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Proximate composition, amino acid profile, and vitamin contents of *Kadal* (A fermented grain flour), Produced from Blends of Millet and Bambara Groundnut Flours

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Abstract

Kadal flour is a fermented grain flour that is produced by naturally fermenting grains in water, washing, drying, milling, and sieving. This study evaluated the effect of natural fermentation and fermented Bambara groundnut supplementation on the nutritional quality of kadal flour produced from whole and decorticated millet grains. Millet and Bambara groundnut were fermented for 72 h, processed into flour, and blended at millet-to-Bambara groundnut ratios of 80:20, 70:30, and 60:40, for both whole millet and Bambara groundnut and decorticated millet and Bambara groundnut kadal flour blends, with control samples composed of 100% whole and 100% decorticated millet kadal flours, respectively. Proximate composition, energy value, amino acid profile, and vitamins B_1 and B_9 were determined using standard methods. Fermentation increased moisture and fibre contents but reduced protein, ash, carbohydrate, energy value, and as well as most of the essential and non-essential amino acids, with significant decrease in decorticated millet kadal flour. However, the fermentation process resulted to increase in phenylalanine, threonine, and tyrosine contents. Supplementation with fermented Bambara groundnut flour significantly improved protein, fat, ash, fibre, carbohydrate, energy values, amino acid contents, and vitamins B_1 and B_9, with higher inclusion levels producing greater increases. Whole millet–Bambara groundnut kadal flour blends had higher contents than their decorticated grain counterparts. The sample with 60% whole millet and 40% whole Bambara groundnut) recorded the highest nutrient contents and energy value of 380.11 kcal/100 g. It was concluded that production of kadal flour from blends of whole millet and Bambara groundnut could help in reducing the problem of malnutrition particularly in sub-Saharan Africa. Moreover, decortication of grains destined for kadal flour processing is not recommended as it leads to greater loss in nutrients.

Keywords: Fermentation, kadal flour, millet, Bambara groundnut, whole grain

Introduction

Millets are annual cereal grasses cultivated primarily for the production of edible grains (Geetha *et al*.,2025) [14]. Pearl millet is a nutrient-dense cereal that contains substantial amounts of both macro- and micronutrients (Yehuala *et al*., 2025) [38]. Millet contains 347 Kcal/100g energy, 10.9g protein,5.43g fat, and 61.8g carbohydrate (Pandey *et al*., 2025) [28]. Furthermore, pearl millet is an important source of micronutrients, including folate, copper, zinc, iron, magnesium, calcium, and several B vitamins, as well as unsaturated fatty acids (Dayakar *et al*., 2018) [9]. Bambara groundnut (Vigna subterranea) is an underutilized and under-researched legume belonging to the family Fabaceae and the subfamily Faboideae (Mudau and Adebo 2025; Ramatsetse *et al*., 2023) [21, 30]. It has considerable potential for addressing malnutrition worldwide, especially in Africa, because it is rich in protein, essential amino acids, dietary fibre, and vitamins. Beyond its nutritional value, the crop also contains antioxidant compounds, including phenolics, flavonoids, and tocopherols, which help neutralize free radicals and may contribute to the prevention of oxidative damage (Songule *et al*.,2025; Adedayo *et al*., 2021; Oyeyinka *et al*., 2021) [2, 27, 33].

Blends of cereals and legumes have attracted considerable interest in nutritional research (Adegoke *et al*., 2025). Cereals are rich sources of carbohydrates that supply dietary energy, whereas legumes contribute substantial amounts of protein, dietary fibre, and essential micronutrients (Olson *et al*., 2021).

The combination of these food groups provides a more balanced nutrient composition, which is important for combating persistent food insecurity, protein energy malnutrition, and nutrition related health conditions among infants, children, and adults (Kumari and Sangeetha, 2016 [16]; Olson *et al*., 2021).

Fermentation is a microbial biotransformation process that has been practiced worldwide for thousands of years in the production of foods, beverages, and dairy products (Fitsum *et al*., 2025). Through microbial activity, it enhances food preservation, generates a wide range of products, and improves nutritional quality, sensory characteristics, and shelf life. Fermentation is especially important in resource-limited settings because it increases nutrient bioavailability, reduces antinutritional factors, and produces beneficial bioactive compounds (Sharma *et al*., 2020 [34]; Voidarou *et al*., 2021).

Kadal flour is a fermented grain flour that is produced by steeping grains in water to ferment naturally, washing, drying, milling, and sieving the grains (Umar *et al*., 2022). It is commonly produced and consumed by some tribes in northern Nigeria, when it is transformed into a stiff dough and eaten with local soups. This research aimed to produce *kadal* flour from blends of whole and decorticated millet and Bambara groundnut in order to improve the nutritional quality of *kadal* flour that is usually prepared from cereal grains alone.

Materials and Methods

Two kilograms each of millet and Bambara groundnut were cleaned and divided into two portions, with one millet portion decorticated using an Abrasive disc dehuller and winnowed. All portions were separately steeped in 15 liters of water and naturally fermented for 72 hours. After fermentation, one Bambara groundnut portion was decorticated using a clean wooden mortar and pestle, and all grains were washed, sun-dried, milled separately, sieved through a 400 µm mesh, packaged in coded plastic buckets, stored at ambient temperature. *Kadal* flours blends were produced from fermented whole millet and Bambara groundnut, at millet: Bambara groundnut ratios of 80:20, 70:30, and 60:40. The same ratios were used to formulate *kadal* flour from blends of decorticated millet and Bambara ground. Control samples consisted of 100% whole millet flour for whole-grain *kadals* and 100% decorticated millet flour for decorticated-grain *kadals*.

