoa was checked and stirred at intervals to ensure even roasting.

2.4 Preparation and standardization of gluten-free Chikki

The Punjab Agricultural University's, Food and Nutrition Department and Food Science and Technology Department in Ludhiana developed gluten-free Chikki using standardized recipes. The procedure for the preparation of standardized gluten-free Chikki is given in Figure 1. The experiment comprised eighteen treatments, with three different cooking methods (salt, dry, microwave roasting), as well as three different germinated quinoa varieties (EC 507741, EC507743, EC507744), each with two ratios (50:50, 60:40) of jaggery and quinoa seeds of gluten-free Chikki (Table 1).

Germinated quinoa gluten-free Chikki

Roasted germinated quinoa seed ratio
↓
prepared of jaggery syrup
↓
Added jaggery along with water and ghee (to stabilize the crystallization)
↓
Stir until the consistency comes to the hard crack stage (temperature 148-153°C)
↓
As the temperature reaches 148°C, add the roasted quinoa seeds and mix thoroughly
↓
Poured mixture into a greased tray
↓
Cut into square into pieces
↓
Allowed to cool for 35-40 min
↓
Packed into HDPE bags

Figure 1: Preparation of germinated quinoa gluten-free Chikki.

Table 1: Standardized recipe of germinated quinoa gluten-free Chikki

Genotype	Cooking method	Chikki	Ingredient (g)			
			Jaggery	Quinoa	Ghee	Water (ml)
EC 507741	Dry roasting	R_1	60	40	10	5
		R_2	50	50	10	5
EC 507743		R_3	60	40	10	5
		R_4	50	50	10	5
EC 507744		R_5	60	40	10	5
		R_6	50	50	10	5
EC 507741	Salt roasting	S_1	60	40	10	5
		S_2	50	50	10	5
EC 507743		S_3	60	40	10	5
		S_4	50	50	10	5
EC 507744		S_5	60	40	10	5
		S_6	50	50	10	5
EC 507741	Microwave roasting	M_1	60	40	10	5
		M_2	50	50	10	5
EC 507743		M_3	60	40	10	5
		M_4	50	50	10	5
EC 507744		M_5	60	40	10	5
		M_6	50	50	10	5

Values are in percentage.

2.5 Sensory evaluation

The developed Chikki were organoleptically evaluated for color, appearance, flavor, texture, taste and overall acceptability by a semi-trained panel of 10 judges from the Department of Food and Nutrition using a 9-point Hedonic rating scale (Wichchukit and O' Mahony, 2015). Experimental samples of gluten-free Chikki were served to the judges. The samples were appropriately coded to avoid any bias in judgment.

2.6 Nutritional analysis of highly acceptable Sample

2.6.1 Proximate composition

The proximate composition includes moisture, total ash, crude protein, crude fat, crude fiber, total carbohydrate, and energy of developed gluten-free Chikki was examined using AOAC (2010) method. The hot-air oven drying method was used to calculate the moisture content. To determine the amount of ash present, the samples were burned in a muffle furnace for 6 h at 550°C. The total protein content was measured using the Kjeldahl method with the KELPLUS nitrogen estimation system. Total fat content was determined using Soxhlet extraction equipment. To calculate total carbohydrates, the sum of all proximate values-moisture content, crude protein, crude fat, crude fiber and total ash was subtracted from 100. The factorial approach was employed to calculate energy content (AOAC, 2010; Biswal *et al.,* 2020; Khan and Das, 2019).

2.6.2 Mineral content

The mineral composition was analyzed by using ICP-MS (Agilent Technologies Model 7800), following digestion with hydrogen peroxide and nitric acid in a microwave system (Anton Paar, Multiwave GO). Digestates were diluted, analyzed against a calibration curve (six standards and a blank), and quantified for mineral content (Ahmad *et al.*, 2021).

2.6.3 Estimation of amino acids

The amino acids were analyzed using HCl digestion, OPA derivatization, and Liquid Chromatography (Agilent 1260 Infinity with DAD). Tryptophan was separately analyzed by basic digestion and HPLC with fluorescence detection (Agilent 1260 Infinity), and results were reported as g amino acid per 100 g protein (Jaudzems and Fuerer, 2022).

2.6.4 Fatty acid composition

The fat extraction was performed using the Soxhlet extraction method. A 0.1 g sample of the extracted fat underwent methylation with boron trifluoride (BF3) to produce fatty acid methyl esters (FAMEs). The FAMEs were analyzed on GC (Agilent 7890) using a CP-Sil 88 column (100 m x 0.25 mm, df = 0.2 µm) with an oven program set to start at 80°C, ramping at 4°C/min to 220°C (5 min hold), then at 4°C/min to 240°C (10 min hold). The carrier gas was helium with a constant flow rate of 1.0 ml/min. Injection was performed with a split flow rate of 20 ml/min, at a temperature of 250°C and an injection volume of 2.0 µl. Fatty acids were detected using a flame ionization detector (FID) at 270°C. A 37-component FAME mix standard was utilized for calibration and identification (AOAC, 2001).

