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Evaluation of Gluten-Free Flatbread Substituted with Some Cereals and Legumes

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ABSTRACT

There is a growing consumer demand for functional gluten-free foods, as products containing gluten can trigger celiac disease in genetically susceptible individuals. This research aimed to develop a gluten-free flatbread with enhanced nutritional quality and functional properties. The flatbread was prepared using legume flour (lentil or chickpea) in combination with rice and corn flour. Sensory evaluation, chemical composition, and physical properties of various formulations were analyzed. The results showed that gluten-free flatbread made from 100% lentil or 100% chickpea had higher protein content compared to other formulations. The addition of chickpeas and lentils significantly reduced hardness while increasing springiness and resilience. Flatbreads made from 100% chickpea or 100% lentil remained fresher than those made from corn flour by the end of the storage period. The highest sensory scores were attributed to combinations of (50% lentil/rice), (50% chickpea/rice), (50% lentil/corn), and (50% chickpea/corn). The study also examined the effects of various legume/cereal blends on albino rats, focusing on Biological Value (BV), True Digestibility (TD), and Net Protein Utilization (NPU) of the flatbread formulations. The Biological Value (BV) of the recipes was notably high, with all exceeding 70%. The Protein Efficiency Ratio (PER) of the gluten-free flatbreads ranged between 2.37 and 3.0, surpassing the standard value of 2.5. The NPU values were significantly influenced by the proportion and quality of protein. In conclusion, it is possible to create gluten-free flatbreads with quality similar to conventional bread.

1. Introduction

Celiac disease is a chronic inflammatory, autoimmune-mediated disorder that primarily affects the duodenum (Caio et al., 2019). It is classified as a digestive disorder that damages the villi—tiny, hair-like projections in the small intestine responsible for nutrient absorption leading to an immune reaction against gluten (Barada et al., 2010). This condition results in a continuous intolerance to gluten, gliadin, and related prolamins found in wheat, rye, and barley. The disease is characterized by intestinal damage caused by an immune system defect (autoimmune response) that occurs in genetically predisposed individuals (Amin et al., 2002). A gluten-free diet requires the consumption of gluten-free cereals such as rice, corn, sorghum, millet, and teff, as well as pseudo-cereals like buckwheat, amaranth, quinoa, and canthus. Additionally, naturally gluten-free foods, including potatoes, legumes, oilseeds, tapioca, nuts, fruits, and vegetables, are essential dietary components (Pruska-Kedzior et al., 2008). Gluten-free bread formulated with rice flour and gums significantly affects dough properties. Among various gums, xanthan and xanthan–guar gum mixtures have been found to be the most effective in improving dough structure. The best firmness and specific volume values were observed in bread containing xanthan

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and xanthan–guar gum (Demirkesen et al., 2010). Several types of flour, such as barley, corn, cassava, and chickpea, have been extensively studied for their potential use in composite flour bread (Ali et al., 2000). For example, blending rice flour with corn and cassava starch can produce gluten-free bread with a well-structured crumb, enjoyable flavor, and appealing appearance (Lopez et al., 2004; Gujral & Rosell, 2004). However, traditional gluten -free bread often has a less flexible crumb that hardens quickly and is prone to crumbling. Additionally, the taste characteristics of these products vary depending on the ingredients used. According to the FAO, using composite flour in various food products could be economically beneficial by reducing or even eliminating the demand for wheat in bread and pastry production through the use of domestically grown ingredients (Jisha et al., 2008). Despite the availability of gluten-free products, their nutritional quality remains a significant concern due to typically lower levels of protein, fiber, and essential nutrients (Conte et al., 2019). However, ensuring the nutritional value of gluten-free products is crucial, given the growing population affected by celiac disease (Aprodu et al., 2016). Rice contains high levels of aspartic and glutamic acids, with lysine being the limiting amino acid (FAO, 2004). It is considered the primary staple food in many countries and serves as an important source of vitamins, including riboflavin, thiamine, and niacin. Additionally, rice is rich in aspartic acid, thiamine, niacin, vitamin B6, and folate (Watson, 1997). Maize flour also contains high levels of essential vitamins and minerals, including potassium, phosphorus, zinc, calcium, and iron. Among the gluten-free cereals available, lentils and chickpeas are winter legumes grown in the highlands of Upper Egypt (Kadria et al., 2021). Legume proteins can be incorporated into baked products to enhance protein content and improve amino acid composition (Bojňanská et al., 2012; Mohammed et al., 2012). Xu et al. (2019) investigated the thermal, pasting, and chemical properties of lentil, chickpea, and yellow pea flours, as well as their moisture adsorption characteristics. Their findings showed that total starch content decreased in germinated yellow pea and lentil, whereas germination had no significant effect on chickpeas. However, increasing the proportion of lentils and chickpeas in baked bread negatively impacted the qualitative parameters, particularly loaf volume and volume efficiency (Bojňanská et al., 2012). Chickpeas are an excellent source of protein and carbohydrates (Kaur & Singh, 2005). Akubor et al. (2003) formulated blends of plantain and legume flours, producing gluten-free products with high nutritional value and acceptable sensory properties. Proteins are essential structural and functional components of body cells (Michaelsen et al., 2003). They play a crucial role in the development of skin and muscles, as well as in hormone and enzyme production (Arnarson, 2017). Functional foods resemble conventional foods but provide additional physiological benefits, reducing the risk of chronic diseases beyond basic nutritional functions (Flamm et al., 2001). Traditionally, protein digestibility has been estimated through in vitro fermentation models, and in recent years, several trials have emerged to assess the biological value of proteins (Marinangeli & House, 2017). The objective of this study was to develop a novel gluten-free flatbread suitable for individuals with gluten allergies, while enhancing its nutritional quality and functional properties using rice, corn, lentils, and chickpeas. The study aimed to evaluate the flatbread's physical, chemical, nutritional, and sensory properties, as well as its staling behavior, compared to a control sample. Additionally, it aimed to improve the biological value and digestibility of various cereal-legume mixtures as a potential complementary gluten-free food.

2. Materials and Methods

Materials

Broken rice from a low-amylose (15.27%) variety of Sakha 104 (Japonica qhti unit, Damietta, Egypt) was used. The percentage of broken rice kernels was 27%. Chickpeas, lentils, crushed fava beans, white beans, corn flour, salt, cumin, and sunflower oil were purchased from a local market in Cairo, Egypt.

Methods

Preparation of Rice and Legume Flours

Rice and legumes, including chickpeas, lentils, crushed fava beans, and white beans, were carefully cleaned to remove impurities and then washed with tap water. They were soaked in tap water for 8 hours at room temperature (25 ± 2°C), following the method outlined by Khattab and Arntfield (2009). After soaking, the legumes were drained and chopped using a Moulinex 750-watt French blender. The chopped mixture was then dried to produce flakes, which were ground into flour using a Universal high-speed grinder (MDY-200, 3500W, 2800 rpm, China). To enhance flavor, 1.5% salt and 1.5% cumin (by weight) were added to the flour for each recipe. The flour formulations included 100% legume flour used individually or mixed in a 1:1 ratio with rice or corn flour. These flour combinations were then used to prepare flatbread.

Preparation of Flatbread

Flatbread was prepared using a method similar to traditional Indian flatbreads such as dosai. Dosai is an Indian bread made from a mixture of rice and pulses, cooked on a hot surface (Nagaprabha & Prakash, 2009). The basic dough formula included flour, water, and a leavening agent (Brown, 1993).