Proximate composition of the *kadal* flour samples was determined using standard AOAC procedures. Moisture was measured by oven drying, crude fat by Soxhlet extraction, ash by muffle furnace incineration, crude fibre by sequential acid–alkali digestion, protein by the Kjeldahl method, and carbohydrate by difference (AOAC, 2010). Energy value was determined by the Atwater general factor method using the conversion factors of 4 kcal/g for protein, 4 kcal/g for carbohydrate, and 9 kcal/g for fat (Egan *et al*., 1981 [10]; FAO, 2003). The amino acid profile of the *kadal* flour samples was determined using the methods described by Benítez (1989) [8]. Vitamins B_1 and B_9 were determined as described by Albawarshi *et al*. 2022) [6].

Results and Discussion

The moisture content increased significantly ($P < 0.05$) after fermentation, from 8.95 ± 0.01% in raw millet flour to 11.75 ± 0.01% in whole millet *kadal* and 12.96 ± 0.02% in decorticated millet *kadal* (Table 1). The increase in the moisture content may be attributed to water absorption during the 72-hour fermentation period. Decorticated millet *kadals* had higher moisture contents than whole millet *kadals*. The incorporation of fermented Bambara groundnut flour reduced moisture content in both whole and decorticated grain *kadal* flour blends, with values decreasing as the proportion of fermented Bambara groundnut increased, ranging from 10.14–11.31% and 10.61–11.40%, respectively. Ojokoh and Bello (2014) [24] also reported an increase in the moisture content of fermented millet and soybean flour blends from 5.74% to 7.28%. Akinola *et al*. (2017) [4], however, reported a decrease in the moisture content of millet flour from 5.93% to 4.94% after fermentation. Lower moisture content is desirable because it improves shelf life and storage stability. Protein content decreased significantly ($P \leq 0.05$) after fermentation, from 9.69% in raw millet flour to 8.34% in whole millet *kadal* and 7.59% in decorticated millet *kadal*. Yahuza and Baba (2025) [37] however, reported an increase in the protein content of millet flour after fermentation from 11.50 to 13.40%. The decrease in the protein content of millet flour after fermentation may be attributed to microbial degradation and utilization of proteins during fermentation. However, supplementation with fermented Bambara groundnut flour increased protein content in both whole and decorticated grain *kadal* flour blends. The whole grain *kadal* flour blends had higher protein values (8.53–8.74%) than decorticated grain *kadal* flour blends (7.64–7.91%). The higher protein content of the whole grain *kadal* flour blends was due to the presence of the bran and germs which are rich in protein. Similar increase in protein contents in fermented millet and soybean flour blends were reported by Ojokoh and Bello (2014) [24]. Fat content increased significantly from 4.50% in raw millet flour to 5.34% in whole millet *kadal*, but decreased to 3.89% in decorticated millet *kadal*. Similar increase in fat content after millet fermentation were reported by Ekissi *et al*. (2020) [11] and Akinola *et al*. (2020) Madau and Adebo (2024) [5, 20], who reported increase from 2.80 to 6.95%, 1.83 to 3.71%, and 6.50 to 9.70g/kg, respectively. The increase in the fat content of whole millet *kadal* may be due to ester formation during fermentation and retention of the lipid rich germ. Addition of fermented Bambara groundnut flour further increased fat content in both whole and decorticated *kadal* flour blends, ranging from 5.56–5.75% and 4.16–4.32%, respectively. Ojokoh and Bello (2014) [24] observed a decrease in fermented millet–soybean flour. Ash content decreased significantly after fermentation, from 1.68% in raw millet flour to 1.45% in whole millet *kadal* and 1.14% in decorticated millet *kadal*. Contrary to the findings in the present study, Yahuza and Baba (2025) and madau and Adebo (2024) [20, 37], both reported significant incease in the ash content of millet after fermentation from 2.10 to 2.30% and 15.50 to 16.60g/kg, espectively. The reports by Ekissi *et al*. (2020) [11] and Akinola *et al*. (2017) [4], were in agreement with the findings in the present study, as they also reported significant decrease in the ash content of millet flour after fermentation from 1.25% to 0.94% and 4.37% to 3.34%, respectively. The decrease in ash content after fermentation may be attributed to the leaching of soluble inorganic salts during fermentation (Akinola *et al*., 2017) [4]. Decorticated *kadal* flour had lower ash contents because the seed coat, which contains a substantial proportion of the grain minerals, was removed during decortication. Addition of fermented Bambara groundnut flour significantly increased ash content in both whole and decorticated grain *kadal* flour blends, ranging from 1.54–1.74% and 1.23–1.36%, respectively. Onweluzo and Nwabugwu (2009), however, reported a decrease in the ash content of fermented millet and pigeon pea flour from 3.75% to 2.90%. The findings of Ojokoh and Bello (2014) [24] agree with the present study, as they also reported an increase in the ash content of fermented millet and soybean flour, although the values reported (2.64%–3.92%) were higher than those obtained in the present study. Fibre content increased significantly after fermentation, from 2.29% in raw millet flour to 2.56% in whole millet *kadal* and 2.36% in decorticated millet *kadal*. Increasing levels of fermented Bambara groundnut flour further increased fibre content, ranging from 2.58–2.72% in whole-grain blends and 2.40–2.50% in decorticated-grain blends. Similar increases in fiber content after fermentation were reported by Madau and Adebo (2025) [21], and Ekissi *et al*. (2020) [11], from 27.10 to 49.40g/kg and 2.25% to 4.43%. Yahuza *et al*. (2025) [37] and Akinola *et al*. (2017) [4] however, reported a decrease in the fiber content of millet flour after fermentation from 7.80 to 7.50% and 1.20% to 0.54%, respectively.