2.6.5 Estimation of dietary fibre

Water-soluble components were extracted using a Soxhlet apparatus to determine the dietary fiber content in the sample. The insoluble residue was filtered, cleaned and dried to obtain insoluble dietary fiber (IDF). The filtrate was treated with acid and ethanol to precipitate polysaccharides, allowing the collection of soluble dietary fiber (SDF) through filtration, cleaning and drying. Both fiber fractions underwent co-precipitated protein and ash modifications (AOAC, 2010).

2.6.6 Total antioxidant activity DPPH method

The antioxidant capacity was measured using the DPPH (2,2-diphenyl-1-picrylhydrazyl) assay, which is a standard method for assessing free radical scavenging activity. This method creates a violet-colored solution in methanol. The analysis was conducted using a spectrophotometric approach (Dehshahri *et al.,* 2012).

2.6.7 Flavonoids

The estimation of flavonoids is performed using the aluminum chloride colorimetric assay, where the sample is reacted with aluminum chloride and the absorbance is measured at 415 nm. Flavonoid content is then quantified by comparison with a standard calibration curve, typically expressed as quercetin equivalents (Mathur and Vijayvargiya, 2017).

2.6.8 Total phenols

The Folin-Ciocalteu method was employed for the estimation of total phenol content. The sample was extracted with 80% ethanol and after evaporation, the supernatant was used for estimation. Absorbance was measured at 650 nanometers, and the results were expressed as mg of gallic acid equivalent per g of the sample (Mathur and Vijayvargiya, 2017).

2.6.9 Saponins

The saponin content was estimated by extracting the ground sample with 20% aqueous ethanol. The extraction was carried out at 55°C for 4 h, followed by filtration and re-extraction. The combined extracts were concentrated, purified using diethyl ether and n-butanol, washed with sodium chloride and then dried to determine the saponin content (Obdoni and Ochuko, 2001).

2.7 Storage stability

The highly acceptable sample of gluten-free Chikki was packed in 100 g portions in high-density polyethylene (HDPE) bags and were stored at room temperature for 60 days. Average climate data was recorded as 28°C temperature and 35% humidity in the months of March and April 2023(https://weather-and-climate.com/ludhiana-punjab). The stored samples were analyzed every two weeks to evaluate sensory attributes such as appearance, color, texture, flavor, taste and overall acceptability.

2.8 Peroxide value and free fatty acid

Total lipids were extracted using the Bligh and Dyer method. The lipids were extracted and analyzed for free fatty acid and peroxide values in a mixture of chloroform and methanol (2:1 v/v).

2.8.1 Free fatty acid

The acid value of the sample was determined according to the method described by Raghuramulu *et al.* (2003). The percentage of free fatty acids (FFAs) was calculated using oleic acid as the reference factor. The acid value was calculated using the formula:

Acid value = (Titre value × 0.00561 × 1000)/Weight of sample

The percentage of free fatty acid was determined using the equation:

Peroxide value = Acid value /1.99

2.8.2 Peroxide value

The peroxide value was determined by the liberation of iodine from an acid solution of potassium iodide, following the method described by Raghuramulu *et al.*(2003). The peroxide value of the oil was calculated as follows:

Peroxide value of oil (meq/kg of sample) = (Titre – blank) × Normality × 1000/Weight of sample

2.9 Statistical analysis

The Kruskal-Wallis and Mann-Whitney tests were used to determine the significant difference between tested parameters using SPSS software (IBM SPSS Statistics version 27). Data was reported as mean ± SD for at least three triplicates for each sample. *p*-value at 0.05 indicate a substantial difference.

3. Results

3.1 Sensory evaluation of germinated quinoa-based gluten-free Chikki

The eighteen samples of gluten-free Chikki were supplemented with germinated quinoa roasted seeds at two different levels: 40% and 50%. These samples were prepared using three different roasting methods (salt, dry, and microwave) combined with three genotypes of germinated quinoa (EC507741, EC507743 and EC507744). Jaggery was used in varying amounts (50% and 60%) to create the different gluten-free Chikki samples. Table 2 and Figure 2 display the average results of a panel of 10 semi-trained judge's organoleptic assessment of gluten-free Chikki using a 9-point Hedonic scale.

The results indicated that the R3 sample, composed of 40% dry roasted germinated quinoa seeds of the EC507743 genotype and 60% jaggery, achieved the highest overall acceptability score of 8.15 ("like very much"), followed by salt roasting (sample S1 overall acceptability score 8.00) and microwave roasting (sample M2 overall acceptability score of 7.54). The R3 sample not only excelled in overall acceptability but also received the highest scores in specific sensory attributes, including color, texture, flavor, and taste, and was selected for further nutritional analysis.

