NUTRITIONAL COMPOSITION OF OFADA RICE AND TROPICAL ALMOND FLOUR BLENDS SUBJECTED TO SOLID STATE FERMENTATION

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ABSTRACT

The quest for nutritious and healthy food to promote health has increased in recent decades. Food scientists have applied various processing methods to enhance nutritional value. This study aimed to assess the effect of fermentation on the nutritional composition of fermented Ofada rice fortified with tropical almond seeds. Ofada rice was purchased from a market in Ire Ekiti, Ekiti State, while tropical almond fruits were obtained from the tree at the Federal University of Technology Akure (FUTA) campus. Rice and almond seeds were mixed in different proportions: 100:0, 90:10, 80:20, 70:30, 60:40, and 50:50. Samples underwent solid state fermentation for 72 hours. Fibre content increased after fermentation from 5.24% to 14.27%. Protein content significantly ($p = 0.05$) increased from 6.55% to 8.14% in almond seeds, 3.14% to 4.53% in rice, and 2.42% to 6.74% in blends. Carbohydrate content decreased in the blends from 81.69% to 45.24% post-fermentation. Sodium and calcium contents reduced, while potassium, magnesium, and iron increased significantly (138.37–400.33 ppm, 7.32–103.44 ppm, 2.88–6.89 ppm, respectively). Vitamin B1, B2, B12, C, D, and E contents increased across fermented blends. The findings indicate that fermentation enhances the nutritional quality of Ofada rice and tropical almond seeds.

Keywords: Fermentation, Ofada, Rice, Almond Seeds, Nutritional Composition, Vitamin

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1. | Introduction

Fermentation is an ancient biotechnology procedure which has been widely used to improve nutritional, sensory and functional characteristics of food substrates (Augustin *et al.*, 2023). It is the metabolic process of microorganisms, mostly bacteria, yeasts, and molds, that act on the raw food materials to produce products of better nutritional value and health benefit (Marco *et al.*, 2017; Tamang *et al.*, 2020). Fermentation has been shown to play one of the most important functions, the metabolism of complex macromolecules, including proteins, carbohydrates, and lipids, into simpler and more digestible and bioavailable forms (Adebo *et al.*, 2021). Moreover, it was demonstrated that fermentation enhances the bioavailability of essential amino acids, fatty acids, vitamins, and minerals and lowers antinutritional factors (phytates and tannins) (Onuekwesi *et al.*, 2026).

Ofada rice, which is a locally cultivated Nigerian strain of *Oryza sativa*, is also high in dietary fiber, essential minerals, and polyphenols, although as with any other cereals, its potential as a food source is constrained by the presence of antinutrients and relatively low concentration of some essential amino acids (Efunwole *et al.,* 2022). Tropical almond (*Terminalia cata:a*) seeds, conversely, are already underutilized oilseeds that are abundant in lipids, proteins, and micronutrients and have demonstrated potential in the development of functional foods (Bindu, 2019). Nevertheless, they are rich in fats and some contain anti-nutritional factors, which require processing methods that can be used to provide optimal nutritional balance of these products to human being.

A combination of cereals and oilseeds or legumes is a tactical measure to complementary nutrition because it can equalize the content of amino acids and improve the overall quality of proteins in a food item (Adebo *et al.,* 2022). It has also been reported that fermentation of such blends additionally enhances the nutritional and functional properties to produce products that contain higher concentrations of essential amino acids and nutritionally beneficial fatty acids (Lawal *et al.,* 2015). An example of this is lactic acid bacteria and yeasts, engaged in natural fermentation who have been shown to release enzymes like proteases and lipases that cause changes in the protein and lipid fractions of the raw material to produce enriched amino acid and fatty acid profiles (Johansson *et al.,* 2019; Adegoke and Onifade 2025).