The increase in fiber content after fermentation may be attributed to the activity of cellulolytic microorganisms that modify fibre-related compounds during fermentation (Adebo *et al*., 2022 [1]). Carbohydrate content decreased significantly after fermentation, from 72.88% in raw millet flour to 70.46% in whole millet *kadal* and 72.07% in decorticated millet *kadal*. The higher carbohydrate contents in the decorticated *kadal* was attributed to removal of the bran and germ, which increased the relative starch concentration. The addition of fermented Bambara groundnut flour increased the carbohydrate content in both whole- and decorticated-grain blends, reaching 72.90% in WMLBK3 and 73.31% in DMLBK3. Similar decreases in carbohydrate content after fermentation were reported by Yahuza and Baba (2025) [37], from 65.00 to 62.70%. The decrease in fiber content after fermentation may be due to microbial fermentation, α-amylase-mediated starch hydrolysis, and other enzymatic activities that break down carbohydrates into simpler sugars (Adebo *et al*., 2022 [1]).

The energy value of raw millet flour (371.38 kcal/100g) decreased significantly after fermentation to 364.38 kcal/100g in whole millet *kadal* and 354.65 kcal/100g in decorticated millet *kadal*. In line the the findings in the present study, Yahuza and Baba (202%0, also reported a significant decrease in the energy value of millet flour after fermentation from 364.30 to 361.10%. Supplementation with fermented Bambara groundnut flour significantly increased the energy value in both whole- and decorticated-grain blends, with WMLBK3 recording the highest value (380.11 kcal/100 g) among the whole-grain blends and DMLBK3 the highest (366.68 kcal/100g) among the decorticated-grain blends. On the other hand, the essential amino acid profile of the millet–Bambara groundnut *kadal* flour blends generally decreased after fermentation but improved with supplementation of fermented Bambara groundnut flour at varying inclusion levels (Table 2a).

The decline in amino acid concentrations during the natural fermentation of millet flour is largely driven by the metabolic activities of fermenting microorganisms. During fermentation, proteolytic enzymes produced by lactic acid bacteria (LAB) and yeasts break down storage proteins into smaller peptides and free amino acids. These released amino acids are then assimilated by the microorganisms for cell growth and protein synthesis or further transformed into various metabolic compounds, leading to a reduction in their measurable concentrations in the fermented flour (Samtiya *et al*., 2022; Mohapatra *et al*., 2024) [19, 35] The reduction in essential amino acids was more pronounced in the decorticated millet flour than in the whole millet flour, while the incorporation of fermented Bambara groundnut flour resulted in increased amino acid contents. The tryptophan content decreased significantly after fermentation, from 5.16±0.01 in raw millet flour (RMLF) to 1.94±0.01mg/100g protein in whole millet *kadal* (WMLK) and 2.56±0.01mg/100g protein in decorticated millet *kadal* (DMLK) (Table 2a).

Table 1: Proximate Composition of *kadal* Prepared from Blends of Millet and Bambara Groundnut flours

Sample Code[2]	**Parameters (%)**[1]						
	Moisture	**Protein**	**Fat**	**Ash**	**Fiber**	**Carbohydrate**	**Energy Value***
RMLF	8.95^{g}±0.01	9.69^{a}±0.03	4.50^{e}±0.03	1.68^{b}	2.29^{h}±0.01	72.88^{d}±0.04	371.38^{b}±0.04
WMLK	11.75^{b}±0.01	8.43^{e}±0.03	5.34^{d}±0.04	1.45^{d} 0.02	2.56^{c}±0.02	70.46^{h}±0.02	364.38^{f}±0.02
WMLBK1	11.31^{c}±0.02	8.53^{d}±0.05	5.56^{c}±0.02	1.54^{c}±0.02	2.58^{c}±0.02	70.49^{g}±0.01	367.04^{d}±0.05
WMLBK2	10.70^{e}±0.01	8.62^{c}±0.09	5.69^{b}±0.01	1.65^{b}±0.03	2.65^{b}±0.02	70.69^{f}±0.03	370.01^{c}±0.06
WMLBK3	10.14^{f}±0.01	8.74^{b}±0.16	5.75^{a}±0.02	1.74^{a} 0.01	2.72^{a}±0.01	72.90^{d}±0.03	380.11^{a}±0.03
DMLK	12.96^{a}±0.02	7.59^{i}±0.04	3.89^{i}±0.02	1.14^{h}±0.01	2.36^{g}±0.01	72.07^{e}±0.02	354.65^{i}±0.02
DMLBK1	11.40^{d}±0.03	7.65^{h}±0.08	4.16^{h}±0.02	1.23^{g} 0.02	2.40^{f}±0.02	73.10^{c}±0.05	362.04^{h}±0.07
DMLBK2	11.10^{d}±0.04	7.73g±0.09	4.23^{g}±0.01	1.28^{c} 0.01	2.46^{e}±0.01	73.21^{b}±0.04	363.79^{g}±0.06
DMLBK3	10.61^{e}±0.01	7.91^{f}±0.54	4.32^{f}±0.03	1. 0.02	2.50^{d}±0.03	73.31^{a}±0.01	366.68^{e}±0.02

[1]Values are Means ± Standard Deviations of Duplicate Determinations. In any column, means bearing similar superscripts are not significantly different at p-value of 5% (P>0.05).