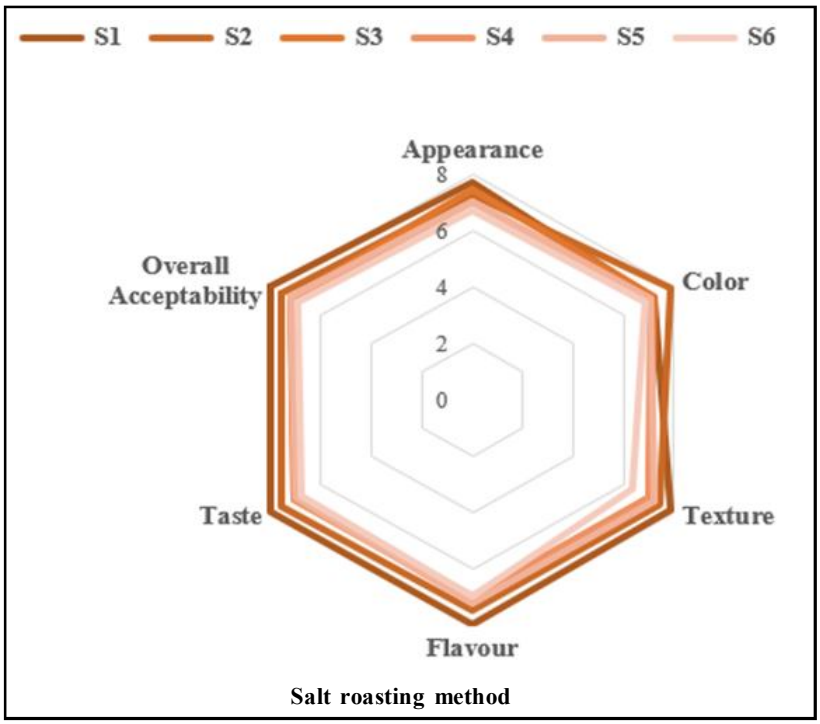
3.2 Chemical composition of most acceptable gluten-free Chikki

The most acceptable gluten-free Chikki (R3) was prepared using standardized procedures. The chemical constituents, including proximate composition, mineral content, amino acids, dietary fiber, fatty acid composition, antioxidant and bioactive compounds, were assessed and given in Table 3.

Table 2: Organoleptic scores of glutens-free Chikki developed using germinated quinoa

