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Effect of Fermentation Period on the Nutrient Composition and Pasting Properties of Chickpea (*Cicer Arietinum*) Seed Flour

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Abstract

This study evaluated the effect of fermentation duration on the nutritional composition and pasting properties of chickpea (Cicer arietinum) seed flour. Cleaned and manually sorted chickpea seeds were divided into four portions (1 kg each). One portion was processed into raw flour and used as the control, while the remaining portions were subjected to spontaneous fermentation by naturally occurring microflora for 48, 72, and 96 hours, respectively. The resulting flours were analyzed for proximate composition, mineral and vitamin contents, and pasting characteristics using standard analytical methods. Proximate analysis showed that moisture content ranged from 6.24 to 7.86%, crude protein from 10.72 to 22.46%, fat from 1.21 to 3.47%, ash from 1.32 to 2.38%, crude fibre from 2.14 to 3.31%, carbohydrate from 62.07 to 74.66%, and energy value from 343.46 to 368.27 kJ/100 g. Mineral composition revealed calcium levels of 74.42–108.60 mg/100 g, potassium 88.37–126.21 mg/100 g, phosphorus 83.72–135.20 mg/100 g, magnesium 92.35–163.77 mg/100 g, sodium 7.35–14.40 mg/100 g, and zinc 4.18–10.31 mg/100 g. Vitamin analysis indicated that ascorbic acid ranged from 3.22 to 8.73 mg/100 g, thiamine 1.58–7.32 mg/100 g, niacin 1.16–7.12 mg/100 g, riboflavin 1.36–7.18 mg/100 g, folic acid 1.38–5.22 mg/100 g, and vitamin A 2.01–6.57 mg/100 g. The pasting properties demonstrated peak viscosity values between 33.26 and 73.21 RVU, trough viscosity 32.74–65.44 RVU, breakdown viscosity 30.24–64.37 RVU, setback viscosity 41.66–86.56 RVU, final viscosity 64.33–103.16 RVU, peak time 4.32–8.59 minutes, and pasting temperature 32.41–87.43°C. Fermentation significantly influenced both nutritional and functional attributes ($p < 0.05$). Specifically, extended fermentation increased protein, mineral, and vitamin contents, as well as peak and breakdown viscosities, while fat and carbohydrate contents, along with trough, setback, and final viscosities and peak time, decreased relative to the raw sample. Among the treatments, the flour fermented for 96 hours exhibited the highest nutrient density and improved pasting characteristics, indicating enhanced functional quality. These findings suggest that prolonged fermentation enhances the nutritional and technological properties of chickpea flour, making it a promising ingredient for diverse food applications. Its utilization may contribute to improved dietary quality and help address malnutrition and food insecurity, particularly in developing regions.

Keywords: *Chickpea seeds, fermentation, proximate composition, micronutrients contents, pasting properties.*

Introduction

Legumes, belonging to the family *Leguminosae* (Fabaceae), are widely recognized as nutritionally rich and economically important crops cultivated across diverse agro-ecological regions of the world [1]. They represent a major source of plant-based protein, particularly in developing countries where access to animal-derived protein is limited. The protein content of legumes typically ranges from 20% to 40%, making them a valuable dietary component for human nutrition [1]. In addition to proteins, legumes are rich in dietary fibre, complex carbohydrates, essential minerals, and vitamins, contributing significantly to a balanced diet. The amino acid profile of legumes is characterized by high levels of lysine but relatively low concentrations of sulphur-containing amino acids such as methionine and cysteine [2]. Conversely, cereals are deficient in lysine but adequate in sulphur-containing amino acids. Therefore, the combination of cereals and legumes in food formulations provides a complementary effect, resulting in improved protein quality and a more balanced amino acid composition suitable for human dietary requirements [2]. Legumes used for human consumption are broadly categorized into pulses and oilseeds. Pulses refer to the dried edible seeds of leguminous crops such as beans, lentils, and peas, which are commonly consumed as staple foods. Oilseeds, including soybean and groundnut, are primarily cultivated for their oil content, although they also serve as important protein sources [3]. In many low- and middle-income countries, legumes play a critical role in alleviating protein-energy malnutrition and enhancing food security [3], legumes contain several antinutritional factors such as phytates, tannins, trypsin inhibitors, and lectins, which can impair nutrient digestibility and bioavailability [2,3]. These compounds may also affect palatability and limit their utilization in food systems. However, various traditional and modern processing methods—including soaking, cooking, roasting, germination, decortication, and fermentation—have been shown to effectively reduce or eliminate these antinutritional components [2,3]. Among these techniques, fermentation is particularly significant due to its ability to improve nutritional quality and functional properties.

The biochemical activities of microorganisms during fermentation enhance protein digestibility, increase the bioavailability of minerals, and modify the physicochemical characteristics of legume-based products [1]. Consequently, fermentation represents a promising approach for optimizing the utilization of legumes in the development of nutrient-dense foods, thereby contributing to improved public health and food security.