[2]WMLF = Whole Millet Flour; WMLK = Whole Millet *kadal*; DMLK = Decorticated Millet *kadal*; WMLBK = Whole Millet and Bambara groundnut *kadal*; DMLBK = Decorticated Millet and Bambara groundnut *kadal*; 1, 2, and 3 represents ration of Maize to Bambara groundnut 80:20, 70:30, and 60:40, respectively.

*Energy was expressed in Kcal/100g

However, supplementation with fermented whole and decorticated Bambara groundnut flour significantly improved the tryptophan content of the *kadal* flour blends. The values increased with higher proportions of fermented Bambara groundnut flour, ranging from 2.74±0.02 to 4.17±0.01mg/100g protein in the whole-grain blends and from 2.98±0.03 to 3.82±0.01mg/100g protein in the decorticated-grain blends. Nevertheless, these values remained lower than the 5.16 ± 0.01 recorded for raw millet flour. Mohapatra *et al*. (2024) [19], contrary to the findings in the present study, reported an increase in the tryptophan content of LAB-fermented millet flour, 0.28 to 0.34 mg/100 g protein, although the values obtained in their study were co lower than those observed in the present work. Histidine content decreased significantly after fermentation, from 3.23 ± 0.01 in raw millet flour to 0.68 ± 0.01mg/100 g protein in whole millet *kadal* and 0.83 ± 0.03 mg/100 g protein in decorticated millet *kadal*. Similar reductions in histidine content after fermentation of millet flour were reported by Osman (2010) [26], from 2.25 to 2.00g/16gN, whereas Mohapatra *et al*. (2024) [19] however, observed an increase in the histidine content of LAB-fermented pearl millet flour from 5.55 to 10.18mg/100g protein. Supplementation with fermented Bambara groundnut flour significantly increased histidine content in both whole- and decorticated-grain blends, rising from 1.13 to 1.32mg/100g protein and 1.18 to 1.75mg/100g protein. The leucine contents also decreased significantly after fermentation from 5.41±0.01 in raw millet flour to 0.95 ± 0.02 mg/100 g protein in whole millet *kadal* (WMLK), and 3.07±0.01mg/100 g protein in decorticated millet *kadal* (DMLK). The leucine contents increased significantly upon the addition of fermented Bambara groundnut flour. The highest increase of 3.65±0.02 (WMLBK3) was observed for whole millet and Bambara groundnut flour blends, and 4.83±0.01 in sample (DMLBK3) for decorticated millet and Bambara groundnut *kadal* flour blends. Fermentation significantly reduced the isoleucine content of millet flour, decreasing from 4.95 ± 0.01 in raw millet flour (RMLF) to 1.36±0.01mg/100g protein in whole millet *kadal* (WMLK) and 1.85±0.04mg/100g protein in decorticated millet *kadal* (DMLK). However, supplementation with fermented Bambara groundnut flour increased the isoleucine content, with the highest value recorded in WMLBK3 (7.34±0.01) and DMLBK3 (4.78±0.01). Osman (2010) [26] also reported a decrease in the isoleucine content from 9.54 to 18.92 mg/100 g protein in raw and fermented millet flours, respectively.

Fermentation significantly increased the phenylalanine content of millet flour, increasing it from 2.13±0.01 in raw millet flour to 6.26±0.02mg/100g protein in whole millet *kadal* and 3.46±0.06mg/100 g protein in decorticated millet *kadal*. Supplementation with fermented Bambara groundnut flour further improved the phenylalanine levels, with the highest values recorded in WMLBK3 (8.93±0.01mg/100g protein) and DMLBK3 (6.15±0.05mg/100g protein). These findings indicate that both fermentation and Bambara groundnut supplementation contributed to improved phenylalanine content, consistent with reports by Osman (2010) and Mohapatra *et al*. (2024) [19, 26].

The valine content of millet flour decreased significantly after fermentation, from 6.34 ± 0.01 in raw millet flour to 2.76 ± 0.01mg/100g protein in whole millet *kadal* and 1.82 ± 0.02 mg/100 g protein in decorticated millet *kadal*. However, supplementation with fermented Bambara groundnut flour significantly improved the valine content, increasing from 3.87±0.02 to 4.34± 0.01 mg/100g protein in the whole millet blends and from 2.98±0.03 to 4.81±0.01 mg/100g protein in the decorticated millet blends. Similar reductions in valine after millet fermentation were reported by Osman (2010) [26], from 5.41 to 5.05g/16gN whereas Mohapatra *et al*. (2024) [19] reported an opposite trend, observing a significant increase in valine content following fermentation from 9.23 to 18.63 mg/100 g protein.