Genotype	Cooking method	Level	Appearance	Color	Texture	Flavor	Taste	Overall acceptability
EC507741	**Salt roasting**	S_1	$7.71^{a} \pm 0.45$	$7.19^{b} \pm 0.25$	$7.86^{a} \pm 0.64$	$8.00^{a} \pm 0.1$	$8.00^{a} \pm 0.10$	$8.00^{a} \pm 0.53$
		S_2	$7.25^{a} \pm 0.45$	$7.86^{a} \pm 0.64$	$7.43^{a} \pm 1.18$	$7.49^{a} \pm 0.17$	$7.57^{a} \pm 0.21$	$7.57^{a} \pm 0.23$
EC507743		S_3	$7.43^{a} \pm 0.38$	$7.25^{ab} \pm 0.49$	$7.00^{b} \pm 0.93$	$7.14^{b} \pm 0.12$	$7.06^{b} \pm 0.14$	$7.19^{b} \pm 0.12$
		S_4	$7.00^{b} \pm 0.15$	$7.08^{b} \pm 0.57$	$7.00^{b} \pm 0.43$	$7.00^{b} \pm 0.29$	$7.08^{b} \pm 0.15$	$7.14^{b} \pm 0.29$
EC507744		S_5	$7.03^{a} \pm 0.14$	$7.10^{b} \pm 0.51$	$7.20^{ab} \pm 0.33$	$7.25^{b} \pm 0.18$	$7.00^{b} \pm 0.17$	$7.22^{ab} \pm 0.14$
		S_6	$6.71^{b} \pm .03$	$6.86^{b} \pm 0.83$	$6.32^{c} \pm 0.88$	$7.00^{b} \pm 0.20$	$6.81^{c} \pm 0.16$	$6.92^{c} \pm 0.19$
		$\chi 2$ Value	**9.27***	**10.45***	**16.38****	**8.14***	**11.657****	**13.29****
EC507741	**Dry roasting**	R_1	$7.21^{b} \pm 0.40$	$7.71^{b} \pm 0.43$	$7.16^{b} \pm 0.35$	$7.62^{b} \pm 0.26$	$8.00^{a} \pm 0.53$	$7.86^{ab} \pm 0.33$
		R_2	$7.78^{a} \pm 0.13$	$7.74^{a} \pm 0.03$	$8.00^{a} \pm 0.67$	$7.89^{a} \pm 0.87$	$8.00^{a} \pm 0.94$	$7.87^{a} \pm 0.37$
EC507743		R_3	$7.28^{b} \pm 0.6$	$7.88^{a} \pm 0.60$	$8.03^{a} \pm 0.71$	$8.00^{a} \pm 0.41$	$8.11^{a} \pm 0.16$	$8.15^{a} \pm 0.92$
		R_4	$7.80^{a} \pm 0.9$	$7.17^{b} \pm 0.8$	$7.75^{ab} \pm 0.97$	$7.88^{a} \pm 0.93$	$7.88^{b} \pm 0.93$	$7.39^{b} \pm 0.65$
EC507744		R_5	$7.57^{a} \pm 0.73$	$7.07^{b} \pm 0.03$	$7.71^{b} \pm 0.88$	$7.86^{b} \pm 0.64$	$7.68^{b} \pm 0.54$	$7.79^{b} \pm 0.52$
		R_6	$7.29^{b} \pm 0.88$	$7.29^{b} \pm 0.81$	$7.43^{b} \pm 0.05$	$7.29^{b} \pm 1.03$	$7.21^{b} \pm 0.37$	$7.09^{b} \pm 0.07$
		$\chi 2$ Value	**1.71****	**1.54****	**0.51^{NS}**	**0.01^{NS}**	**2.99***	**2.01****
EC507741	**Microwave roasting**	M_1	$6.57^{b} \pm 0.76$	$6.27^{b} \pm 0.70$	$6.81^{b} \pm 0.25$	$6.06^{c} \pm 0.12$	$6.61^{b} \pm 0.19$	$6.86^{b} \pm 0.25$
		M_2	$7.00^{a} \pm 0.51$	$7.11^{a} \pm 0.42$	$7.23^{a} \pm 0.6$	$7.54^{a} \pm 0.32$	$7.00^{a} \pm 0.31$	$7.25^{a} \pm 0.18$
EC507743		M_3	$7.29^{a} \pm 0.03$	$7.43^{a} \pm 0.9$	$7.14^{a} \pm 0.09$	$7.14^{a} \pm 0.09$	$7.12^{a} \pm 0.51$	$7.50^{a} \pm 0.35$
		M_4	$7.16^{a} \pm 0.33$	$7.10^{a} \pm 0.51$	$7.00^{b} \pm 0.20$	$7.22^{b} \pm 0.20$	$7.03^{a} \pm 0.64$	$7.14^{a} \pm 0.25$
EC507744		M_5	$6.43^{b} \pm 0.68$	$6.31^{b} \pm 0.52$	$6.17^{bc} \pm 0.4$	$6.57^{b} \pm 0.31$	$6.71^{b} \pm 0.29$	$6.92^{b} \pm 1.4$
		M_6	$6.86^{a} \pm 0.34$	$6.16^{b} \pm 0.81$	$6.26^{b} \pm 0.25$	$6.30^{b} \pm 0.27$	$6.28^{b} \pm 0.27$	$6.61^{b} \pm 0.79$
		$\chi 2$ Value	**1.73****	**2.36***	**0.72^{NS}**	**0.9^{NS}**	**8.41***	**5.63^{NS}**