Chickpea (*Cicer arietinum* L.) is one of the most important pulse crops in India and ranks among the leading grain legumes in terms of area and production [4]. The seeds exhibit considerable variability in size, shape, and colour, ranging from round to wrinkled forms, and from light shades such as white and yellow to darker hues including brown and black. Immature chickpea seeds are commonly consumed as vegetables, either raw, boiled, or incorporated into various traditional dishes [5]. Owing to its rich nutritional profile, chickpea serves as a valuable dietary component, providing substantial amounts of plant-based protein, dietary fibre, and essential minerals such as iron, phosphorus, and magnesium [6]. It is also a good source of vitamins, including folic acid, vitamin C, tocopherol, riboflavin, and pyridoxine. Historically cultivated in the Middle East and South Asia, chickpea—also known as garbanzo bean or chana—has been an integral part of human diets for centuries. Its consumption is associated with numerous health benefits, including improved digestion, weight management, and reduced risk of chronic diseases such as cardiovascular disorders, hypertension, and type 2 diabetes [7]. Chickpea protein is considered nutritionally superior among pulses due to its relatively high digestibility and favourable net protein utilization value, although it is limited in tryptophan and sulphur-containing amino acids [4,8]. In addition to macronutrients, chickpeas are rich in bioactive compounds such as flavonoids, tannins, isoflavones, and polyphenols, which possess significant antioxidant properties and contribute to the scavenging of free radicals in the human body [9,10].

Fermentation is a biochemical process mediated by microorganisms, in which complex organic compounds such as carbohydrates are enzymatically converted into simpler substances, including organic acids, gases, or alcohol, under anaerobic conditions [11]. This process not only enhances the preservation of food but also improves its nutritional and functional qualities. Microbial activity during fermentation leads to the breakdown of complex macromolecules, thereby increasing nutrient bioavailability and reducing antinutritional factors [12]. As a result, fermented foods often exhibit improved digestibility, enhanced flavour, and extended shelf-life due to reduced pH and inhibition of pathogenic microorganisms [11,13], fermentation can significantly influence the functional properties of food materials, particularly their pasting characteristics. Pasting properties are critical rheological parameters that describe the behaviour of starch when subjected to heat and water, leading to swelling, gelatinization, and eventual disintegration of starch granules. These properties are typically evaluated using instruments such as a Rapid Visco Analyzer or a rotational rheometer, which measure viscosity changes during controlled heating and cooling cycles [14].

Key parameters include pasting temperature, peak viscosity, trough viscosity, breakdown viscosity, final viscosity, setback viscosity, and peak time. These attributes play a crucial role in determining the texture, stability, and overall quality of food products [15]. Understanding the effects of fermentation on both the nutritional composition and pasting behaviour of chickpea flour is essential for optimizing its utilization in food processing. Therefore, the present study was undertaken to evaluate the impact of fermentation on the nutrient profile and pasting properties of chickpea flour, with the aim of enhancing its application in the development of functional and nutritionally improved food products.

Materials and Methods

Procurement of Raw Materials

Mature chickpea (*Cicer arietinum* L.) seeds were procured from Ogbete Main Market, Enugu, Enugu State, Nigeria. The selection of this market was based on the availability of fresh, high-quality seeds from reliable vendors. The samples were transported to the laboratory and stored under appropriate conditions prior to analysis.

Pre-processing of Seed Samples

A total of 4 kg of chickpea seeds were manually sorted to remove extraneous materials such as stones, damaged seeds, and debris. The cleaned seeds were then divided into four equal portions (1 kg each). One portion was designated for the production of unfermented (raw) flour, while the remaining three portions were used for the preparation of fermented flours through spontaneous fermentation at ambient temperature (29 ± 2 °C) for 48, 72, and 96 hours, respectively.

Production of Unfermented Chickpea Flour

Unfermented chickpea flour was prepared following the method described by [16] with minor modifications. One kilogram of sorted seeds was thoroughly washed with approximately 2.5 L of potable water to remove adhering impurities. The seeds were then drained and dried in a hot air oven (Model DHG 9101 ISA) at 60 °C for 12 hours. The dried seeds were dehulled using an attrition mill, followed by winnowing to separate the hulls. The dehulled cotyledons were milled into fine flour and sieved through a 500 µm mesh sieve to obtain uniform particle size. The resulting flour was packaged in airtight polyethylene bags and stored under refrigeration until further analysis.

Production of Fermented Chickpea Flours

Fermented chickpea flours were produced according to the method described by [21], with slight modifications. Three kilograms of sorted seeds were cleaned and soaked in 4 L of potable water for 6 hours to facilitate softening and ease of dehulling. After soaking, the seeds were drained and manually dehulled. The dehulled seeds were milled into a uniform paste using an attrition mill and divided into three equal portions (1 kg each).

Each portion of the paste was transferred into separate covered plastic containers and mixed with potable water in a ratio of 3:2 (water: paste). The mixtures were allowed to ferment spontaneously by naturally occurring microflora at ambient temperature (29 ± 2 °C) for 48, 72, and 96 hours, respectively.