The lysine content of raw millet flour (RMLF) decreased significantly after fermentation, from 5.17±0.01 to 3.87±0.02mg/100g protein in whole millet *kadal* (WMLK) and 2.00 ± 0.02 mg/100 g protein in decorticated millet *kadal* (DMLK). However, the incorporation of fermented Bambara groundnut flour significantly improved the lysine content, with the highest values recorded in WMLBK3 (4.26±0.01) for whole grain blends and DMLBK3 (4.81±0.01) for decorticated grain blends.

The methionine content of raw millet flour (RMLF) decreased significantly after fermentation, from 5.17±0.01 to 2.23±0.02mg/100g protein in whole millet *kadal* (WMLK) and 1.87±0.02mg/100g protein in decorticated millet *kadal* (DMLK). The addition of fermented Bambara groundnut flour significantly increased methionine levels in both blend types, with values ranging from 2.73±0.03 to 5.26±0.01 mg/100g protein in whole millet blends and from 2.77±0.03 to 3.88±0.01mg/100g protein in decorticated millet blends. Nevertheless, Osman (2010) and Mohapatra *et al*. (2024) [19, 26] reported slight increases in methionine content after millet fermentation, which contrasts with the decrease observed in the present study.

The threonine content of raw millet flour (RMLF) increased significantly after fermentation, rising from 0.97±0.01 to 1.54±0.02 mg/100 g protein in whole millet *kadal* (WMLK) and 1.81±0.02 mg/100g protein in decorticated millet *kadal* (DMLK). Additional significant increases were observed in the fermented millet–Bambara groundnut flour blends, with values increasing from 2.45±0.03 to 4.23±0.02 mg/100g protein in the whole grain blends and from 2.62±0.03 to 4.54±0.01mg/100g protein in the decorticated grain blends. However, these findings differ from those reported by Osman (2010) [26], who observed a decrease in threonine content following pearl millet fermentation. Fermentation significantly increased the threonine content of millet flour from 0.97 ± 0.01 in raw millet flour (RMLF) to 1.54±0.02 mg/100g protein in whole millet *kadal* (WMLK) and 1.81±0.02mg/100g protein in decorticated millet *kadal* (DMLK). Supplementation with fermented Bambara groundnut flour further increased threonine levels, reaching 4.23± 0.02mg/100 g protein in whole millet *kadal*, and 4.54±0.01mg/100g protein in decorticated millet *kadal*. These findings contrast with Osman (2010) [26], who reported a decrease in threonine content after pearl millet fermentation.

Fermentation also led to a significant reduction in some non-essential amino acids, including asparagine and arginine, whereas supplementation with fermented Bambara groundnut flour significantly enhanced their concentrations in both whole and decorticated millet blends (Table 2b). The decline in amino acid concentration during cereal flour fermentation is mainly due to the metabolic activities of lactic acid bacteria and yeasts, which hydrolyze storage proteins into peptides and free amino acids before utilizing many of them for microbial growth and converting others into metabolic compounds, thereby reducing their measurable concentrations (Nkhata *et al*., 2018; Tamang *et al*., 2020) [23, 34]. Additionally, prolonged soaking during fermentation causes water-soluble amino acids and peptides to leach into the steeping water, leading to further losses in the final flour (Nkhata *et al*., 2018) [23]. Asparagine decreased from 5.64 ± 0.05mg/100g protein in raw millet flour to 3.61±0.03mg/100g protein in whole millet *kadal* (WMLK) and 3.16±0.01mg/100g protein in decorticated millet *kadal* (DMLK), but increased significantly to 6.32 ± 0.01mg/100g protein in whole millet *kadal* and 4.13± 0.01mg/100g protein in decorticated millet *kadal* after Bambara groundnut addition. Similarly, the arginine content of raw millet flour (RMLF), 5.91±0.02, decreased significantly to 2.80±0.01mg/100g protein in whole millet *kadal* (WMLK), and 2.73±0.01mg/100g protein in decorticated

Table 2a: Essential Amino Acid Profile of *Kadal* Prepared from Blends of Whole and Decorticated Millet and Bambara Groundnut Flours

Sample Code[2]	**Amino Acids (mg/100g protein)[1]**								
	Tryptophan	**Histidine**	**Leucine**	**Isoleucine**	**phenylalanine**	**Valine**	**Lysine**	**methionine**	**Threonine**
RMLF	5.16^{a}±0.01	3.23^{a}±0.01	5.41^{a}±0.01	4.97^{b}±0.01	2.13i±0.01	6.34^{a}±0.01	5.17^{b}±0.01	5.17^{b}±0.01	0.97^{h}±0.01
WMLK	1.94^{i}±0.01	0.68^{g}±0.01	0.95^{h}±0.02	1.36^{b}±0.02	6.26^{d}±0.02	2.76^{g}±0.01	3.87d±0.02	2.23^{h}±0.02	1.54^{g}±0.02
WMLBK1	2.74^{g}±0.02	1.13^{e}±0.01	2.85^{g}±0.02	2.97^{e}±0.01	7.32^{c}±0.01	3.87e±0.02	3.79e±0.02	2.73^{g}±0.03	2.45^{e}±0.03
WMLBK2	3.35^{d}±0.02	1.23^{d}±0.03	3.41^{e}±0.01	4.04^{d}±0.01	8.13^{b}±0.01	4.02$^{d\pm}$0.01	4.17c±0.01	4.11^{c}±0.03	3.85^{c}±0.05
WMLBK3	4.17^{b}±0.01	1.32^{c}±0.02	3.65^{d}±0.02	7.34^{a}±0.01	8.93^{a}±0.09	4.34$^{c\pm}$0.01	4.26b±0.01	5.26^{a}±0.01	4.23^{b}±0.02
DMLK	2.56^{h}±0.01	0.83^{f}±0.03	3.07^{f}±0.03	1.85^{g}±0.04	3.41^{h}±0.06	1.82$^{h\pm}$0.02	2.00^{i}±0.02	1.87^{i}±0.02	1.87^{f}±0.01