Values are mean ± SD. * Values are significant at 5% level
NS: Non-significant



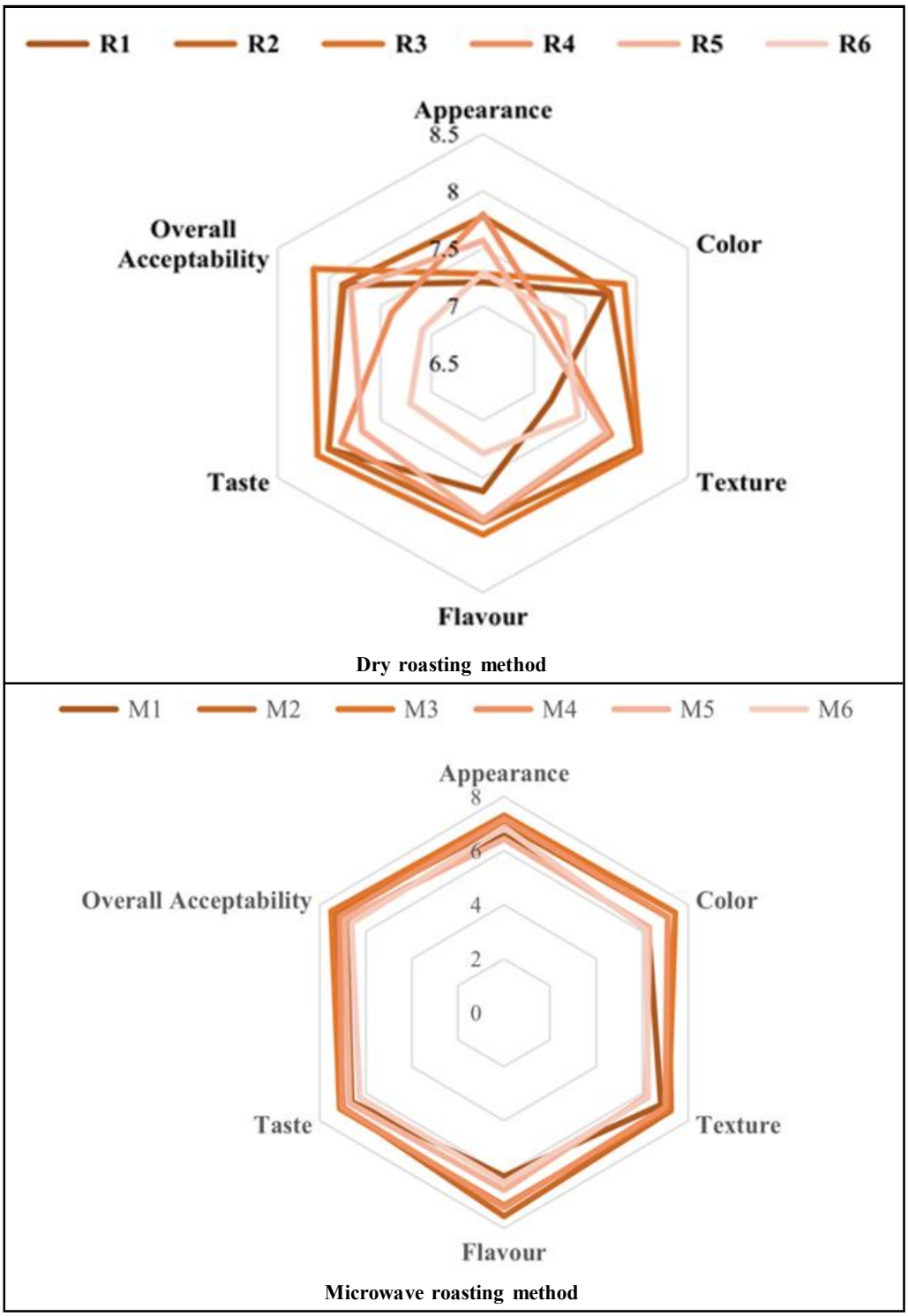


Figure 2: Organoleptic scores of gluten-free Chikki developed using different roasting methods.

The most acceptable gluten-free Chikki (R3) was observed to have 7.5% moisture,1.5% ash, 10.7% crude fat, 9.5% crude protein,7.2% crude fiber and 70.8% carbohydrates, with an energy content of 414 kcal/100 g. The gluten-free Chikki contains 9.0 g/100 g of total dietary fiber, with 8.2 g/100 g being soluble fiber and 0.8 g/100 g being insoluble fiber. The gluten-free Chikki was found to contain 73.6 mg/100 g of calcium and 225.2 mg/100 g of phosphorus. Additionally, it contained 136.5 mg/100 g of magnesium and 376.3 mg/100 g of potassium. The iron and zinc concentrations were reported as 2.2 mg/100 g and 2.0 mg/100 g, in gluten-free Chikki, respectively. The highly acceptable gluten-free Chikki was found to be rich in essential amino acids, and it contained 6.4 g of lysine, 3.6

g of methionine, and 0.3 g of tryptophan per 100 g of protein. The antioxidant activity and total phenol content in gluten-free Chikki were measured at 18.37% and 41.38 GAE/100 g, respectively, while flavonoid content was found to be 6.41 mg QE/100 g. Also showed negligible saponin content in highly acceptable Chikki (R3). Additionally, the gluten-free Chikki contained 1.2% polyunsaturated fatty acids (PUFA), 7.6% saturated fatty acids (SUFA), and 1.9% monounsaturated fatty acids (MUFA). The most acceptable gluten-free Chikki (R3) was found nutritionally rich and served as a healthy gluten-free snack alternative.

Table 3: Nutritional analysis of most acceptable gluten-free Chikki developed using germinated quinoa

	Parameters	Most acceptable gluten-free Chikki
Proximate composition	Moisture (%)	7.5 ± 0.1
	Ash (%)	1.5 ± 0.07
	Crude fat (%)	10.7 ± 0.18
	Crude protein (%)	9.5 ± 0.08
	Crude fiber (%)	7.2 ± 0.26
	Carbohydrates (%)	70.8 ± 0.3
	Energy (kcal/100 g)	417.4 ± 0.19
Mineral content	Magnesium (mg/100 g)	136.5 ± 7.05
	Phosphorous (mg/100 g)	225.2 ± 11.62
	Potassium (mg/100 g)	376.3 ± 19.43
	Calcium (mg/100 g)	73.6 ± 3.8
	Iron (mg/100 g)	2.2 ± 0.12
	Zinc (mg/100 g)	2.0 ± 0.1
Amino acid	Lysine (g/100 g)	6.4 ± 0.26
	Methionine (g/100 g)	3.6 ± 0.09
	Tryptophan (g/100 g)	0.3 ± 0.04
	Cysteine (g/100 g)	0.42 ± 0.16
Fatty acid profile	SUFA (%)	7.6 ± 0.14
	MUFA (%)	1.9 ± 0.03
	PUFA (%)	1.2 ± 0.02
Dietary fiber	Total dietary fibre (%)	9 ± 0.18
	Soluble dietary fibre (%)	8.2 ± 0.16
	Insoluble dietary fibre (%)	0.8 ± 0.02
Antioxidant and bioactive compounds	Antioxidant activity (%)	18.37 ± 1.72
	Phenol (mg gallic acid/g)	41.38± 3.15
	Flavonoids (mg QE/100 g)	6.41 ± 0.6
	Saponin (%)	0 ± 0