To achieve the desired moisture content, warm water was added in a ratio of 220 to 250 of the flour weight for each legume or legume-cereal flour combination. The mixtures were stirred thoroughly to form a semi-liquid paste, which was then divided into equal 50±5g portions. Each portion was baked in a greased pan (10 cm diameter) with sunflower oil for 2–3 minutes on each side, following the method described by Prasad et al. (2012). Additionally, corn flour was mixed with water to prepare corn bread, which served as a control. All flatbread recipes, along with the control corn bread, were subjected to sensory evaluation to determine the most preferred formulations, as presented in Table 2.

Chemical analysis

The chemical composition of the various flatbread samples including moisture, protein, ash, and fat content was determined using the AOAC (2005) methods. Total carbohydrate content was calculated by difference using the following equation:

Total available carbohydrates (%) = 100 - (protein% + fat% + moisture% + ash%+ available Fiber %)

Energy value of the samples, was calculate according to FAO/WHO/UNU (1985). The equation used for this calculation is: Total valuable calories = 4 (protein %) + 4 (carbohydrates %) + 9 (fat %).

Textural profile analysis (TPA)

The texture profile analysis of flatbread was performed using a texture analyzer (Conetech, Model B, Taiwan) equipped with specialized software, as described by Bourne (2002). The texture parameters measured included hardness, resilience, cohesiveness, gumminess, chewiness, adhesiveness, and springiness.

Color measurement

Color measurements were conducted using a handheld portable colorimeter (CHROMA METER CR-400, Jaflat) according to Matos and Rosell (2013).The instrument was calibrated with a white tile, and color values were expressed in terms of lightness (L^*), redness (a^*), and yellowness (b^*).

Sensory Evaluation of flat bread

Flatbread samples were evaluated for their sensory attributes. Half slices of each bread sample were presented to a panel of ten trained assessors on white disposable plates. The panelists assessed the samples based on color and appearance, taste, flavor, body and texture, and overall acceptability. The evaluation was conducted using a nine-point hedonic scale-based scorecard, as described by Srilakshmi (2007).

Amino acid profiles

The amino acid composition of different flatbread recipes was analyzed according to AOAC (2019) using an amino acid analyzer (Biochrom 30). Tryptophan was determined following the method of Hernandes and Bates (1969), using the formula:

Chemical amino acid score (%) = 100×[(mg of amino acid in 1 g test protein)/(mg of amino acid in reference pattern) (FAO/WHO, 1991)

Protein Efficiency Ratio (PER) was calculated using the equation suggested by Alsmeyer et al., (1974).

PER= -0.684+0.456 Leucine - 0.047 Proline (g/100g protein).

Biological experiment

Two types of diets were tested: Diets containing 100% legume flour and diets containing a 50% legume-cereal flour mixture. The composition of these blends is presented in Table 1-a. The selection of ingredients was based on their protein content, ensuring that each combination met the WHO's recommended nutrient intake for rats.

Management of Experimental Animals

A biological evaluation of protein quality was conducted over 14 days using 35 adult male albino rats (initial body weight: 75±5g). The experiment was conducted at the rat house of the Regional Center for Food and Feed (RCFF), Agricultural Research Center (ARC), Giza, Egypt. The rats were randomly divided into seven groups (Table 1-a), with five animals per group. Each rat was housed individually in stainless-steel metabolic cages (Model 1000, England; dimensions: 0.35×0.22× 1.35m) equipped for separate urine and feces collection. The cages were maintained in a clean, well-ventilated room at a temperature of 22–24°C and 45–55% relative humidity. Each group received a different diet: Control casein diet, cornbread (control recipe), various gluten-free flatbread recipes. A separate group was fed a protein-free basal diet to determine endogenous and metabolic nitrogen loss in feces and urine.

Composition of tested diets

Table 1-b showed that the experimental diets were formulated according to the method of Chapman et al. (1959). The basal diet included: Corn starch (90%), corn oil (5%), mineral mixture (4%) (Hegsted et al., 1941, vitamin mixture (1%) (Campbell, 1963; INC Pharmaceutical, Ohio, USA). The test diets were prepared by incorporating cornbread and different flatbread formulations as a protein source at a 10% level, replacing corn starch in the basal diet. The control diet contained casein as the protein source. After a 9-day acclimatization period, urine and feces were collected over five days. The collected samples were air-dried and weighed. Nitrogen content in urine and feces was determined using the micro-Kjeldahl method (AOAC, 2005). These values were used to calculate the biological value (BV%), true digestibility (TD%), and net protein utilization (NPU) for each tested recipe.

Table 1-a. Different experimental flat bread tested formulas

Group	Diets	Diets Composition - Casein basal diet
Control	Basel diet	(Casein)
G1	Lentil / rice (50%)	Rice/lentil flat bread 1:1
G2	Chickpea /rice (50%)	Rice/chickpea flat bread 1:1
G3	Lentil \Corn (50%)	Corn / lentil flat bread 1:1
G4	Chickpea \ Corn (50%)	Corn / chickpea flat bread 1:1
G5	lentil 100%	Lentil flat bread 100 %
G6	Chickpea 100%	Chickpea flat bread 100%

Parameters Measured

The Biological Value (BV %), True Digestibility (TD %), and Net Protein Utilization (NPU %) of the tested flatbread recipes were determined following the method described by Eggum (1973). These parameters were calculated using the following equations:

$$BV = \frac{(mg\ N.consumed) - (mg\ N.feces - metabolic\ N) - (Urine\ N - 76) \times 100}{mg\ N.consumed - (mg\ N\ feces - metabolic\ N)}$$

$$TD = \frac{mg\ N.\ consumed - (mg\ faces - metabolic\ N) \times 100}{mg\ N.consumed\ NPV}$$

$$NPU = BV \times TD$$

Table 1-b. Composition of Tested Diets

Diets	L/R (50%) 1	Ch/R (50%) 2	L/C (50%) 3	ChC9 (50%) 4	L (100%) 5	Ch (100%) 6	Casein basal diet diet 7	Protein-free basal diet 8
TF (gm)	65.00	70.00	67.70	68.00	40.80	41.70	-	-
Casein (85%)	-	-	-	-	-		11.76	-
Corn starch (%)	25.00	20.00	22.30	22.00	49.20	48.30	78.24	90.00
Minerals mixture (%)	4.00	4.00	4.00	4.0	4.00	4.00	4.00	4.00
*vitamins mixture (%)	1.00	1.00	1.00	1.0	1.00	1.00	1.00	1.00
Corn Oil (%)	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
**Total	100	100	100	100	100	100	100	100

(TF), Tested Flat breads (gm) which provide 10 g protein, * vitamin A (800 IU); Vit. D3 (1,200 IU.); Vit. E (3 IU), Vit. K3-KASTAB (2mg); Vit. B2 - Riboflavin (3mg); Nicotinic acid (10mg); Pantothenic acid (150mg); Manganese (80mg); Zinc (50mg).Copper (2mg); Iodine (1.2mg); Cobalt (0.2mg), Selenium (0.1mg). R: rice, C: corn, L: lentil, Ch: check pea.**Total = (TF+ Casein +Corn Starch + +Minerals mixture + vitamins mixture +Corn oil) =100%

Economic Study and Cost Reduction Analysis

The total cost (L.E.) and cost reduction percentage (%) of different gluten-free flatbread samples were calculated to evaluate the economic feasibility of the formulations. The total cost reduction (%) was determined by comparing the cost of gluten-free flatbread recipes with conventional alternatives.