DMLBK1	$2.98^{f}\pm0.03$	$1.18^{d}\pm0.03$	$3.67^{d}\pm0.01$	$2.55^{f}\pm0.00$	$5.64^{g}\pm0.05$	$2.98^{f}\pm0.03$	$2.71^{h}\pm0.01$	$2.77^{f}\pm0.02$	$2.62^{d}\pm0.03$
DMLBK2	$3.17^{e}\pm0.01$	$1.32^{c}\pm0.01$	$3.86^{c}\pm0.02$	$4.04^{d}\pm0.02$	$5.94^{f}\pm0.01$	$3.87^{e\pm}0.02$	3.26f±0.02	$3.26^{e}\pm0.02$	$3.86^{c}\pm0.01$
DMLBK3	$3.82^{c}\pm0.01$	$1.75^{b}\pm0.01$	$4.83^{b}\pm0.01$	$4.78^{c}\pm0.01$	$6.15^{e}\pm0.05$	$4.81^{b\pm}0.01$	$4.81^{a}\pm0.02$	$3.88^{d}\pm0.04$	$4.54^{a}\pm0.01$

[1]Values are Means ± Standard Deviations of Duplicate Determinations. In any column, means bearing similar superscripts are not significantly different at p-value of 5% (P>0.05).

[2]WMLF = Whole Millet Flour; WMLK = Whole Millet *kadal*; DMLK = Decorticated Millet *kadal*; WMLBK = Whole Millet and Bambara groundnut *kadal*; DMLBK = Decorticated Millet and Bambara groundnut *kadal*; 1, 2, and 3 represents ration of Maize to Bambara groundnut 80:20, 70:30, and 60:40, respectively.

Millet *kadal* (DMLK) but increased to 3.78 ± 0.02mg/100g protein in WMLBK3 and 4.15 ± 0.04mg/100g protein in DMLBK3 with Bambara groundnut supplementation. Osman (2010) [26] reported a decrease in the arginine content of fermented millet flour, from 4.28 to 3.28g/16 g N, which agrees with the findings in the present study. Mohapatra *et al*. (2024) [19], however, reported an increase in the arginine content of LAB-fermented millet flour from 22.12 to 42.80mg/100g protein. The alanine content of raw millet flour (RMLF) was 2.14 ± 0.0101mg/100g protein and decreased significantly after fermentation to 1.84 ± 0.0201mg/100g protein in whole millet *kadal* (WMLK) and 0.36±0.0101mg/100g protein in decorticated millet *kadal* (DMLK). However, supplementation with fermented Bambara groundnut flour increased the alanine content, reaching 4.62 ± 0.0101mg/100g protein in whole grain *kadal* flour blend and 1.46 ± 0.02 01mg/100g protein in decorticated grain *kadal* flour blends. Osman (2010) [26] reported a slight decrease in alanine after millet fermentation, whereas Mohapatra *et al*. (2024) [19] observed an increase in LAB-fermented millet flour.

Similarly, the aspartic acid content decreased significantly from 6.46 ± 0.03 in raw millet flour to 2.71 ± 0.0101mg/100g protein in WMLK and 2.82±0.0101mg/100g protein in DMLK. Supplementation with fermented Bambara groundnut increased the content to 5.82 ± 0.02 in WMLBK3 and 4.12 ± 0.04 in DMLBK3. This decrease agrees with Osman (2010) [26], who also reported a reduction in aspartic acid following millet fermentation. The glutamic acid content decreased from 2.42 ± 0.02 in raw millet flour to 2.25 ± 0.0101mg/100g protein in DMLK and 1.77 ± 0.01 01mg/100g protein in WMLK. However, Bambara groundnut supplementation significantly increased glutamic acid, from 2.85 ± 0.04 to 3.48 ± 0.02 in the decorticated blends and from 2.53 ± 0.04 to 4.16 ± 0.02 in the whole millet blends. Glycine also decreased significantly after fermentation, from 4.45 ± 0.02 in raw millet flour to 3.14 ± 0.02 in WMLK and 3.13 ± 0.01 in DMLK. The addition of fermented Bambara groundnut flour increased glycine, with the highest values of 4.45 ± 0.02 in decorticate grain *kadal* flour blend and 7.35 ± 0.03 in the whole-grain blend. Osman (2010) [26] similarly reported a decrease in glycine content in millet dough, from 2.72 to 2.48g/16gN after 24 hours of fermentation. In contrast, Mohapatra *et al*. (2024) [19] observed an increase in glycine content in LAB-fermented millet flour, from 10.53 to 22.60 mg/100 g protein.