Values are mean ± SD.

3.3 Shelf-life evaluation of highly acceptable gluten-free Chikki

The most acceptable gluten-free Chikki (R3) (100 g) was packed in high-density polyethylene bags and stored at room temperature. The stored samples were analyzed at regular intervals every two weeks for up to 60 days. Sensory attributes such as appearance, color, texture, flavor, taste, and overall acceptability of the stored gluten-free Chikki were evaluated and presented in Table 4.

In the most acceptable gluten-free Chikki (R3), the texture remained relatively stable over the 60 days, indicating a consistent texture throughout the storage period. decreasing only slightly from 8.3 on day 0 to 6.0 on day 60. A gradual decline was observed in appearance and color scores, from 8.3 to 6.0, suggesting a loss of pigmentation. Similarly, taste and flavor scores decreased from 8.3 and 8.5 to 6.0 by the end of storage, respectively. Overall acceptability scores declined steadily from 8.0 to 6.0, reflecting a decreasing satisfaction level over a prolonged time.

The peroxide value and free fatty acid (FFA) value are important indicators of the storage quality and freshness of food products. Figure 3 illustrates the peroxide value of the highly acceptable gluten-free Chikki over 60 days. It was observed that the peroxide value

increased from 0.011 meq/kg on day 0 to 0.034 meq/kg by day 60. Additionally, Figure 4 shows that the FFA value remained low and stable, rising slightly from 0.10% on day 0 to 0.20% by day 60, indicating minimal lipid hydrolysis over time. Both values were found to be within acceptable ranges: 0.6 meq/kg for peroxide value and 2.0% for free fatty acids.

Table 4: Effect of storage on the sensory attributes of gluten-free Chikki developed using germinated quinoa

Days	Appearance	Color	Texture	Flavor	Taste	Overall acceptability
0	8.3	8.1	8.3	8.5	8.3	8.0
15	8.0	8.0	7.9	8.2	8.2	7.8
30	8.0	8.0	7.9	7.8	7.8	7.8
45	7.0	7.0	7.0	7.0	7.0	7.0
60	‘6.0	6.0	6.0	6.0	6.0	6.0

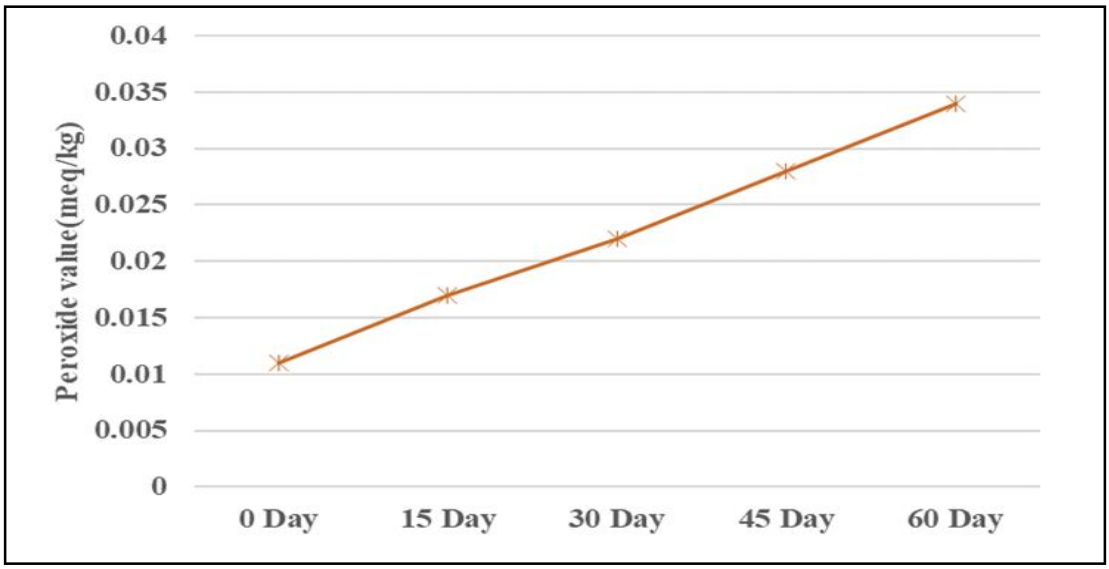


Figure 3: Effect of storage on the peroxide value of gluten-free Chikki developed using germinated quinoa.