Statistical analysis

The obtained results were statistically analyzed using a one-way analysis of variance (ANOVA) at a significance level of $p < 0.05$. Mean values were reported along with their corresponding standard deviations (SD). All statistical analyses were conducted using Assistat, Version 7.7, developed in Brazil, following the methodology proposed by Silva and de Azevedo (2009).

3. Results and Discussion

Sensory evaluation of gluten-free flatbread prepared from different blends

Sensory evaluation is a crucial tool for assessing food acceptability. It plays a significant role in product improvement, quality maintenance, and new product development (Kramer and Twigg, 1970). An exploratory experiment was conducted to evaluate gluten-free flatbread prepared using five different ingredient groups: Rice with legumes, corn with legumes, 100% legumes (individual types), mixed legumes and control (100% corn flour).

Sensory evaluation was used to select the best-performing recipes, which were then further analyzed for quality properties (Figure 1, Table 2).

Gluten-free flatbread samples were evaluated for their sensory characteristics, and the results are summarized in Table 2.

Group 1 (Rice Blends): The highest-rated samples were rice flour with lentils (R/L) and rice flour with chickpeas (R/Ch), with no significant differences between them. Sensory scores for taste, color, aroma, texture, appearance, and overall acceptability were 8.05 & 8.05, 7.8 & 7.7, 8.4 & 7.65, 8.55 & 8.25, 8.6 & 8.15, and 8.3 & 8.15, respectively. These scores were comparable to those of the control (8.1, 8.45, 7.85, 8.25, 8.25, and 8.1).

Group 2 (Corn Blends): Corn flour with lentils (C/L) and corn flour with chickpeas (C/Ch) also performed well, with no significant differences compared to the control. Their overall acceptability scores were 8.0 and 7.9, respectively, compared to the control score of 8.1.

Group 3 (100% Legumes): Flatbreads made entirely from lentil or chickpea flour received high scores, indicating good sensory acceptance.

Groups 4 & 5 (Mixed Legumes & Control): Mixed-legume recipes had lower sensory scores compared to the other groups. These findings align with Bojňanská et al. (2012), who reported varying acceptability levels in chickpea- and lentil-flour-supplemented breads. Hefnawy et al. (2012) found that incorporating 30% corn flour maintained sensory qualities similar to those of the control. Similarly, Miñarro et al. (2012) observed good sensory acceptance in gluten-free bread containing chickpeas.

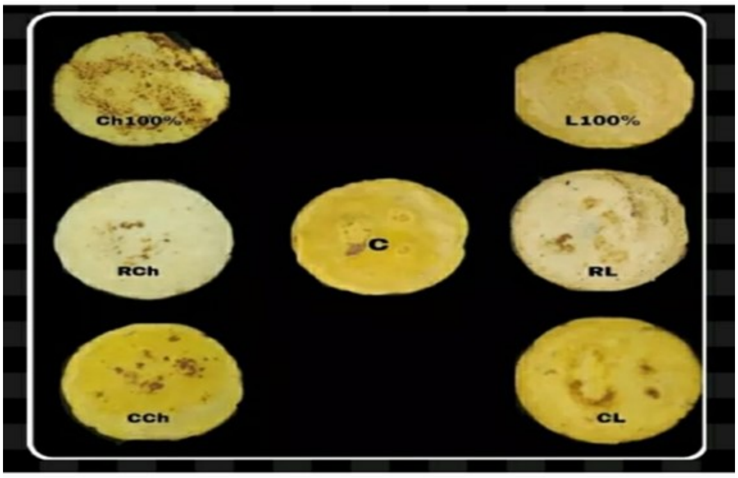
Selected samples for further analysis

Based on sensory evaluation, the following six samples were chosen for physical, chemical, and sensory analysis, alongside the control sample: R/L (50% rice & lentil), R/Ch (50% rice & chickpea), C/L (50% corn & lentil), C/Ch (50% corn & chickpea), L (100% lentil), Ch (100% chickpea) and Control (100% corn). These selected formulations were further studied for their quality attributes, as illustrated in Figure 1.

Table 2. Sensory evaluation of different flat bread blends

Recipes	Taste (9)	Color (9)	Aroma (9)	Body Texture (9)	Appearance (9)	Overall acceptability (9)
Corn bread	8.15^{a}± 0.67	8.45^{a}±0.68	7.85^{ab} ±9.44	8.25^{ab} ±0.79	8.25^{ab} ±0.79	8.1^{ab} ± 0.77
Rice bread	7.45^{abc}±0.68	7.6^{abc}±0.84	7.65^{ab} ±0.72	7.55^{b} ± 1.20	7.35^{bc} ±0.88	7.2^{b}±0.42
Group 1 - rice /Legumes 50%						
L/rice bread	8.05^{a}± 0.82	7.80^{a} ±1.14	8.45^{a} ± 0.45	8.55^{a} ± 0.49	8.60^{a} ±0.51	8.30^{a} ± 0.97
Ch/rice bread	8.05^{a}± 0.83	7.70^{a} ±1.14	7. 75^{ab} ±0.75	8.25^{ab} ±0.79	8.15^{ab} ±0.88	8.15^{ab} ±0.88
P/rice bread	6.85^{bc}± 1.56	6.85^{bc}±1.56	7.15^{b} ± 1.20	7.4^{ab} ± 1.24	6.05^{cd}±1.30	7.25^{b} ± 1.06
b/rice bread	7.34^{b}± 1.40	7.20^{b}± 1.00	6.60^{c}±1.30	7.22^{b} ±1.30	6.69^{c}± 0.77	7.18^{b} ±1.80
Group2- corn /Legumes 50%						
L/Corn bread	7.95^{a}± 1.01	7.85^{a} ± 1.15	7.65^{ab} ± 1.06	8.05^{ab} ± 0.93	7.90^{abc} ±1.22	8.00^{ab} ±0.82
Ch/Corn bread	7.70^{abc}±0.12	8.05^{ab}±0 .83	7.80^{ab}± 1.05	7.85^{ab} ± 1.03	7.95^{abc}±0.76	7.95^{ab} ±0.76
P/Corn bread	7.15^{b}± 0.99	7.18^{b} ± 0.75	7.17^{b} ± 1.03	7. 25^{ab} ±1.03	7.27^{b} ±1.06	7.28^{b} ±0.88
B/Corn bread	7.26^{b}±0.87	7.25^{b} ± 0.74	7.15 ^{b} ± 1.15	7. 25^{ab} ±1.06	7. 25^{b} ± 0.09	7.35^{b} ±0.94
Group3 - Legumes 100%						
L bread	7.40^{abc}±1.20	7.15^{ab}±1.37	7.25^{bc} ±1.27	7.55^{ab} ±1.21	7.05^{bc} ± 1.26	8.30^{a} ±1.30
Ch bread	7.35^{abc}±0.90	7.00^{abc}±0.84	7.35^{b} ± 1.25	7.25^{bc} ±1.25	7.00^{bc} ±0.97	8.15^{ab} ±0.70
Pea bread	6.85^{bc} ±1.56	7.70^{bc}±0.81	7. 1^{b} ±51.20	7.40^{ab} ±1.24	7.05^{bc} ± 1.30	7.25^{b} ±1.06
Bean bread	6.70^{c}±0.79	6.90^{b}±0.77	7.05^{b} ± .065	7.35^{b} ± 1.45	6.45^{c} ± 1.06	7.2^{b} ± 0.95
Group 4 - mix legumes 50%						
L\Ch bread	7.15^{b}±1.05	7.65^{ab}±1.05	7.85^{ab}±1.05	7.90^{ab}±1.12	7.40^{bc} ± 1.37	6.25^{c} ±1.05
L/P bread	7.25^{b}±1.37	7.45^{abc}±1.14	7.45^{b}±0.89	7.80^{ab}±0.78	7.50^{bc} ±1.05	6 .28^{c} ± 1.00
L/b bread	6.90^{bc}±1.02	6.90^{bc} ±1.25	7.30^{b}± 1.31	7.55^{ab}±1.12	6.95^{c} ±1.04	6.15^{c} ± 0.97
Ch/p bread	7. 30^{b}±1.20	7.25^{b}±1.27	7.30^{b}±1.43	7.45^{ab}±1.10	7.30^{bc} ±1.40	6. 55^{bc} ± 0.97
Ch/b bread	6.90^{bc}±1.02	7.05^{bc} ±1.03	7.30^{b} ±1.22	7.30^{b}± 1.35	7.20^{b} ± 1.21	6 .25^{c} ± 1.09
P/b bread	6.75^{c}±1.16	7.05^{bc}±1.403	7.45^{b}±1.27	7.65^{ab}±1.02	7.20^{b} ± 1.05	6.15^{c} ±0.94