It has been established in previous research that fermentation is capable of heavily increasing the concentration of monounsaturated fatty acids and polyunsaturated fatty acids, which are known to provide cardioprotective properties, as well as raising the levels of essential amino acids, which are essential for human growth and development (Isam *et al.,* 2024). Considering the nutritional potential of Ofada rice and tropical almond seeds, the study of the influence of fermentation on their combined preparations is necessary in the future of the creation of nutritionally enriched, functional food, particularly in areas that are overwhelmed with protein-energy malnutrition. Therefore, this study aims to evaluate the impact of fermentation on the fatty acid and amino acid compositions of blends made from Ofada rice and tropical almond seeds. Understanding the biochemical changes induced by fermentation in such blends is critical for optimizing their application in dietary interventions and food product development.

2. | Materials and Methods

2.1 | Sample Collection and Preparation

Ofada rice was bought at one of the markets in Ire Ekiti, Ekiti State, Nigeria and tropical almond fruits (*Terminalia cata:a*) were harvested at The Federal University of Technology Akure (FUTA) campus. The Ofada rice was carefully washed to remove debris and stones and ground into a fine powder. The tropical almond fruits were sun dried to reduce the rancidity of the kernel and facilitate dehulling. The dry seeds were then removed by hand dehusking to get the brown spindle-shaped kernels, soaked in sterile water for 12 hours and then oven dried at a temperature of 60°C over a period of 24 hours, dried to a fine powder, and stored in airtight containers for further analysis (Okafor *et al.,* 2021).

2.1.1 | Formulation of Blends

The powdered Ofada rice and tropical almond seed flours were blended in varying proportions to formulate six different samples: 100:0, 90:10, 80:20, 70:30, 60:40, and 50:50 (Ofada rice: tropical almond seed, w/w).

2.1.2 | Fermentation Process

Each blend (1 kg) was subjected to natural fermentation in sterile containers with distilled water at a ratio of 1:3 (sample: water, w/v) for 72 hours at ambient temperature (~28 ± 2 °C). Post-fermentation, the samples were dried, oven-dried at 100 °C for 1 hour, and milled into fine powders using Model 200L090 Bentall attrition mill for subsequent analyses, (Ishaku *et al.,* 2024).

2.1.3 | Proximate Composition

The proximate composition including moisture content, crude protein, crude fat, crude fiber, ash, and carbohydrate was determined using standard methods according to AOAC (2012).

2.2 | Mineral and Vitamin Analysis

Mineral elements (e.g., calcium, magnesium, iron, and potassium) were quantified using Atomic Absorption Spectrophotometry (AAS) according to AOAC (2012) and sodium was determined using flame photometry as described by Khan *et al.* (2023). Vitamin C content was determined via titrimetric methods, while vitamins A and E were analysed using High-Performance Liquid Chromatography (HPLC) techniques, adhering to AOAC (2012) official methods.

2.2.1 | Statistical analysis:

All experimental data were obtained from three independent trials and expressed as mean values ± standard error (SE) and analyzed using one way analysis of variance (ANOVA) and the means were compared using Duncan's New Multiple range test at $P \leq 0.05$ level of significance (SPSS version 26).

3. | Results and Discussion

Proximate composition of unfermented and fermented Rice and Almond flour

The proximate composition (Table 1) yielded nutritionally significant results. Moisture content increased with fermentation across all samples. Moisture content of the rice increased from 7.70% before fermentation to 9.88% after fermentation, as was the case of the almond flour, and both the almond flour and the rice were also increased after fermentation to 9.83% of the moisture content in the almond flour and 16.05% in the rice before fermentation respectively. There was also a great increase in moisture content in fermentation of the different ratios of rice and almond flour (13.29 -15.65%) as presented in Table 1. This increase can be attributed to the hydration and metabolic activity of fermenting microorganisms, which has been previously observed and reported Lui *et al.,* (2025) that microbial activity during fermentation often increases water retention in substrates.

The fat content of rice increased from 1.83% before fermentation 1.94% after fermentation. Almond flour was also remarkably high in fats (from 32.19% - 33.08%), a Figure that is higher than most other traditional nuts available. This could indicate the retention of fat during fermentation or microbial bioconversion of some carbohydrate or protein fractions into lipids, as reported by Oyeleke (2014).