Upon completion of fermentation, excess water was decanted, and the fermented paste was dewatered manually.

The fermented pastes were subsequently dried in a hot air oven (Model DHG 9101 ISA) at 60 °C for 10 hours. The dried materials were milled into flour using an attrition mill and sieved through a 500 µm mesh sieve to ensure uniformity. Each flour sample was packaged separately in airtight polyethylene bags and stored under refrigerated conditions for subsequent analyses.

Proximate Composition and Energy Content

The unfermented and fermented chickpea flour samples were analyzed for moisture, crude protein, crude fat, ash, and crude fibre contents on a dry weight basis following standard procedures described in [17]. Carbohydrate content was estimated by difference. The energy value of each sample was calculated using the Atwater conversion factors, where protein and carbohydrate contents were multiplied by 4 kcal/g and fat content by 9 kcal/g. All analyses were conducted in triplicate, and mean values were reported.

Mineral Composition

Mineral analysis of the flour samples was carried out on a dry weight basis according to the methods outlined in [17]. Samples were subjected to dry ashing in a muffle furnace at 550 °C until a constant weight was achieved. The resulting ash was transferred into a 100 mL Erlenmeyer flask and digested with 20 mL of an acid mixture comprising concentrated nitric acid, perchloric acid, and sulphuric acid. The mixture was heated gently in a digestion unit under a fume hood until dense white fumes appeared, indicating complete digestion. The digest was allowed to cool, diluted with distilled water, and filtered into a 100 mL volumetric flask, then made up to volume with distilled water. The concentrations of calcium, magnesium, phosphorus, potassium, zinc, and iron were determined using an atomic absorption spectrophotometer (Perkin–Elmer Model 300, Norwalk, Connecticut, USA), calibrated with appropriate standard solutions. All measurements were performed in triplicate.

Vitamin Composition

Vitamin contents of the flour samples were determined on a dry weight basis following extraction procedures described in [17]. Ascorbic acid was quantified using the titrimetric method. Thiamine, niacin, riboflavin, and folic acid contents were determined using a digital fluorimeter, while vitamin A content was analyzed using a UV–Visible spectrophotometer (Model CE2021 – 2000 series, England). All determinations were conducted in triplicate to ensure accuracy and reproducibility.

Pasting Properties

The pasting properties of the flour samples were evaluated using a Rapid Visco Analyzer (RVA TECHMASTER, Perten Instruments, London) in accordance with the method described in [17]. Approximately 3 g of each flour sample was weighed and mixed with 25 mL of distilled water to form a slurry within the RVA canister. The canister was placed in the instrument, and the slurry was subjected to a controlled heating and cooling cycle, increasing from 50 °C to 95 °C and then cooling back to 50 °C over a 14-minute period. The parameters measured included peak viscosity, trough viscosity, breakdown viscosity, final viscosity, setback viscosity, pasting temperature, and peak time. All analyses were carried out in triplicate.

Statistical Analysis

The data obtained from all experimental determinations were subjected to one-way analysis of variance (ANOVA) using Statistical Product and Service Solutions (SPSS), version 28.0. Mean values were expressed as mean ± standard deviation of triplicate determinations. Differences among means were considered statistically significant at $p < 0.05$, and separation of means was performed using Tukey's post hoc test.

Results and Discussion

Proximate Composition and Energy Content of Unfermented and Fermented Chickpea Flour Samples

The proximate composition and energy values of both unfermented and fermented chickpea flour samples are presented in Table 1. The results demonstrate that fermentation significantly influenced the nutritional composition of chickpea flour.

The moisture content of the fermented samples ranged from 7.24% to 7.86%, with the highest value observed in the 96-hour fermented sample and the lowest in the 48-hour sample. A gradual increase in moisture content with extended fermentation time was evident. This trend may be attributed to increased water absorption and metabolic activities of fermenting microorganisms. The slightly higher moisture levels in fermented samples compared to the unfermented control could influence shelf stability, as higher moisture content is known to promote enzymatic and microbial activity, potentially leading to product deterioration. Generally, flour products with moisture content below 13% are considered microbiologically stable.

The crude protein content increased significantly ($p < 0.05$) with fermentation time, ranging from 14.71% to 22.46%. The highest protein content was recorded in the sample fermented for 96 hours. This increase can be attributed to microbial synthesis of protein and the breakdown of complex protein compounds into simpler, more bioavailable forms. Proteolytic activity during fermentation enhances amino acid availability by degrading protein–antinutrient complexes such as protein–phytate and protein–tannin interactions. Consequently, the improved protein profile of fermented chickpea flour suggests enhanced nutritional quality and digestibility.