Control: corn 100%, R: rice, C: corn, p: Pea, B: bean L: lentil, Ch.: check pea
*Values are means of three replicates ±SD. Each mean value, within the same raw, followed by the same letters is not significantly different at 0.05 level.



Corn bread 100%, Ch100%, L100%, Ch/rice50%, L/rice 50%, Ch/corn50%, L/Corn 50%

Figure 1. Different flat bread samples after sensory evaluation

Chemical composition of gluten-Free flatbread prepared from different blends

The chemical composition of gluten-free flatbread made from various blends was analyzed and is presented in Table 3. All recipes exhibited a significant increase in protein content, ranging from 13.7% to 24.5%, compared to the control flatbread made from corn flour (7.08%). The highest protein content was found in flatbreads made from 100% lentil and 100% chickpea flour, containing 24.5% and 23.96% protein, respectively. This increase can be attributed to the naturally higher protein levels in chickpeas and lentils. In terms of Dietary Reference Intake (DRI) for protein, each 100 g of dried flatbread provided 27.5%, 25.5%, 26.6%, 26.25%, 43.8%, and 42.8% of the daily protein requirement for a 19 to 50 year-old male weighing 65kg (based on a recommended intake of 56g of protein per day) for the following blends: Rice/lentil (50%), rice/chickpea (50%), corn/Lentil (50%), corn/Chickpea (50%), 100% Lentil and 100% Chickpea. These findings align with Samah (2004), who reported that combining cereals and legumes enhances both protein content and protein quality in cereal-based complementary foods.

Fat content: Flatbreads made from 100% chickpea or mixed with corn or rice had higher fat content than other samples, likely due to the naturally higher fat content of chickpeas.

Ash content: A significant increase in ash content was observed in corn/chickpea (2.8%) and 100% chickpea (2.65%) samples, compared to other blends and the control.

Carbohydrate content: All gluten-free flatbread samples showed a notable decrease in carbohydrate content compared to the control (85.52%). The greatest carbohydrate reductions were observed in 100% lentil (61.18%) and 100% chickpea (61.36%) flatbreads. This decrease is attributed to the increase in protein content, which naturally lowers the proportion of carbohydrates.

Caloric Value

The control sample (100% corn flour flatbread) had the highest caloric value at 403.97Kcal. All other samples showed a significant caloric reduction, making them more suitable for dietary considerations. Overall caloric values ranged from 348.66 to 403.97Kcal. These findings are consistent with Gonzales et al. (2016), who stated that chickpea-based baked food products are good sources of nutrients, particularly energy, containing 105 to 526Kcal.

Color characteristics of gluten free flat bread prepared from different blends.

Color is a crucial characteristic influencing the acceptability of food products, as noted by Nithya et al. (2016). It is also one of the most important quality attributes of flatbread, as emphasized by Mahmoud et al. (2013). This study evaluates the color parameters lightness (L^*), redness (a^*), and yellowness (b^*) of gluten-free flatbreads, as presented in Table 4. The results demonstrated significant differences in color attributes across all flatbread samples compared to the control. Notably, flatbreads made from 100% chickpea or 100% lentil exhibited lower L^* values relative to the control, while their a^* and b^* values were higher, indicating increased redness and yellowness. Specifically, increasing the proportion of chickpea or lentil flour significantly reduced L^* values (54.43 for chickpea and 51.13 for lentil), producing darker bread. Concurrently, a^* values rose to 8.06 and 7.08, and b^* values increased to 36.32 and 35.83 for chickpea and lentil flatbreads, respectively, reflecting greater redness and yellowness. In contrast, the control sample displayed the highest L^* value (70.2) alongside significantly lower a^* and b^* values (1.81 and 32.69), indicating reduced redness and yellowness. These findings align with Olojede et al. (2020), who reported that adding chickpea flour to bread formulations darkens the product due to enhanced Maillard reactions, driven by lysine and sugars in chickpeas. Additionally, Sharima-Abdullah et al. (2018) observed that incorporating vegetable proteins and chickpea flour improves color and visual appeal, underscoring the importance of optimizing ingredient proportions to boost consumer acceptance.

Table 3. Chemical composition of different flat bread recipes (on dry weight g/100g)

Recipes	Protein (%)	Fat (%)	Fiber (%)	Ash (%)	Total Carbohydrates (%)	Caloric Value (Kcal/100g)
Control	07.08^{c} ± 6.56	3.73 ^{b}± 0.11	02.15^{e}±0.33	1.52^{cd} ± 0.22	85.52^{a}±0.20	403.97^{a}± 2.00
L100%	24.50 ^{a}± 0.51	0.66 ^{d} ± 0.07	12.30^{a}± 0.20	1.36^{d} ± 0.01	61.18^{e}±0.20	348.66^{f}± 0.34
Ch 100%	23.96 ^{a}± 0.40	4.83 ^{a} ± 0.72	07.20^{d} ± 0.20	2.65^{a} ± 0.13	61.36^{e}±0.30	384.75^{b}± 0.52
L/rice (50%)	1 5.40 ^{b}±0.36	2.26 ^{c} ± 0.20	07.90^{c} ± 0.10	1.60^{c}±0.15	72.84^{c}±0.23	373.30^{d}± 1.82
Ch/rice(50%)	14.30 ^{0b}±0.80	4.23 ^{ab} ±0.25	08.02^{c}± 0.61	2.26 ^{b}±0.20	71.19^{c}±0.23	380.03^{c}± 0.01
L/Corn (50%)	14. 90 ^{b}±0¨60	2.50 ^{c} ± 0.43	09.20^{b}± 0.20	2.46^{ab}±0.05	71.34^{c}±0.22	365.86^{e}± 0.55
Ch/Corn (50%)	1 4.70^{b}± 0.62	4.50 ^{a} ± 0.70	10.00^{b}±0.70	2.80^{a}±1.50	67.80^{d} ±0.28	371.30^{d}± 0.30