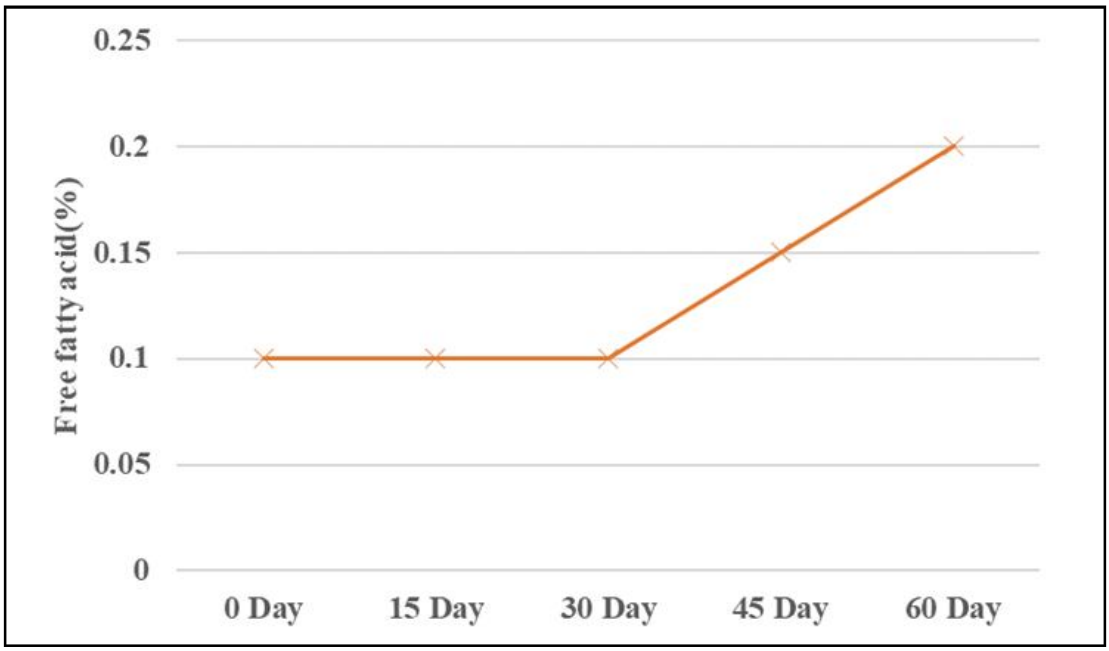


Figure 4: Effect of storage on the free fatty acid of gluten-free Chikki developed using germinated quinoa.

4. Discussion

The study found that dry-roasted Chikki R3 (40% germinated quinoa seeds of EC507743 genotype and 60% jaggery) was the most acceptable among all treatments. This aligns with Kavali *et al.* (2020), who found quinoa optimal for various products with roasting being best for Laddu and Chikki at a 60:40 ratio. Similarly, Sandhya *et al.* (2018) showed no significant sensory differences in cookies made from untreated, roasted, and germinated quinoa flour, confirming quinoa's potential for gluten-free cookie formulations. Sharma and Gujral (2011) found that sand roasting improved barley's antioxidant activity more effectively than microwave cooking. These findings highlight the benefits of incorporating germinated quinoa and varying processing methods to enhance sensory and nutritional qualities in gluten-free products.

The study highlighted the nutritional benefits of dry-roasted germinated quinoa Chikki (R3), showing a robust profile with 7.5% moisture, 10.7% crude fat, 9.5% crude protein, 7.2% crude fiber, and 70.8% carbohydrates. Similar to Johri *et al.* (2023), who reported high protein and fatty acids in Chikki with flaxseed and finger millet, Abhirami and Karpagapandi (2018), who found multigrain Nutri-Chikki nutritionally superior to groundnut Chikki, the R3 sample demonstrated superior nutritional qualities. Chukwuma *et al.* (2016) noted that roasting increased protein, fat, and fiber in maize, aligning with Kavli *et al.* (2020), which found roasted quinoa products had better nutritional quality than fried or boiled ones. The R3 Chikki's high dietary fiber content, with 9 g/100 g total fiber (8.2 g soluble), mirrors the fiber-rich profiles of quinoa and amaranth reported by Lamothe *et al.* (2015).