The tyrosine content of millet flour increased slightly after fermentation, from 3.24 ± 0.02 in raw millet flour to 3.41 ± 0.02mg/100g protein in whole millet *kadal* and 3.12 ± 0.01mg/100g protein in decorticated millet *kadal*. Supplementation with fermented Bambara groundnut flour further increased tyrosine, reaching 4.44 ± 0.02mg/100g protein in whole grain *kadal* and 4.11 ± 0.03 in decorticated grain *kadal*. This agrees with Osman (2010) [26], who also reported a slight increase after fermentation. In contrast, cysteine decreased significantly after fermentation, from 4.12 ± 0.02 in raw millet flour to 2.13 ± 0.02mg/100g protein in WMLK and 2.05 ± 0.02mg/100g protein in DMLK. Bambara groundnut supplementation increased cysteine, with the highest values recorded in WMLBK3 (6.05 ± 0.01mg/100g protein) and DMLBK3 (3.26±0.01mg/100g protein).

Proline also decreased significantly after fermentation, from 4.45 ± 0.02 in raw millet flour to 2.13 ± 0.02mg/100g protein in WMLK and 1.95±0.14mg/100g protein in DMLK (Table 2b). However, its content increased with Bambara groundnut supplementation, reaching 2.30±0.02mg/100g protein in WMLBK3 and 4.17±0.02mg/100g protein in DMLBK3. This decrease agrees with Osman (2010) [26], but contrasts with the increase reported by Mohapatra *et al*. (2024) [19].

Similarly, serine decreased from 3.24±0.03 in raw millet flour to 1.50±0.02mg/100g protein in WMLK and 1.95±0.01mg/100g protein in DMLK. Supplementation with fermented Bambara groundnut flour significantly improved serine levels, reaching 4.84±0.02 in WMLBK3 and 2.82±0.02 in DMLBK3.

Table 2b: Non-Essential Amino Acid Profile of *kadal* Prepared from Blends of Whole and Decorticated Millet and Bambara Groundnut Flours

Sample Code[2]	**Amino Acids (mg/100g protein)[1]**									
	Asparagine	**Arginine**	**Alanine**	**Aspartate**	**Glut/acid**	**Glycine**	**Tyrosine**	**Cysteine**	**Proline**	**Serine**
RMLF	$5.64^{b}\pm0.05$	$5.91^{a}\pm0.02$	$2.14b^{d}\pm0.01$	$6.46^{a}\pm0.03$	$2.42^{g}\pm0.02$	$4.45^{c}\pm0.02$	$3.24^{e}\pm0.02$	$4.12^{c}\pm0.02$	$4.45^{a}\pm0.02$	$3.24^{b}\pm0.02$
WMLK	$3.61^{g}\pm0.03$	$2.80^{g}\pm0.01$	$1.84^{e}\pm0.02$	$2.71^{i}\pm0.02$	$1.77^{i}\pm0.01$	$3.14^{g}\pm0.02$	$3.41^{d}\pm0.02$	$2.13^{g}\pm0.02$	$1.21^{h}\pm0.02$	$1.50^{f}\pm0.03$
WMLBK1	$3.13^{h}\pm0.02$	$3.37^{e}\pm0.03$	$2.18^{c}\pm0.06$	$3.23^{g}\pm0.02$	$2.53^{f}\pm0.04$	$3.57^{e}\pm0.02$	$3.46^{d}\pm0.04$	$3.14^{e}\pm0.02$	$1.83^{g}\pm0.01$	$3.12^{bc}\pm0.01$
WMLBK2	$4.96^{d}\pm0.01$	$3.46^{d}\pm0.01$	$3.25^{b}\pm0.03$	$5.64^{c}\pm0.02$	$3.71^{b}\pm0.01$	$7.14^{b}\pm0.01$	$4.12^{b}\pm.005$	$4.41^{b}\pm0.04$	$2.27^{e}\pm0.04$	$3.23^{b}\pm0.02$
WMLBK3	$6.32^{a}\pm0.01$	$3.78^{c}\pm0.02$	$4.62^{a}\pm0.04$	$5.82^{b}\pm0.02$	$4.16^{a}\pm0.02$	$7.35^{a}\pm0.02$	$4.44^{a}\pm0.02$	$6.05^{a}\pm0.01$	$2.30^{e}\pm0.02$	$4.84^{a}\pm0.02$
DMLK	$3.16^{f}\pm0.03$	$2.73^{h}\pm0.01$	$0.36^{i}\pm0.02$	$2.82^{h}\pm0.01$	$2.25^{h}\pm0.01$	3.13g±0.04	$3.12^{f}\pm0.01$	$2.05^{h}\pm0.02$	$1.95^{f}\pm0.14$	$1.95^{ef}\pm0.01$
DMLBK1	$4.45^{e}\pm0.02$	$3.27^{f}\pm0.05$	$0.67^{h}\pm0.04$	$3.42^{f}\pm0.03$	$2.85^{e}\pm0.04$	$3.45^{f}\pm0.01$	$3.26^{e}\pm0.03$	$2.15^{g}\pm0.04$	$3.50^{d}\pm0.05$	$2.25^{de}\pm0.03$
DMLBK2	$5.32^{c}\pm0.02$	$3.48^{d}\pm0.01$	$0.98^{g}\pm0.02$	$3.82^{e}\pm0.02$	$3.24^{d}\pm0.01$	$3.76^{d}\pm0.02$	$3.66^{c}\pm0.06$	$3.10^{f}\pm0.02$	$3.80^{c}\pm0.02$	$2.64^{cd}\pm0.05$
DMLBK3	$4.13^{f}\pm0.01$	$4.15^{b}\pm0.04$	$1.46b^{f}\pm0.02$	$4.12^{d}\pm0.04$	$3.48^{c}\pm0.04$	$4.45^{c}\pm0.03$	$4.11^{b}\pm0.03$	$3.26^{d}\pm0.01$	$4.17^{b}\pm0.02$	$2.82^{bc}\pm0.02$

[1]Values are Means±Stanadard Deviations of Duplicate Determinations. In any column, means bearing similar superscripts are not significantly different at p-value of 5% (P>0.05).