Table 4. Color characteristics of gluten free flat bread prepared from different blends

Recipes	*L**	*a**	*b**
Corn (100%)	70.12^{a}±0.12	1.81^{e}±0. 81	32.69^{d}± 0.09
Lentil (100%)	51.13^{g}±0.13	8.06^{a} ±0.06	36 .32^{a}± 0.32
Chickpea (100%)	54.43^{f} ±0.44	7.08^{b}±0.08	35.83^{b}± 0.03
L/rice (50%)	66.32^{c} ±0.32	5.36^{d} ±0.36	32.16^{e}± 0.16
Ch/ rice (50%)	67.47^{b}±0.47	5.56^{cd} ±0.11	31.08^{f} ± 0.08
L/Corn (50%)	63.9^{e} ±0.9	7.00^{b}±0.10	34 .32^{c}± 0.32
Ch/Corn (50%)	65.32^{d}±0.32	6.07^{c}±0.07	32.83^{d}± 0.03

Control: corn bread 100% , R: rice, C: corn, L: lentil, Cch : check pea
*Values are means of three replicates ±SD. Each mean value, within the same raw, followed by the same letters is not significantly different at 0.05 level. *L** = lightness color score are *a** = redness color score *b** = yellowness color score.

Texture profile analysis of gluten free flat bread prepared from different blends.

Hardness is a critical textural property in evaluating baked goods due to its direct association with the human perception of freshness (Karaoğlu & Kotancılar, 2009). The texture results of gluten-free flatbreads prepared from different recipes are shown in Table 5. Hardness varied significantly across all gluten-free flatbread samples, ranging from 4.3 to 11.15N. The highest hardness value (11.15±0.75N) was observed in the sample containing 100% corn flour, followed by the C/Ch 50% blend (corn/chickpea at 7.62±0.3N), while the lowest hardness (4.3±0.26N) was recorded in the 100% chickpea sample. The results clearly demonstrate that incorporating chickpea or lentil flour significantly reduced hardness while increasing springiness and resilience. Conversely, adding corn or rice flour to blends significantly increased hardness and decreased springiness and resilience. Notably, the highest springiness (2.68±0.08mm) and resilience (0.16±0.02) values were observed in the 100% chickpea sample, chickpea sample, which also improved quality parameters such as porosity, specific volume, and crust-to-crumb ratio. Texture and SEM analyses revealed that increasing chickpea flour concentration decreased crumb firmness and produced a continuous, smoother texture (Mohammad et al., 2014). This may be attributed to chickpea's high protein content, which promotes a more porous structure and softer crumb. Protein content in flour is a key factor influencing hardening and staling rates (Pateras et al., 2007). Table 5 also indicates that chewiness and gumminess values decreased as hardness diminished, following a similar trend to hardness. These findings align with Ibrahim (2011), who reported that gumminess and chewiness are hardness-dependent parameters. Chewiness and adhesiveness are texture attributes strongly correlated with sensory evaluations conducted by trained panels (Esteller et al., 2004). The use of chickpea as an ingredient in gluten-free foods has expanded due to its nutritional value and its ability to enhance product quality (Capriles & Arêas, 2014).

Table 5. Texture profile analysis of gluten free flat bread prepared from different blends

Recipes	Hardness (N)	Adhesive-ness (mj)	Resilience	Cohesiveness	Gumminess	Springiness (mm)	Chewiness
Control	11.15ᵃ±0.75	5.6 ᵃ±0.55	0.03ᵉ±0.02	1.10ᵉ±0.10	12.39ᵃ±0.10	0.37 ᵃ±0.78	56.4ᵃ±0.20
L 100%	5.74ᵈ±0.22	2.30ᶜᵈ±0.10	0.08ᶜᵈᵉ±0.11	2.16ᵇ±0.05	12.28ᵃ±0.07	2.58ᵇ±0.50	33.90ᶜ±1.00
Ch 100%	4.30ᵉ±0.26	2.70ᵇ±0.10	0.16ᵇᶜ±0.02	0.32ᶠ ±0.21	14.40ᵃ±0.22	2.68ᵈ±0.08	39.14ᵇ±0.79
L/rice (50%)	6.02ᵈ±0.13	0.90ᵉ±0.01	0.05ᵈᵉ± 0.03	1.60ᶜ±0.14	9.90ᶜ±0.10	2.60ᵇ±0.56	29.30ᵈ±0.80
Ch/rice (50%)	7.07ᵇ±0.23	1. 23ᵉ±0.15	0.02ᵉ±0.05	1.26ᵈ±0.07	9.50ᵈ±0.10	2.55ᵇᶜ±0.16	21.50ᵉ±1.00
L/Corn (50%)	5.80ᵈ±0.90	2.30ᶜᵈ±0.10	0.05ᵈᵉ±0.04	1.75ᶜ±0.05	10.48ᵇ±0.20	2.54ᵇ±0.47	33.90ᶜ±0.20
Ch/Corn (50%)	7.62ᵇ±0.31	2.60ᵇᶜ±0.10	0.11ᶜᵈ±0.05	1.24ᵈᵉ±0.05	9.78ᶜᵈ±0.20	2.60ᵇ ±0.30	29.80ᵈ±0.25

Control: corn 100%, R: rice, C: corn L: lentil, Ch.: check pea.*Values are means of three replicates ±SD. Each mean value, within the same raw, followed by the same letters is not significantly different at 0.05 level.

Table 6. Effect of storage time (hr) on Hardness & stalling of different flat bread recipes

Recipes	Hardness (Figure 2a)			
	Zero	24 h	48 h	72 h
Corn 100%	11.3ᵃ±1.13	21.07 ᵃ ±0.07	41.04ᵃ±0.07	76.90ᵃ±0.9
L 100%	5.07ᶜᵈ±0.07	6.99 ᵉ ±0.99	12.21ᶠ±0.21	25.30ᵍ±0.3
Ch 100%	4.3ᵇ±0.20	8.30 ᵈ ±0.30	15. 4ᵉ±0.40	29.00ᶠ±0.10
L/rice 50%	5.6ᶜ±0.52	13.08 ᶜ ±0.08	22.07ᵈ±0.07	40.70ᵉ±0.72
Ch/rice50%	7.07ᵈ±0.07	17.07 ᵇ ±0.07	22.07ᵈ±0.07	43.60ᵈ±0.5
L/Corn 50%	5.58ᶜ±0.16	17.0 7ᵇ±0.07	24.06ᵇ±0.06	46.50ᶜ±0.52
Ch/Corn50%	7. 9ᵈ±0.60	17.65ᵇ±0.65	24.80ᵇ±0.80	50.50ᵇ±0.51
	Stalling (Figure 2b)			
Corn 100%	284.40ᵃ±21.1	392.80ᵃ±0.80	484.7ᵃ±0.72	598.50ᵃ±0.51
L 100%	193.50ᵈ±0.52	276.60ᵈ±0.60	334.6ᶠ±0.61	417.90ᵉ±0.90
Ch 100%	273.57ᶜ±0.56	276.60ᵈ±0.60	334.6 ᶠ±0.61	420.60ᵉ±0.06
L/rice 50%	257.57ᵇᶜ±0.56	316.80ᶜ±0.80	341.4ᵉ±0.40	452.90ᵈ±0.59
Ch/rice50%	284.50ᵃ±0.50	355.50ᵇ±0.50	408.2ᶜ±0.30	510.70ᶜ±0.07
L/Corn 50%	273.60ᵃᵇ±0.55	318.40ᶜ±0.42	348.3ᵈ±0.32	456.20ᵈ±0.52
Ch/Corn50%	288.57ᵃ±0.56	342.00ᵇᶜ±0.01	418.4ᵇ±0.40	525.60ᵇ±0.60