From a nutritional standpoint, the observed increase in protein content is advantageous, given the fundamental roles of proteins in cellular growth, enzymatic and hormonal functions, immune regulation, and maintenance of physiological homeostasis. The enhancement recorded in this study is consistent with previous reports indicating that fermentation improves both the quantity and bioavailability of proteins in legumes. Overall, the findings suggest that extended fermentation, particularly up to 96 hours, significantly improves the nutritional quality of chickpea flour, thereby enhancing its suitability as a nutrient-dense ingredient in diverse food formulations.

The fat content of the fermented flours ranged from 2.71% to 3.12%, with significant differences ($p < 0.05$) observed among the samples. A notable reduction in fat content was recorded in the fermented samples compared to the unfermented control. This decline may be attributed to the activity of lipolytic enzymes during fermentation, which hydrolyze lipids into fatty acids and glycerol. Additionally, microorganisms may utilize these fatty acids as an energy source, leading to further reduction in fat levels. The decreased fat content enhances the nutritional profile of fermented chickpea flour, particularly for individuals managing conditions such as diabetes, cardiovascular disorders, and hypercholesterolemia. Although fats provide a concentrated source of energy and contribute to flavor, satiety, and thermal insulation, their reduction in this context may be beneficial for specific dietary applications.

The ash content of the fermented flour samples ranged from 2.14% to 2.38%, showing a slight increase with prolonged fermentation time. Since ash content is an indicator of total mineral composition, this trend suggests a relative enhancement of mineral availability in fermented samples. The values obtained in this study are lower than those reported for germinated pigeon pea flours, yet the increase compared to the unfermented sample indicates that fermentation may improve mineral concentration or bioavailability through the breakdown of antinutritional factors.

The crude fibre content ranged from 3.13% to 3.31% and exhibited a gradual increase with fermentation duration. This increase may be associated with microbial synthesis and structural modifications of plant cell wall components during fermentation. Although the values are lower than those reported for fermented maize flour, the higher fibre content relative to the unfermented sample is nutritionally beneficial. Dietary fibre plays a critical role in gastrointestinal health by enhancing digestion, promoting bowel movement, and facilitating the excretion of bile acids, sterols, and lipids.

The carbohydrate content of the fermented flour samples ranged from 62.07% to 68.16%, with a decreasing trend observed as fermentation time increased. The lowest value was recorded in the 96-hour fermented sample. This reduction is likely due to the enzymatic breakdown of complex carbohydrates into simpler sugars, which are subsequently metabolized by fermenting microorganisms. Such a decline in carbohydrate content is consistent with previous findings in fermented legume products. From a health perspective, reduced carbohydrate levels may be advantageous in formulating foods for individuals with metabolic disorders, including diabetes and cardiovascular diseases. Furthermore, fermentation enhances the digestibility of starch and protein fractions, thereby improving the overall nutritional quality and functional properties of the flour.

The energy content of the fermented chickpea flours ranged from 354.22 to 368.27 kJ/100 g. The sample fermented for 48 hours exhibited the lowest energy value (354.22 kJ/100 g), whereas the 96-hour fermented sample recorded the highest value (368.27 kJ/100 g). The observed increase in energy content with prolonged fermentation may be associated with the relative increase in protein concentration, as well as compositional shifts resulting from the reduction of carbohydrate and fat fractions. The energy values obtained in this study are higher than those previously reported for fermented African oil bean seed flour, indicating a comparatively improved caloric contribution, fermentation of chickpea seeds for 48, 72, and 96 hours resulted in a progressive enhancement of protein, ash, and crude fibre contents, accompanied by a modest reduction in fat and carbohydrate levels. These compositional modifications suggest that controlled fermentation can be effectively utilized to improve the nutritional quality and functional value of chickpea flour.

Table 1: Proximate composition (%) and energy content of unfermented and fermented chickpea flour samples

	Samples			
Parameters	**Unfermented**	**Fermented for 48 h**	**Fermented for 72 h**	**Fermented for 96 h**
Moisture	$6.24^{d}\pm0.13$	$7.24^{c}\pm0.01$	$7.51^{b}\pm0.33$	$7.86^{a}\pm0.01$
Crude Protein	$10.72^{d}\pm0.29$	$14.71^{c}\pm0.17$	$17.24^{b}\pm0.09$	$22.46^{a}\pm0.05$
Fat	$3.47^{a}\pm0.12$	$3.12^{b}\pm0.10$	$2.88^{c}\pm0.00$	$2.71^{d}\pm0.07$
Ash	$1.32^{d}\pm0.02$	$2.14^{c}\pm0.11$	$2.27^{b}\pm0.05$	$2.38^{a}\pm0.15$
Crude fibre	$2.14^{d}\pm0.22$	$3.13^{c}\pm0.14$	$3.20^{b}\pm0.16$	$3.31^{a}\pm0.06$
Carbohydrate	$74.66^{d}\pm0.05$	$68.16^{b}\pm0.02$	$64.47^{c}\pm0.41$	$62.07^{d}\pm0.21$
Energy (kJ/100g)	$343.46^{d}\pm0.03$	$354.22^{c}\pm0.12$	$363.36^{b}\pm0.19$	$368.27^{a}\pm0.02$

Values are mean ± standard deviation of triplicate replications. Means within the same row with the different superscripts are significantly ($p<0.05$) different.