The amount of ash also decreased considerably in rice (0.62% - 0.42%) and almond flour (4.92% - 0.78%) before and after fermentation respectively. It also notably decreased with the different ratios of the rice and almond flour blends after fermentation of (0.12% -1.54%) other than RASF 70:30 where a little significant increment was seen between 1.57% before fermentation and 1.62% after fermentation. This is as presented in Table 1. This variation may be due to leaching or microbial utilization of mineral components during fermentation (Terefe *et al.,* 2021).

The content of fibre slightly increased in rice from 0.95% before fermentation to 1.01% after fermentation. There was a reduction in the fibre content of almond flour from 33.58% before fermentation to 28.49% after fermentation, though still higher than the fibre content in rice. The content of fibre also declined following fermentation of the rice and almond flour in the RASF 50:50 as well as 70:30 portions (14.27 and 5.24%). Although it increased in RASF 60:40, 80:20, and 90:10 portions (5.24, 4.96 and 4.74%). This is consistent with findings by Abdulla *et al.* (2025), who reported that microbial fermentation can alter dietary fibre fractions, sometimes breaking down insoluble fibre while increasing soluble fibre content.

Protein content increased significantly after fermentation, with rice having 3.18% before fermentation to 4.53% after fermentation and almond flour 6.55% before fermentation to 8.14% after fermentation. The protein levels also improved substantially over the fermenting ratios between (4.74% - 6.74%) as presented in Table 1. These profiles were significantly altered by fermentation, which enhanced protein content in almond seeds by 8.14% to 6.55% and which would have been caused by the production of microbial biomass as was described in the proteomic studies of Song *et al.* (2023).

The level of carbohydrate went down considerably after fermentation of the almond flour (14.66 %), but a tremendous downward change in carbohydrate (76.05 %) was recorded in the fermented rice samples. The amounts of carbohydrate also decreased when the rice and almond flour were fermented on the different proportions (45.24 -55.67) as shown in Table 1. The rice samples (81.69% in RUN) were dominated with carbohydrates; this pattern was

Table 1 | Proximate Composition (%) of Unfermented and Fermented Rice and Almond Flour