Control: corn bread 100%, R: rice, C :corn, L: lentil, C/ch: check pea., *Values are means of three replicates ±SD.
Each mean value, within the same raw, followed by the same letters is not significantly different at 0.05 level

Effect of Storage Time (hrs.) on Hardness & Staling of Different Flatbreads

Staling is a complex process influenced by multiple factors, including amylopectin retrogradation, reorganization of polymers in the amorphous region, moisture loss, redistribution of water between amorphous and crystalline zones, and changes in crumb macroscopic structure (Davidou et al., 1996; Rojas et al., 1999). A gradual decline in freshness (increased staling) was observed in all flatbreads over time. This may result from amylose crystallization post-baking or the inherent properties of lentil flour, which may delay staling. These findings align with Seleem (2000), Ammar et al. (2020), and Matsushita et al. (2020), who reported similar mechanisms in starch-based products. A negative correlation was observed between storage time and freshness, consistent with studies on tortillas by El-Tawil (1998) and Khorshid et al. (1997), who noted that (hardness) increased progressively during storage.

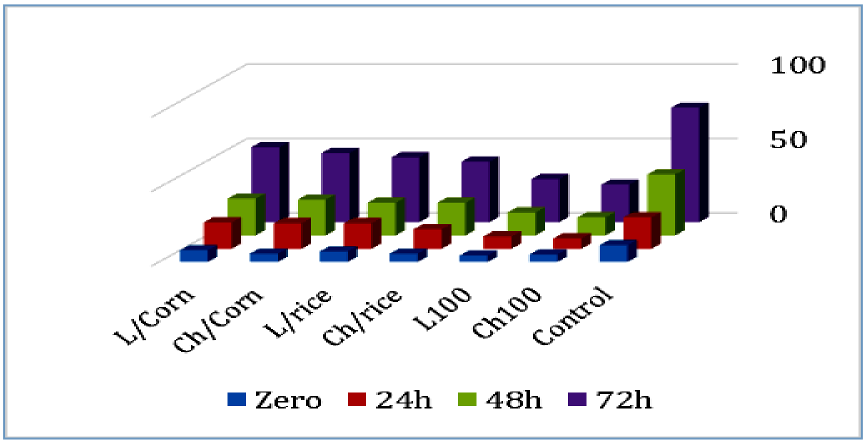


Figure 2a. Effect of storage time (hrs.) on hardness of different flat bread

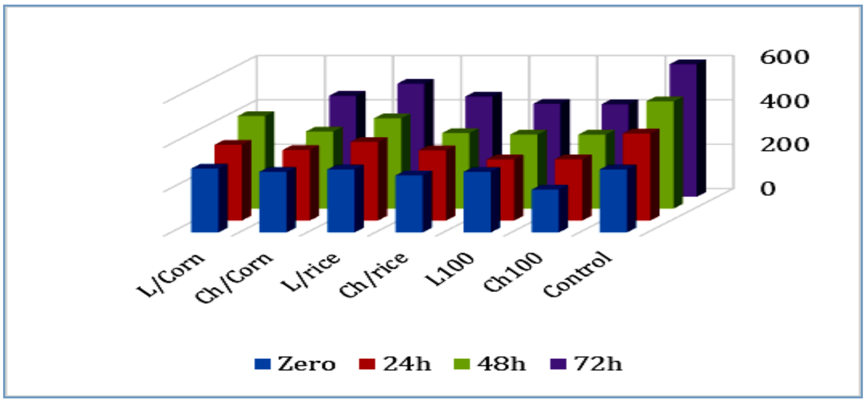


Figure 2b. Effect of storage time (hrs.) on staling of different flat bread

Effect of storage time on hardness and staling

Figures 2a and 2b illustrate the hardness and staling trends of flatbread blends over storage periods of 0, 24, 48, and 72hours. At the initial timepoint (0 hours), the 100% chickpea and 100% lentil blends exhibited the lowest hardness and staling values, followed by rice-legume (RL, RCh) and corn-legume (CL, CCh) blends. In contrast, the control (corn flour bread) displayed the highest hardness and staling values. Both parameters increased progressively during storage, with the most pronounced rise observed in corn and corn-legume blends. Sidhu et al. (1997) reported that freshness, a holistic attribute encompassing taste, aroma, and texture is highly valued in flatbread. However, due to its lean formulation, flatbread is prone to rapid staling during storage, leading to a limited shelf life Staling involves physicochemical changes such as moisture redistribution and starch retrogradation, resulting in increased firmness and altered organoleptic properties. These changes render the bread tougher and less palatable, often deemed unacceptable by consumers (Gujral & Pathak, 2002). A direct correlation exists between prolonged storage time, increased firmness, and reduced freshness.

Amino acid profile and nutritional quality

The amino acid composition of various flatbread formulations (Table 7) revealed glutamic acid as the most abundant amino acid, with concentrations ranging from 16.1 to 18.44g/100g protein across 100% chickpea, 100% lentil, legume-cereal blends (50% chickpea/rice, 50% lentil/rice, 50% chickpea/corn, 50% lentil/corn), and the control (corn flatbread at 17.27g/100g protein). Aspartic acid ranked second, decreasing progressively from 11.61g (100% chickpea) to 8.42g (50% lentil/corn), while corn-containing blends exhibited leucine as the third predominant amino acid. Methionine and tryptophan were the least abundant, with methionine ranging from 0.9g (50% chickpea/rice) to 2.64 g (100% chickpea) and tryptophan varying between 0.65g (100% chickpea) and 1.2g (50% lentil/rice) per 100g protein.