Mineral Composition of Unfermented and Fermented Chickpea Flour Samples

The mineral composition of unfermented and fermented chickpea flour samples is presented in Table 2. The results indicate that fermentation significantly influenced the mineral profile of the flour samples.

The calcium content of the fermented chickpea flours ranged from 87.42 to 108.36 mg/100 g, with the highest value observed in the sample fermented for 96 hours and the lowest in the 48-hour sample. The progressive increase in calcium content with fermentation time may be attributed to microbial activity, which enhances mineral availability through biochemical transformations.

In particular, the reduction of antinutritional factors such as tannins—mediated by endogenous enzymes like tannase—may release bound calcium, thereby increasing its measurable concentration. The calcium values reported in this study exceed those documented for germinated chickpea flour, suggesting that fermentation may be more effective in improving calcium availability. Nutritionally, calcium is essential for bone development, especially in infants and children, and plays vital roles in nerve transmission, blood coagulation, and blood pressure regulation.

The potassium content of the fermented flour samples ranged from 94.75 to 126.21 mg/100 g. Similar to calcium, potassium levels increased with fermentation duration, with the lowest value recorded in the 48-hour

sample and the highest in the 96-hour sample. This increase may be attributed to enhanced mineral bioavailability resulting from the degradation of phytate and other antinutrients that typically bind potassium and limit its absorption. Microbial metabolism during fermentation may also contribute to the release or synthesis of mineral elements. These findings are consistent with previous reports indicating improved potassium availability in fermented legume products. Potassium is physiologically important for maintaining fluid and electrolyte balance, supporting muscle contraction, and contributing to normal cellular function.

The phosphorus content of the fermented chickpea flour samples ranged from 107.25 to 135.20 mg/100 g and exhibited a progressive increase with fermentation time. This trend may be attributed to enhanced mineral availability resulting from microbial activity during fermentation, particularly through the degradation of antinutritional factors such as phytates that otherwise bind phosphorus. The values obtained in this study are higher than those reported for soaked chickpea flour, indicating that fermentation is more effective in improving phosphorus availability. Nutritionally, phosphorus is a critical component of adenosine triphosphate (ATP), serving as a key molecule in cellular energy transfer, and is also essential for the formation and maintenance of healthy bones and teeth.

The magnesium content of the fermented samples increased markedly from 110.28 to 163.77 mg/100 g, compared to 92.35 mg/100 g in the unfermented flour. The observed increase with fermentation time may be associated with microbial metabolism and the breakdown of mineral-binding compounds, thereby enhancing magnesium bioavailability. Magnesium is vital for numerous physiological processes, including maintenance of nerve function, regulation of neuromuscular activity, protein synthesis, and muscle contraction. Similarly, the iron content of the fermented chickpea flours ranged from 9.24 to 14.40 mg/100 g, with the lowest value recorded in the 48-hour fermented sample and the highest in the 96-hour sample.

The increase in iron concentration with extended fermentation may be linked to the reduction of antinutrients such as phytates and tannins, which typically inhibit iron absorption, as well as possible microbial contributions to mineral release. These findings are consistent with previous reports demonstrating enhanced iron levels in fermented legume products. Iron plays a fundamental role in oxygen transport as a component of hemoglobin and myoglobin, and is essential for erythropoiesis and overall metabolic function in the human body.

The zinc content of the fermented chickpea flour samples ranged from 6.23 to 10.31 mg/100 g and showed a consistent increase with fermentation time. This enhancement may be attributed primarily to improved mineral bioavailability resulting from the degradation of antinutritional factors such as phytates, which typically bind zinc and limit its absorption. Microbial activity during fermentation may also contribute to the release of bound zinc, thereby increasing its measurable concentration. The zinc values obtained in this study are notably higher than those reported for processed lima bean flours, indicating the effectiveness of fermentation in enhancing micronutrient availability, the zinc content of the fermented samples was consistently higher than that of the unfermented flour, reinforcing the positive impact of fermentation on mineral enrichment. Zinc is an essential trace element involved in numerous biological functions, including its role as a cofactor for various enzymes required for protein synthesis, DNA replication, and cellular growth. It is also important in immune function, wound healing, and overall physiological development. In general, the findings confirm that fermentation is an effective processing technique for improving the mineral composition and bioavailability in chickpea flour. The overall increase in mineral content observed in the fermented samples underscores the nutritional advantage of fermentation over unprocessed forms.