Samples	Moisture	Ash	Fat	Fibre	Protein	CHO
ASUN	6.69 ± 0.003^{a}	4.92 ± 0.02^{m}	32.19 ± 0.003^{m}	33.58 ± 0.006^{n}	6.55 ± 0.006^{l}	16.42 ± 0.007^{a}
ASF	9.83 ± 0.00^{d}	0.78 ± 0.003^{f}	33.08 ± 0.003^{n}	28.49 ± 0.00^{m}	8.14 ± 0.003^{n}	14.66 ± 0.003^{b}
RUN	7.70 ± 0.03^{b}	0.62 ± 0.003^{e}	1.83 ± 0.003^{a}	0.95 ± 0.003^{a}	3.18 ± 0.02^{c}	81.69 ± 0.003^{n}
RF	9.88 ± 0.00^{e}	0.42 ± 0.003^{c}	1.94 ± 0.003^{b}	1.01 ± 0.00^{b}	$4.53\ 0.01^{f}$	76.05 ± 0.009^{m}
RASUN 50:50	9.57 ± 0.003^{c}	2.11 ± 0.003^{l}	17.02 ± 0.00^{k}	17.23 ± 0.00^{l}	4.91 ± 0.00^{h}	49.21 ± 0.00^{e}
RASF 50:50	13.29 ± 0.03^{k}	0.31 ± 0.00^{b}	18.52 ± 0.003^{l}	15.86 ± 0.003^{k}	6.74 ± 0.003^{m}	45.24 ± 0.009^{c}
RASUN 60:40	10.28 ± 0.003^{g}	6.61 ± 0.00^{n}	15.11 ± 0.003^{i}	13.64 ± 0.003^{i}	3.84 ± 0.003^{e}	50.53 ± 0.00^{f}
RASF 60:40	15.65 ± 0.003^{n}	1.54 ± 0.003^{j}	15.17 ± 0.003^{j}	14.27 ± 0.003^{j}	5.24 ± 0.003^{k}	48.11 ± 0.003^{d}
RASUN 70:30	11.29 ± 0.003^{h}	$1.57 \pm 0.00^{i\,i}$	14.21 ± 0.003^{g}	10.01 ± 0.003^{f}	3.50 ± 0.003^{d}	59.42 ± 0.01^{j}
RASF 70:30	14.19 ± 0.003^{m}	1.62 ± 0.00^{j}	14.27 ± 0.003^{h}	5.24 ± 0.003^{c}	5.15 ± 0.003^{j}	51.15 ± 0.003^{g}
RASUN 80:20	10.23 ± 0.003^{f}	1.92 ± 0.00^{k}	11.03 ± 0.00^{d}	9.13 ± 0.00^{e}	2.98 ± 0.01^{b}	64.71 ± 0.01^{k}
RASF 80:20	13.88 ± 0.003^{k}	0.55 ± 0.003^{d}	12.85 ± 0.003^{f}	13.21 ± 0.00^{h}	4.96 ± 0.003^{j}	54.56 ± 0.007^{h}
RASUN 90:10	11.88 ± 0.003^{i}	1.15 ± 0.007^{g}	8.01 ± 0.003^{c}	7.52 ± 0.00^{d}	2.42 ± 0.00^{a}	69.03 ± 0.007^{l}
RASF 90:10	13.65 ± 0.007^{l}	0.12 ± 0.003^{a}	12.75 ± 0.00^{e}	13.09 ± 0.003^{g}	4.74 ± 0.009^{g}	55.67 ± 0.006^{i}

Data are presented as Mean ± S.E. (n=3). Values with the same superscript letter(s) along the same column are not significantly different ($P \leq 0.05$).

Legend: ASUN = Almond seed unfermented; ASF = Almond seed fermented; RASUN = Rice and Almond seed unfermented; RASF = Rice and Almond seed Fermented; CHO = Carbohydrate expected to change after fermentation (76.05% in RF) according to the utilization pattern of microbes in cereal fermentations (Kohajdova and Karovicova, 2021).

3.1 | Mineral Composition

The sodium content also significantly reduced in the fermented rice sample (12.94 ppm) compared to the unfermented rice sample (49.30 ppm). The sodium content reduced significantly in the fermented almond flour (10.55 ppm) compared to the unfermented almond flour (35.61 ppm). The sodium increased significantly in the fermented rice and almond flour blends with the RASF 50:50 blend having the lowest (69.90 ppm), while the highest sodium content was observed in the RASF 90:10 (92.32 ppm) blend compared to the unfermented samples which had a sodium content ranging from (53.13 - 83.26 ppm). This is as presented in Table 2. This reduction in sodium is likely due to lactic acid bacteria (LAB) fermentation which releases bound sodium through proteolytic activity and ion exchange mechanisms (Xin *et al.,* 2021).

The calcium content increased in the fermented rice samples (92.62 ppm) compared to the unfermented rice samples (82.51 ppm). This is in accordance with the findings of Ozabor *et al.* (2025) who reports increase in calcium content after fermentation cloves – cinnamon formulated cereal. While the calcium content reduced significantly in the fermented almond flour (42.77 ppm) compared to the unfermented almond flour (77.91 ppm). Calcium reduced in the fermented rice and almond flour blend RASUN across the fermenting portions with the lowest observed at the RASF 50:50 (48.46 ppm), while the highest calcium content was observed in the RASF 90:10 (70.31 ppm) as presented in Table 2.