Table 7. Amino acids content (g/100g) protein of different bread recipe

Amino acid	Corn 100%	Lentil 100%	Ch100%	L /rice %	Chick /rice	L/corn	Ch /corn
Isoleucine	2.70^{i}±0.10	4.20^{h}± 0.11	03.80^{i}±0.13	4.65^{g}±0.05	4.45^{g}±0.14	3.75^{h} ±0.05	3.55^{h}± 0.05
Leucine	10.10^{b}±0.10	7.10^{d}± 0.13	07.20^{d}±0.10	7.70^{c}±0.023	8.60^{c} ±0.01	8.60^{b}±0.10	8.65^{b}± 0.05
Valine	4.72^{g}±0.02	4.60^{j}± 0.15	4.20^{g} ±0.12	4.85^{f}±0.05	4.60^{f} ±0.19	4.66^{f} ±0.11	4.46^{f} ± 0.02
Threonine	2.84^{i}±0.04	3.76^{k}±0.02	3.70 ^{i} ± 0.16	3.70^{i}±0.10	3.60^{h} ±0.02	3.80^{h} ±0.10	3.77^{g} ± 0.11
Phenyl alanine	5.06^{f} ±0.06	5.00^{f}±0.20	5.30^{e}±0.01	5.02^{8}±0.10	5.18^{e} ±0.01	5.02^{e} ±0.02	5.17^{e} ±0.17
Methionine	2.64 ^{j}±0.04	0.90^{o}±0.10	1.20^{m} ±0.01	2.32^{k}±0.20	2.47^{i}±0.02	1.75 ^{j} ±0.05	1.90 ^{j} ± 0.10
Tryptophan	0.65^{m}±0.02	0.80^{p}± 0.11	0.90^{n} ±0.10	1.15 ^{m}±0.01	1.20^{l} ±0.05	0.71^{l} ±0.01	0.81^{k} ±0.05
Lysine	2.80^{i}±0.04	6.70^{e}± 0.15	6.50^{de} ± 0.18	4.80^{f} ±0.04	4.70^{f} ±0.01	4.70^{f} ±0.02	4.62^{f} ±0.02
Histidine	2.40^{k}±0.10	2.60^{l}±0.12	2.80^{j}±0.11	2.60 ^{j}±0.07	2.50^{j}±0.03	2.50^{i} ±0.10	2.62^{i} ±0.05
Serine	2.40^{k}±0.10	4.80^{j}±0.16	4.70^{f} ±0.01	5.09^{e}±0.07	5.04^{i}±0.05	4.04^{g} ±0.04	3.75^{g}±0.05
Cysteine	2.08^{l}±0.01	1.10^{n}±0.02	1.50^{l}±0.11	1.30^{l}±0.04	2.28^{k}±0.20	1.30^{k} ±0.01	1.79^{j} ±0.01
Tyrosine	2.86^{i}±0.02	2.50 ^{m}±0.11	2.20^{k} ±0.21	2.71^{j} ±0.03	2.60^{i} ± 0.17	2.68^{i} ±0.10	2.53^{i}±0.03
Aspartic acid	6.08^{d}±0.04	10.70^{b} ±0.20	11.61^{b}±0.01	8.94^{b}±0.04	9.42^{b}±0.40	8.42^{b}±0.02	8.80^{b} ±0.16
Glutamic acid	18.44^{a}±0.50	16.10^{a}±0.11	16.60^{a}±0.20	17.50^{a}±0.02	17.17^{a} ±0.11	17.27^{a}±0.19	16.92^{a}±0.02
Proline	8.34^{c}±0.10	03.90 ^{j}±0.15	4.40^{g} ±0.21	4.30^{h}±0.01	4.70^{f} ± 0.10	6.17^{d}±0.12	6.37^{d}±0.03
Glycine	3.62^{h}±0.20	04.00^{i}±0.17	3.60^{i}±0.10	3.64^{i}±0.11	3.18^{h} ± 0.10	3.80^{h} ±0.10	3.70^{g}±0.02
Alanine	6.04^{d}±0.04	04.20^{h} ±0.22	4.10^{h}±0.12	5.17^{e} ±0.09	5.02^{e} ± 0.33	5.12^{i} ±0.13	5.04 ^{ef} ± 0.21
Arginine	5.26^{e}±0.20	07.60^{c}±0.22	9.00^{0}±0.16	7.10^{d} ±0.05	7.48^{d} ± 0.15	6.43^{c} ± 0.03	7.50 ^{c} ± 0.05

Control: corn bread 100% , R: rice, C :Corn, L: lentil, Ch: chickpea. *Values are means of three replicates ±SD. Each mean value, within the same raw, followed by the same letters is not significantly different at 0.05 level.

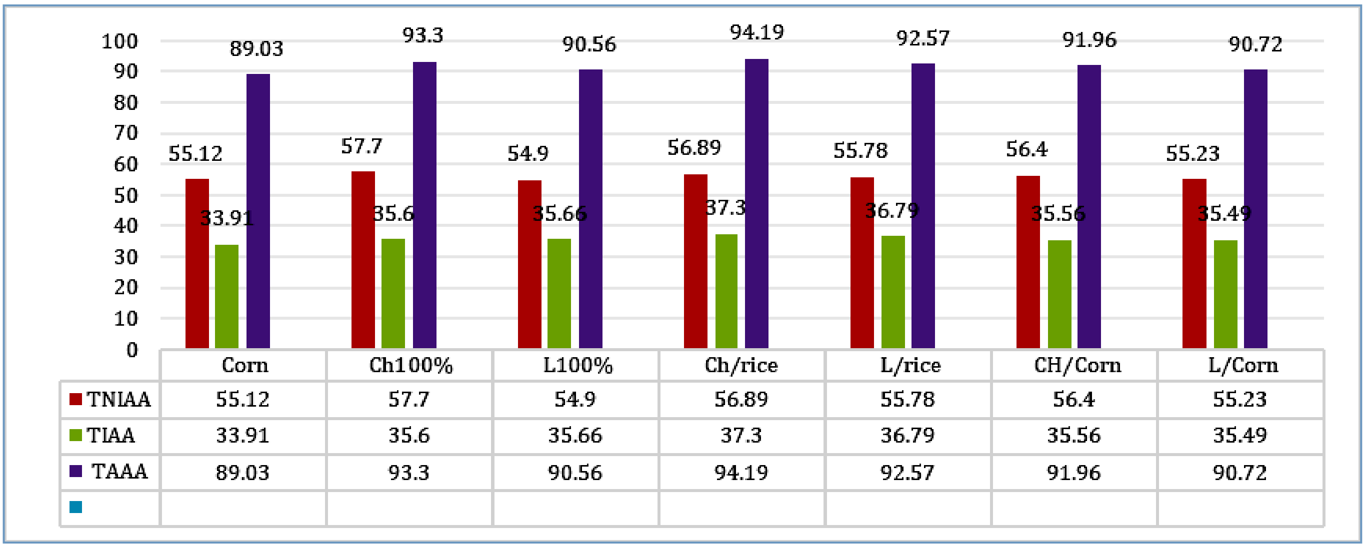


Figure 3. Amino acid composition in different flat bread recipes

Figure 3 shows the Total Essential Amino Acids (TEAA), Total Non-Essential Amino Acids (TNEAA), and Total Amino Acids (TAA) of different flatbread recipes. TEAA values ranged from 33.91% to 37.3%, with the highest value observed in the 50% chickpea/rice blend and the lowest in the control (corn bread). TNEAA values varied between 55.12% and 57.7%, where the 100% chickpea recipe exhibited the highest TNEAA (57.7%), followed closely by the 50% chickpea/rice (56.89%) and 50% chickpea/corn (56.4%) blends. The 100% lentil (L100) recipe recorded 54.9%, while lentil/corn and lentil/rice blends showed slightly lower values. For total amino acids (TAA), the 50% chickpea/rice blend had the highest value, followed by the 100% chickpea recipe, whereas the control corn bread had the lowest. Overall, formulations containing chickpea (either alone or blended with rice/corn) demonstrated superior TAA and TEAA values compared to other recipes.