Table 2: Mineral composition (mg/100g) of unfermented and fermented chickpea flour samples

	Samples			
Parameters	**Unfermented**	**Fermented for 48 h**	**Fermented for 72 h**	**Fermented for 96 h**
Calcium	74.42^{d}±0.11	87.42^{c}±0.09	95.65^{b}±0.66	108.36^{a} ±0.01
Potassium	88.37^{d}±0.19	94.75^{c}±0.17	112.33^{b} ±0.38	126.21^{a} ±0.06
Phosphorus	83.72^{d}±0.23	107.25^{c} ±0.02	122.65^{b} ±0.08	135.20^{a} ±0.05
Magnesium	92.35^{d}±0.54	110.28^{c}±0.14	134.76^{b} ±0.05	163.77^{a} ±0.11
Iron	7.35^{d}±0.12	9.24^{c}±0.06	11.22^{b} ±0.02	14.40^{a} ±0.04
Zinc	4.18^{d} ±0.35	6.23^{c} ±0.05	8.13^{b} ±0.12	10.31^{a} ±0.31

Values are mean ± standard deviation of triplicate replications. Means within the same row with the different superscripts are significantly ($p<0.05$) different.

Vitamin Composition of Unfermented and Fermented Chickpea Flour Samples.

The vitamin composition of unfermented and fermented chickpea flour samples is shown in Table 3.

The ascorbic acid content of the fermented chickpea flour samples ranged from 5.31 to 8.73 mg/100 g, with the highest value observed in the 96-hour fermented sample and the lowest in the 48-hour sample. A progressive increase in ascorbic acid content with fermentation time was evident. This enhancement may be attributed to microbial activity during fermentation, particularly the enzymatic synthesis and release of vitamin C through hydrolytic processes. Although the values obtained in this study are slightly lower than those reported for lime-cooked maize flour, the increase relative to the unfermented sample highlights the beneficial effect of fermentation. Nutritionally, ascorbic acid plays a vital role in strengthening blood vessel walls, supporting bone formation, enhancing immune response, and facilitating iron absorption.

The thiamine content of the fermented flour samples ranged from 2.22 to 7.32 mg/100 g, also showing a marked increase with extended fermentation time. The highest concentration was recorded in the 96-hour fermented sample, while the lowest was observed in the 48-hour sample. This increase may be associated with microbial biosynthesis of thiamine during fermentation, as well as compositional changes resulting from the breakdown or utilization of other components.

Additionally, the relative increase in thiamine concentration may reflect the reduction of competing constituents through leaching or microbial metabolism. Thiamine (vitamin B1) is essential for carbohydrate metabolism and functions as a coenzyme in the form of thiamine pyrophosphate (TPP), which is critical for energy production and proper cellular function.

The niacin content of the fermented chickpea flour samples ranged from 2.33 to 7.12 mg/100 g, with the highest value recorded in the sample fermented for 96 hours and the lowest in the 48-hour sample. The results indicate that fermentation significantly enhanced the niacin content relative to the unfermented flour. This increase may be attributed to microbial biosynthesis and enzymatic activities during fermentation, which facilitate the release and formation of niacin. Although the values obtained are slightly lower than those reported for germinated pigeon pea flour, the observed improvement confirms the positive effect of fermentation on vitamin enrichment. Nutritionally, niacin (vitamin B3) is essential for the metabolism of carbohydrates, proteins, and lipids, and plays a crucial role in maintaining the proper functioning of the nervous and digestive systems.

The riboflavin content of the fermented flours ranged from 2.14 to 7.18 mg/100 g, also showing a significant increase ($p < 0.05$) with extended fermentation time. The highest riboflavin concentration was observed in the 96-hour fermented sample, while the lowest was recorded in the 48-hour sample. The increase in riboflavin content may be associated with microbial synthesis and enzymatic transformations occurring during fermentation. Although the values are slightly lower than those reported for other processed legume flours, the trend clearly demonstrates enhancement due to fermentation. Riboflavin (vitamin B2) functions as a coenzyme in various metabolic pathways and is essential for energy production, cellular function, and redox reactions in the human body.

The folic acid content of the fermented chickpea flour samples ranged from 2.18 to 5.22 mg/100 g, with the highest value observed in the 96-hour fermented sample and the lowest in the 48-hour sample. The progressive increase in folic acid content with fermentation time may be attributed to microbial biosynthesis and enzymatic activity during the fermentation process. This trend is consistent with previous findings reported for processed chickpea products. Folic acid (vitamin B9) plays a critical role as a coenzyme in nucleic acid and amino acid metabolism and is essential for cell division and growth. It is also associated with the prevention of cardiovascular diseases and certain forms of cancer.

The vitamin A content of the fermented flour samples ranged from 2.44 to 6.57 mg/100 g and increased significantly ($p < 0.05$) with extended fermentation time. The highest value was recorded in the 96-hour fermented sample. This increase may be linked to enhanced bioavailability or transformation of precursor compounds during microbial activity. Although the values reported in this study are slightly lower than those documented for other fermented legume flours, the observed improvement confirms the beneficial effect of fermentation. Vitamin A is essential for vision, immune function, cellular differentiation, and the maintenance of epithelial tissues, the results demonstrate that fermentation markedly enhances the vitamin profile of chickpea flour. The fermented samples consistently exhibited higher concentrations of essential vitamins compared to the unfermented flour, highlighting fermentation as an effective processing technique for improving the micronutrient quality of legume-based food products.