The potassium content increased significantly after the fermentation of rice from 170.00 ppm before fermentation to 243.76 ppm after fermentation and almond flour from 243.76 ppm before fermentation to 400.33 ppm after fermentation. Potassium (K) exhibited remarkable increase, rising from 151.31 ppm in in unfermented almond flour to 400.33 ppm in fermented almond flour. This surge is consistent with research by Ozabor *et al.* (2025), showing that fermentation breaks down phytate-bound potassium in seeds, significantly improving its solubility. Similarly, the potassium content reduced in the 50:50 ratio of the fermented rice and almond flour (141.93 ppm), whereas there was a slightly significant increase in the fermented samples across the other fermenting ratios (144.14, 152.25, 156.13, and 170.05 ppm). This is as presented in Table 2.

The magnesium content significantly increased in the fermented samples. Magnesium in rice increased from 11.16 ppm before fermentation to 109.41 ppm after fermentation and almond flour from 7.32 ppm before fermentation to 38.73 ppm after fermentation. The magnesium content also increased across fermenting rice and almond flour ratios for the RASF samples with the lowest magnesium content observed at RASF 50:50 (74.19 ppm) while the highest magnesium content was observed at RASF 90:10 (103.44 ppm) as presented in Table 2. The increase in magnesium content corroborating Adebo and Adeyanju (2025), who found that LAB fermentation degrades phytate-Mg complexes, enhancing Magnesium release.

The iron content increased significantly in the fermented food samples, with rice rising from 2.88 ppm before fermentation to 3.06 ppm after fermentation and almond flour from 3.16 ppm before fermentation to 4.35 ppm after fermentation. Also, the iron content increased across the fermenting ratios of the fermented rice and almond flour blends with the lowest iron content observed at RASF 50:50 (4.36 ppm) while the highest was observed at RASF 80:20 (6.89 ppm) as presented in Table 2. The increase in iron was also reported by Zhang *et al.,* (2022) in cereal, who stated that fermentation reduces polyphenol-iron chelation, increasing soluble iron in plant foods

It was also observed that the chromium content varied across the samples. Chromium increased in rice before fermentation 0.01 ppm – 0.03 ppm after fermentation while it reduced significantly in the fermented almond flour, from 0.03 ppm before fermentation to 0.01 ppm after fermentation. While the chromium increased in the fermented rice samples (0.03 ppm). Although, in the 50:50 and 90:10 fermented blends, it was observed that the chromium content remained unchanged (0.02 ppm), supporting data from Rudiana *et al.* (2018), which indicated that Cr is largely unaffected by fermentation due to its low affinity for phytates. Chromium increased after fermentation in the RASF 60:40, 70:30 (0.02 ppm). While it also decreased after fermentation in the RASF 80:20 portion (0.01). This is as presented in Table 2.

It was also observed that the zinc content reduced significantly in the fermented samples. Zinc content reduced in rice from 1.22 ppm before fermentation to 0.35 ppm after fermentation and almond flour from 0.95 ppm before fermentation to 0.72 ppm after fermentation. The Zinc content also remarkably reduced significantly after fermentation in all the fermented samples with the highest zinc level observed at RASF 70:30 (0.79 ppm) while the lowest was observed at RASF 60:40 (0.42 ppm) as presented in Table 2. The reduction in zinc content aligns with Molly *et al.* (2018), who proposed that while phytate degradation increases Zn solubility, microbial uptake and organic acid chelation may reduce measurable Zn in fermented food products.

3.2 | Vitamin composition

The vitamin profiles (Table 3) showed remarkably good fermentation-induced improvements. The Vitamin B_{12} content of rice increased from 9.30 µg/100g before fermentation to 10.41 µg/100g after fermentation and almond flour from 9.82 µg/100g before fermentation to 10.75 µg/100g after fermentation. The Vitamin B_{12} content also increased across the various ratios of the fermented rice and almond samples before fermentation ranging from 6.10 µg/100g – 9.56 µg/100g to 10.34 - 10.72 µg/100g after fermentation as presented in Table 3. This increase is in alignment with the ability of *Propionibacterium freudenreichii* and *Lactobacillus plantarum* strains to synthesize cobalamin during plant-based fermentation (Anjali *et al.,* 2024),