Table 8. Chemical score and limiting amino acids of different formulas of flat bread

Amino acid	Corn 100%	Lentil 100%	Ch 100%	L/rice 50%	Ch /rice (50%)	L/Corn (50%)	Ch/Corn (50%)	FAO/WHO, 1973
Threonine	71.00	94.00	92.50	92.50	90	95.00	94.25	4.00
Valine	94.40	92.00	84.00	97.00	92	93.20	89.20	5.00
Methionine	120.00*	40.90[a]	54.50[a]	105.50*	112.2*	79.50	86.30	2.20
Isoleucine	67.50	105.00*	95.00	116.25*	111.25*	93.75	88.75	4.00
Leucine	144.20*	101.40*	102.80*	110.00*	122.8*	123.00*	123.5*	7.00
Phenylalanine	180.70*	178.50*	189.30*	179.00*	185*	179.28*	184.6*	2.80
Lysine	51.50[a]	123.00*	119.50*	88.00[a]	86.4[a]	86.40	85.00	5.44
Tryptophan	67.70	83.30	93.75	119.79*	125*	73.90[a]	84.30[a]	0.96
PER **	3.5#	2.37	2.39	2.60#	3.0#	2.9 #	2.96#	Standard value

*Composition supplies 100% or more of the requirement. a, first limiting amino acid.. PER** = - 0.684+0.456 Leucine - 0.047 Proline(g/100g protein .# PER values (a standard value of casein protein) . Chemical amino acid score % = 100 x [(mg of amino acid in 1 g test protein) / (mg of amino acid in reference pattern) .

Table 8 presents the Chemical Score (CS), Protein Efficiency Ratio (PER), and limiting amino acids of various flatbread formulations. The data reveal that lysine is the limiting amino acid in corn bread, with a CS of 51.5%, followed by tryptophan (67.7%). In contrast, methionine serves as the limiting amino acid in chickpea and lentil bread recipes, with CS values of 54.5% (chickpea) and 40.9% (lentil). Generally, lysine is the primary limiting amino acid in legume-cereal flatbread blends, while corn bread is rich in methionine, leucine, and phenylalanine—all exceeding 100% of dietary requirements.

Notably, all bread formulations met or surpassed 100% of phenylalanine requirements, and rice-based recipes exceeded recommended levels of lysine and tryptophan. Cereal proteins typically contain only 2% lysine, less than half the concentration recommended by the FAO/WHO (1973) for human nutrition. The Protein Efficiency Ratio (PER), a key indicator of protein quality, ranged from 2.37 to 3.0 across gluten-free flatbreads. All recipes except the 100% lentil (2.37) and 100% chickpea (2.39) exceeded the standard casein reference value (2.5), indicating high protein quality. The elevated PER values in blended recipes correlate with higher leucine concentrations (Table 8). According to Oluwaniyi et al. (2010) and Zengin et al. (2012), foods with PER values >2.0 are classified as high-quality protein sources, while those >2.5 (the casein benchmark) are considered excellent.

Table 9. Protein quality of different experimental diets

Experimental diets	BV %*	TD %**	NPU %***
Casine diet (control)	84.50[a] ± 3.50	97.25[a] ± 0.50	82.17[a] ± 3.14
L / rice 50%	71.45[cd] ± 5.50	75.30[bcd] ± 0.65	53.80[cde] ± 7.01
Ch / rice50%	70.10[d] ± 6.80	74.31[bcd] ± 0.67	52.09[d] ± 6.00
L /Corn 50%	74.57[bcd]±5.10	78.30[bcd] ± 0.80	58.38[C] ± 0.82
Ch/Corn 50%	70.90[d] ± 5.50	69.71[bcd] ± 0.50	49.42[cd] ± 0.16
L100%	79.50[b] ± 2..66	83.75[b] ± 0.70	66.60[b] ± 0.69
Ch 100 %	76.50[bc]± 4.30	79.07[bc] ± 0.40	60.50[bc] ± 0.57

R: rice, C :corn, L: lentil, Cch: check pea .*Values are means of three replicates ±SD. Each mean value, within the same raw, followed by the same letters is not significantly different at 0.05 level. BV* biological value, (TD)** True digestibility (NPU) ***Net protein utilization

Protein Quality of Experimental Diets

The protein quality parameters true digestibility (TD), biological value (BV), and net protein utilization (NPU) of different flatbread formulations are presented in Table 9. NPU values differed significantly between all flatbread samples and the casein control. The casein diet yielded the highest NPU (82.2%), followed by the 100% lentil (L100%) recipe (66.6%), which surpassed the 100% chickpea (Ch100%) recipe (60.5%). All NPU values exceeded the 60% threshold recommended by PAG (1971) for legume-based blends. Biological value (BV) ranged from 70.1% to 79.5% across recipes. The 100% lentil (L100%) flatbread showed the highest BV (79.5%), followed by the 100% chickpea (Ch100%) recipe (76.5%), while the lowest values were observed in the 50% chickpea/rice (70.1%) and 50% chickpea/corn (70.9%) blends. These results align with Oser (1959), who classifies proteins with a BV of 70–100% as nutritionally adequate. For true digestibility (TD), the casein control (97.3%), L100% (83.75%), and Ch100% (79.07%) recipes exhibited the highest values. No significant differences were observed among the remaining samples: 50% lentil/rice (75.3%), 50% chickpea/rice (74.31%), 50% lentil/corn (78.3%), and 50% chickpea/corn (69.7%).

Table 10. Total cost (L.E) & cost reduction (%) of different gluten-free flat bread samples

Recipes	Cost of 100g sample (L.E)	20%	Total cost (L.E)	No. of .of Loaves	Cost of Loave (40-50g) (L.E)	Cost reduction (%)
Corn flour	8.5	1. 70	10.20	5	2.04	------
L100%	6.0	1.20	7.20	6	1.20	- 41.18
Ch 100%	8.0	1.60	9.60	6	1.60	- 21.56
R\L 50%	4.5	0.90	5.40	5	1.08	- 47.05
R\Ch 50%	5.5	1.10	6.60	5	1.32	- 35.30
C\L 50%	7.25	1.45	8.70	5.5	1.58	- 22.55
C\Ch50%	8.25	1.65	9.90	5.5	1.80	- 11.80

R: rice, C: corn, L: lentil, Cch: check pea

Production Cost Analysis

The production costs of gluten-free flatbread samples are detailed in Table 10. Results indicate that the total cost ranged from 5.40 to 9.90 pounds/100g, compared to the control bread (10.20 pounds/100g). Cost reductions for the formulated blends varied between 11.80% and 47.05%. The lentil-rice flatbread achieved the highest cost reduction (47.05%), followed by the 100% lentil flatbread (41.18%), while the chickpea-corn blend showed the lowest reduction (11.80%). Other samples exhibited cost reductions ranging from 21.56% to 35.30% relative to the control. Overall, all experimental blends were more cost-effective than the control formulation.

4. Conclusion

In response to the growing demand for functional gluten-free baked goods, this study demonstrates that lentil or chickpea flour—either used individually (100%) or blended with corn or rice flour—can successfully produce gluten-free flatbread with acceptable physicochemical properties. The findings reveal that lentil and chickpea flours are superior to yellow corn flour in terms of protein, fiber, and fat content, yielding final products enriched with crude protein, crude fiber, ash, and ether extract compared to the control. The formulated flatbreads are not only gluten-free but also cost-effective, achieving production cost reductions of 11.80% to 47.05% relative to the control (corn bread). Notably, lentil-rice blends showed the highest cost efficiency. These results highlight the feasibility of preparing high-quality gluten-free flatbread using raw materials such as yellow corn, chickpea, rice, and lentil flours, offering a nutritious and affordable option suitable for individuals with celiac disease. Gluten-free bread made from lentils, chickpeas, or blended with corn/rice is recommended as a safe, nutritious alternative for individuals with wheat gluten allergies. Unlike traditional wheat bread, which can harm digestion and growth, this option provides high-quality protein, easy digestibility, and appealing taste, texture, and color. Compared to conventional corn bread, it serves as a complete meal, is cost-effective, and requires minimal preparation time.

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