The calcium, magnesium, and iron deficiencies are common in gluten-free diets. Incorporating quinoa can help address these deficiencies due to its high mineral content (Alvarez *et al.,* 2010). The current study found that gluten-free Chikki is rich in calcium, potassium, phosphorus, and magnesium. Choudhury and Chaudhary (2023) developed five millet biscuit types, with the T5 biscuit (a mix of wheat, pearl millet, foxtail millet, finger millet, and amaranth seed flours) having the highest nutritional value, providing 3.95 mg of iron and 1.44 mg of zinc meeting nearly 1/8th of the daily iron requirement. Roasting, as shown by Chukwuma *et al.* (2016), enhances mineral content in quality protein maize (QPM), increasing micronutrients like iron and zinc compared to boiling. Roasting also improves the nutritional profile of gluten-free products, aligning with the benefits of including quinoa. Furthermore, quinoa provides all nine essential amino acids, including methionine, lysine, and tryptophan. Roasting has been shown to increase these amino acids in maize, emphasizing the advantages of roasting for enhancing nutrient content.

Quinoa is rich in antioxidant phytonutrients with notable nutraceutical benefits (Sandhya *et al.,* 2018). The gluten-free Chikki, with antioxidant activity of 18.37%, total phenol content of 41.38 GAE/100 g, and flavonoids of 6.41 mg QE/100 g, had negligible saponin content due to roasting, which also reduced other anti-nutritional factors. Chukwuma *et al.* (2016) found that roasting reduced phytate by 5.84% and oxalate by 3.13%, while boiling decreased phytate by 9.62% and oxalate by 7.03%, with both methods cutting tannin content by 50%. Similarly, Raj and Singh (2022) showed that heating sorghum flour at 125°C for 30 minutes improved gluten-free bread and cake, producing loaves with higher specific volume (3.08 ml/g) and greater cell density (50.38 cells/cm²), resulting in better textures and consumer preference compared to untreated sorghum flour, which led to thick, low-volume, and poor crumb products.

Schoenlechner *et al.* (2008) noted that amaranth and quinoa have lipid content 2 to 3 times higher than cereals like maize and wheat, with a higher proportion of unsaturated fatty acids. In the current study, the gluten-free Chikki was found to contain 1.2% polyunsaturated fatty acids (PUFA), and 7.6% saturated fatty acid. In the current study, the acceptable gluten-free Chikki (R3) experienced a gradual decline in appearance and color scores, while texture remained stable. Taste and flavor scores decreased, leading to an overall acceptability drop from 8.0 to 6.0. These findings align with Bharti (2019), who observed a slight decrease in acceptability for quinoa and drumstick food mix, and Negi (2021), who reported similar trends in quinoa-based carrot pomace cake. In contrast, Gupta and Singh (2005) found that quality protein maize biscuits remained stable and acceptable for 60 days at ambient temperature.

The Chikki's peroxide value increased over 60 days, indicating ongoing lipid oxidation that could impact taste, smell, and overall quality. Negi (2021) similarly found that quinoa cake taste was affected by oxidation. The FFA value of the Chikki remained stable, rising slightly from 0.10% to 0.20%, suggesting minimal lipid hydrolysis. Mohite and Waghmare (2020) reported similar trends in biscuit texture, with a decrease from 8.6 to 7.1 due to triglyceride breakdown. Comparable trends were observed in studies by Sangwan and Dahiya (2013).

5. Conclusion

The formulation of dry roasted gluten-free Chikki using 40% germinated quinoa seeds from the EC507743 genotype and 60% jaggery achieved the highest overall acceptability score of 8.15. This sample excelled in color, texture, flavor, and taste, making it the most favored among all treatment variations. Nutritionally, the highly acceptable Chikki demonstrated a well-balanced profile: it contains 9.5% crude protein, 10.7% crude fat, 7.2% crude fiber, and 70.8% carbohydrates, providing 414.4 kcal per 100 grams. It is rich in dietary fiber, offering 9 g per 100 g, with 8.2 g of soluble fiber and 0.8 g of insoluble fiber. This Chikki is also a valuable source of essential minerals, including 73.6 mg/100 g of calcium, 225.2 mg/100 g of phosphorus, 136.5 mg/100 g of magnesium, and 376.3 mg/100 g of potassium. Iron and zinc concentrations are 2.2 mg/100 g and 2 mg/100 g, respectively. In terms of essential amino acids, the Chikki is notably rich, providing 6.4 g of lysine, 3.6 g of methionine, and 0.3 g of tryptophan per 100 g of protein. It also exhibits significant antioxidant activity, with an 18.37% antioxidant level, a total phenol content of 41.38 GAE/100 g, and flavonoids measured at 6.41 mg QE/100 g. The saponin content was negligible, which enhances its nutritional value. Over a 60-day storage period, the Chikki's texture remained stable, though there was a slight decline in appearance, color, taste, and flavor scores. The peroxide value increased from 0.011 meq/kg to 0.034 meq/kg, and the free fatty acid (FFA) value rose slightly from 0.10% to 0.20%. Despite these changes, both values remained within acceptable ranges. Overall, this gluten-free Chikki represents a promising snack option for individuals with gluten sensitivity, combining excellent sensory qualities with a strong nutritional profile and acceptable shelf stability.

Conflict of interest

The authors declare no conflicts of interest relevant to this article.

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