Table 3: Vitamin composition (mg/100g) of unfermented and fermented chickpea flour samples

	Samples			
Parameters	**Unfermented**	**Fermented for 48 h**	**Fermented for 72 h**	**Fermented for 96 h**
Ascorbic Acid	$3.22^{d}\pm0.41$	$5.31^{c}\pm0.19$	$7.19^{b}\pm0.13$	$8.73^{a}\pm0.05$
Thiamine	$1.58^{d}\pm0.07$	$2.22^{c}\pm0.29$	$4.55^{b}\pm0.42$	$7.32^{a}\pm0.14$
Niacin	$1.16^{d}\pm0.11$	$2.33^{c}\pm0.33$	$4.21^{b}\pm0.17$	$7.12^{a}\pm0.01$
Riboflavin	$1.36^{d}\pm0.08$	$2.14^{c}\pm0.16$	$4.27^{b}\pm0.01$	$7.18^{a}\pm0.15$
Folic Acid	$1.38^{d}\pm0.15$	$2.18^{c}\pm0.02$	$3.74^{b}\pm0.18$	$5.22^{a}\pm0.19$
Vitamin A (IU)	$2.01^{d}\pm0.20$	$2.44^{c}\pm0.12$	$4.31^{b}\pm0.45$	$6.57^{a}\pm0.04$

Values are mean ± standard deviation of triplicate replications. Means within the same row with the different superscripts are significantly ($p<0.05$) different.

Pasting Properties of Unfermented and Fermented Chickpea Flour Samples

The pasting properties of unfermented and fermented chickpea flours are presented in Table 4, indicating significant modifications as a result of fermentation.

The peak viscosity of the fermented flours ranged from 46.15 to 73.21 RVU, with the highest value recorded in the sample fermented for 96 hours and the lowest in the 48-hour sample. The results demonstrate that fermentation increased the peak viscosity of the chickpea flours compared to the unfermented sample. This increase may be attributed to structural modifications of starch molecules and enhanced water absorption capacity resulting from enzymatic activities during fermentation [38]. Peak viscosity represents the maximum viscosity attained during heating and is directly related to the swelling ability of starch granules and the starch content of the flour [26]. The relatively high peak viscosity observed in the fermented samples suggests greater thickening potential; however, it may limit their suitability for complementary food formulations, where lower viscosity is generally preferred.

The trough viscosity of the fermented flour samples ranged from 32.74 to 54.18 RVU and decreased with increasing fermentation time. The highest trough viscosity was observed in the 48-hour fermented sample, while the lowest was recorded in the 96-hour sample. Trough viscosity reflects the ability of the paste to withstand breakdown under continuous heating and shear stress [15]. The reduction in trough viscosity with prolonged fermentation suggests decreased paste stability under heat but may also indicate a lower tendency for retrogradation. Compared to the unfermented flour, which exhibited a higher trough viscosity, the fermented samples may form more stable pastes with reduced susceptibility to gel hardening during storage. The breakdown viscosity of the fermented flour samples ranged from 37.40 to 64.37 RVU. The flour sample fermented for 96 h exhibited the highest

value (64.37 RVU), whereas the sample fermented for 48 h recorded the lowest value (37.40 RVU). The observed increase in breakdown viscosity with prolonged fermentation may be attributed to the progressive hydrolysis of starch granules by microbial enzymes, resulting in weakened structural integrity of the starch matrix [39]. Breakdown viscosity reflects the susceptibility of starch to disintegration under conditions of heat and mechanical shear. Therefore, the relatively higher breakdown values in the fermented samples indicate reduced resistance to thermal and shear stress compared to the unfermented flour.

The setback viscosity of the fermented chickpea flour samples ranged from 41.66 to 72.10 RVU. The lowest value was observed in the sample fermented for 96 h (41.66 RVU), while the highest value occurred in the 48 h fermented sample (72.10 RVU). A decreasing trend in setback viscosity with increasing fermentation time suggests a reduction in retrogradation tendency of the starch components. These values are considerably lower than those reported for germinated pigeon pea flours (218.02 to 243.26 RVU) [38]. Since setback viscosity is associated with the re-association of amylose molecules during cooling, the reduced values indicate improved paste stability and lower gel firmness in the fermented samples [39].

The final viscosity of the fermented flour samples ranged from 64.33 to 94.31 RVU and showed a decreasing trend with increased fermentation duration. This reduction may be linked to the enzymatic degradation of complex carbohydrates during fermentation, leading to diminished capacity for gel formation [38]. Final viscosity is an important parameter that indicates the ability of starch to form a stable paste or gel after cooking and cooling [23]. Consequently, the lower final viscosity observed in fermented chickpea flours suggests reduced thickening ability, which may influence their suitability in specific food applications requiring lower gel strength, fermentation significantly modified the pasting behaviour of chickpea flour, with extended fermentation (particularly 96 h) resulting in reduced retrogradation, lower final viscosity, and altered thermal stability. These changes are critical in determining the functional applications of the flour in food systems, particularly in products requiring improved digestibility, stability, and modified textural attributes [38, 39].