[2]WMLF = Whole Millet Flour; WMLK = Whole Millet *kadal*; DMLK = Decorticated Millet *kadal*; WMLBK = Whole Millet and Bambara groundnut *kadal*; DMLBK = Decorticated Millet and Bambara groundnut *kadal*; 1, 2, and 3 represents ration of Maize to Bambara groundnut 80:20, 70:30, and 60:40, respectively.

Also, fermentation was observed to significantly increased the vitamin B_1 content of raw millet flour (RMLF) from 1.72 ± 0.01 to 2.39 ± 0.08mg/100g in whole millet *kadal* (WMLK) (Table 3). Supplementation with fermented Bambara groundnut flour further improved vitamin B_1 levels, with the highest value of 3.19 ± 0.09mg/100g recorded in WMLBK3. In contrast, fermentation slightly reduced the vitamin B_1 content of decorticated millet flour to 1.51 ± 0.09mg/100g, although the addition of fermented Bambara groundnut flour increased it to 2.44 ± 0.09mg/100g in DMLBK3. Similar increases in vitamin B_1 after fermentation were reported by Mohapatra *et al*. (2024). Yahuza and Baba (2025) [19, 37], however, contrary to the findings in the present study, reported a decrease from 0.38±0.04mg/100g to 0.31±0.03mg/100g in the vitamin B_1 content of fermented millet flour.

Vitamin B_9 content also increased significantly after fermentation, from 1.93 ± 0.02mg/100g in raw millet flour to 11.89 ± 0.03mg/100g in WMLK and 5.69 ± 0.05mg/100g in DMLK. The incorporation of fermented Bambara groundnut flour produced further significant increases, with the highest values of 17.70 ± 0.20 in WMLBK3 and 12.99 ± 0.16mg/100g in DMLBK3. The significant increase in B-vitamin content observed after cereal fermentation may be associated with microbial biosynthesis, liberation of bound vitamins, and enhanced vitamin extractability**.** Fermenting microorganisms, particularly lactic acid bacteria and yeasts, are capable of producing B-group vitamins, while microbial enzymes break down components of the cereal matrix, releasing vitamins that were previously bound or less accessible and consequently increasing their measurable levels in the fermented flour (Nkhata *et al*., 2018; LeBlanc *et al*., 2017) [4, 23].

Table 3: Vitamins B_1 and B_9 Contents of *Kadal* Prepared from Blends of Whole and Decorticated Millet and Bambara groundnut Flours

Sample Code[2]	Parameters (mg/100g)1	
	Vitamin B_1	**Vitamin B_9**
RMLF	1.72^{d}±0.01	1.93^{f}±0.02
WMLK	2.39^{bc}±0.08	11.87^{c}±0.03
WMLBK1	2.54^{b}±0.01	12.29^{c}±0.08
WMLBK2	2.65^{b}±0.05	17.59^{a}±0.02
WMLBK3	3.19^{a}±0.09	17.70^{a}±0.20
DMLK	1.51^{d}±0.09	5.69^{e}±0.05
DMLBK1	1.60^{d}±0.01	9.12^{d}±0.21
DMLBK2	1.93^{cd}±0.01	9.14^{d}±0.15
DMLBK3	2.44^{b}±0.09	12.99^{b}±0.16

[1]Values are Means±Stanadard Deviations of Duplicate Determinations. In any column, means bearing similar superscripts are not significantly different at p-value of 5% (p>0.05).[2]WMLF = Whole Millet Flour; WMLK = Whole Millet *kadal*; DMLK = Decorticated Millet *kadal*; WMLBK = Whole Millet and Bambara groundnut *kadal*; DMLBK = Decorticated Millet and Bambara groundnut *kadal*; 1, 2, and 3 represents ration of Maize to Bambara groundnut 80:20, 70:30, and 60:40, respectively.

Conclusion

This study concludes that fermentation resulted in an increase in some proximate contents such as moisture and fibre, but with reduction in protein, ash, carbohydrate, energy values, and most essential and non-essential amino acids in millet *kadal* flour. Significantly higher losses were recorded in decorticated samples. However, phenylalanine and threonine increased after fermentation. Supplementation with fermented Bambara groundnut flour significantly improved protein, fat, ash, fibre, carbohydrate, energy values, amino acids, and vitamins B1 and B9, with higher Bambara groundnut inclusion producing greater improvements. Whole millet–Bambara groundnut blends, particularly WMLBK3, consistently showed superior proximate composition, amino acid quality, energy value, and vitamins B_1 and B_9 contents. Consuming *Kadal* flour from blends of fermented whole millet and fermented whole Bambara groundnut while help in partly solving protein-energy malnutrition and micronutrient deficiencies among the segments of the population that regularly consume stiff dough produced from the *kadal* flour blends. Consequently, decortication of grains during *kadal* flour production is highly discouraged as it led to greater losses of nutrients, which can further compound the malnutrition problems facing sub-Saharan Africa.

Conflict of Interest

The Authors hereby declare that there is not any conflict of interest with regard to this article

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