The peak time of the fermented chickpea flours ranged from 4.32 to 7.02 min. The sample fermented for 96 h exhibited the lowest peak time (4.32 min), whereas the 48 h fermented sample showed the highest value (7.02 min). A progressive decrease in peak time with increasing fermentation duration indicates that the fermented flours require less heating time to reach maximum viscosity. This suggests enhanced cooking efficiency, as the fermented samples would cook faster than the unfermented flour, which recorded a higher peak time (8.59 min). Peak time represents the duration required to attain peak viscosity during pasting and is widely regarded as an indicator of cooking time [38].

The pasting temperature of the fermented flour samples ranged from 60.22 to 87.43 °C and increased significantly ($p < 0.05$) with extended fermentation. Pasting temperature corresponds to the point at which a noticeable increase in viscosity begins, reflecting the onset of starch gelatinization [40]. The higher pasting temperatures observed in fermented samples, relative to the unfermented flour, suggest increased structural stability of starch granules and stronger intermolecular associations. This may be attributed to biochemical modifications induced during fermentation, including partial hydrolysis and molecular reorganization of starch components. Elevated pasting temperature also implies greater thermal energy requirement for gelatinization, which may influence processing conditions in food applications [38,39], fermentation exerted a pronounced effect on the pasting characteristics of chickpea flour. Specifically, extended fermentation increased peak viscosity, breakdown viscosity, and pasting temperature, while reducing trough viscosity, setback viscosity, final viscosity, and peak time. These modifications indicate improved cooking efficiency, reduced retrogradation tendency, and altered gel-forming capacity of the fermented flours, thereby enhancing their functional suitability for diverse food formulations [38–40].

Table 4: Pasting properties of unfermented and fermented chickpea flour samples

Parameters	Samples			
	Unfermented	**Fermented for 48 h**	**Fermented for 72 h**	**Fermented for 96 h**
Peak viscosity (RVU)	$33.26^{d}\pm0.03$	$46.15^{c}\pm0.06$	$56.33^{b}\pm0.02$	$73.21^{a}\pm0.01$
Trough viscosity (RVU)	$65.44^{a}\pm0.01$	$54.18^{b}\pm0.15$	$45.30^{c}\pm0.08$	$32.74^{d}\pm0.31$
Breakdown viscosity (RVU)	$30.24^{d}\pm0.06$	$37.40^{c}\pm0.07$	$42.24^{b}\pm0.01$	$64.37^{a}\pm0.10$
Setback Viscosity (RVU)	$86.56^{a}\pm0.02$	$72.10^{b}\pm0.03$	$65.32^{c}\pm0.09$	$41.66^{d}\pm0.06$
Final viscosity (RVU)	$103.16^{a}\pm0.11$	$94.31^{b}\pm0.05$	$81.12^{c}\pm0.07$	$64.33^{d}\pm0.07$
Peak time (Min)	$8.59^{a}\pm0.14$	$7.02^{b}\pm0.01$	$6.83^{c}\pm0.19$	$4.32^{d}\pm0.41$
Pasting temperature (°C)	$32.41^{d}\pm0.17$	$60.22^{c}\pm0.03$	$71.44^{b}\pm0.21$	$87.43^{a}\pm0.19$

Values are mean ± standard deviation of triplicate replications. Means within the same row with the different superscripts are significantly ($p<0.05$) different.

Conclusion

The present study demonstrates that fermentation is an effective processing strategy for enhancing the nutritional and functional quality of chickpea flour. Fermentation significantly improved the proximate composition, mineral profile, and vitamin content of the flour samples compared to the unfermented counterpart. Notably, increases were observed in protein, ash, crude fibre, calcium, potassium, phosphorus, magnesium, sodium, zinc, and essential vitamins including ascorbic acid, thiamine, riboflavin, niacin, folic acid, and vitamin A, while fat and carbohydrate contents showed a modest decline. These changes indicate an overall improvement in nutrient density and bioavailability, highlighting the potential of fermented chickpea flour as a valuable ingredient for nutritional enrichment, the enhanced nutritional profile suggests that fermented chickpea flour could be effectively utilized to fortify staple foods such as cereals, roots, and tubers, thereby addressing protein-energy malnutrition and micronutrient deficiencies, particularly in resource-limited settings, fermentation altered the pasting characteristics of chickpea flour.

Reductions in trough, setback, and final viscosities, along with decreased peak time, indicate improved paste stability and reduced retrogradation tendency. Conversely, increases in peak viscosity, breakdown viscosity, and pasting temperature suggest modifications in starch behavior that may influence processing and product quality, the findings confirm that fermentation, especially at extended durations, enhances both the nutritional composition and functional performance of chickpea flour. Consequently, fermented chickpea flour holds considerable promise for application in diverse food systems, offering both health and technological advantages over unfermented flour.

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