The Vitamin C content also increased before fermentation in rice from 1.06 mg/100g to 6.24 mg/100g after ferment and almond flour from 2.49 mg/100g before fermentation to 8.17 mg/100g after fermentation. The Vitamin C content also showed a significant increase after fermentation across all the various portions of the rice and almond flour with the highest observed at RASF 50:50 (7.22 mg/100g) and the lowest observed at RASF 90:10 (6.12 mg/100g). This substantial increase can be attributed to microbial biosynthesis by lactic acid bacteria and enzymatic liberation from plant matrices (Sunny *et al.,* 2025).

The Vitamin D content also increased before fermentation in rice from 0.04 mg/g to 0.20 mg/g after fermentation and almond flour from 0.7 mg/g to 0.19 mg/g after fermentation. The Vitamin D content also increased across the fermentation ratios of the rice and almond flour RASF ranging from (0.18 - 0.47 mg/g), except for the ratio RASF 70:30 which showed a significant reduction in Vitamin D content (0.21 mg/g). This enhancement likely results from microbial conversion of plant sterols to bioactive forms, a phenomenon well-documented in fungal-fermented cereals (Keyvan *et al.,* 2026)

The Vitamin E content also increased in all the samples after fermentation. Vitamin E content in rice increased from 0.02 mg/g before fermentation to 0.22 mg/g after fermentation while almond flour increased from 0.01 mg/g before fermentation to 3.91 mg/g after fermentation. The Vitamin E content also increased across the fermentation ratios of the rice and almond flour RASF portions ranging from (0.46 - 2.07 mg/g) as presented in Table 3.

Table 2 | Mineral Composition (PPM) of Unfermented and Fermented Rice and Almond Flour

Samples	Na	Ca	K	Mg	Fe	Cr	Zn
ASUN	35.61 ± 0.003^{c}	77.91 ± 0.007^{j}	151.31 ± 0.007^{g}	7.32 ± 0.007^{a}	3.16 ± 0.007^{f}	0.03 ± 0.003^{d}	0.95 ± 0.003^{h}
ASF	10.55 ± 0.003^{a}	42.77 ± 0.003^{a}	400.33 ± 0.3^{m}	38.73 ± 0.003^{h}	4.35 ± 0.009^{g}	0.01 ± 0.00^{a}	0.72 ± 0.00^{e}
RUN	49.30 ± 0.00^{d}	82.51 ± 0.003^{m}	170.00 ± 0.00^{k}	11.16 ± 0.003^{e}	2.88 ± 0.003^{a}	0.01 ± 0.00^{a}	1.22 ± 0.003^{m}
RF	12.94 ± 0.009^{b}	92.62 ± 0.003^{n}	243.76 ± 0.01^{l}	109.41 ± 0.003^{n}	3.06 ± 0.003^{e}	0.03 ± 0.00^{d}	0.35 ± 0.003^{a}
RASUN 50:50	53.13 ± 0.07^{e}	80.06 ± 0.006^{l}	160.43 ± 0.07^{j}	9.23 ± 0.009^{b}	3.01 ± 0.003^{d}	0.02 ± 0.00^{c}	1.02 ± 0.00^{i}
RASF 50:50	69.90 ± 0.00^{h}	48.46 ± 0.008^{b}	141.93 ± 0.007^{d}	74.19 ± 0.003^{i}	4.36 ± 0.003^{g}	0.02 ± 0.00^{c}	0.51 ± 0.003^{c}
RASUN 60:40	61.27 ± 0.03^{f}	70.12 ± 0.003^{f}	138.37 ± 0.03^{a}	10.20 ± 0.003^{c}	3.01 ± 0.00^{b}	0.01 ± 0.00^{a}	7.14 ± 0.003^{j}
RASF 60:40	71.23 ± 0.00^{i}	51.14 ± 0.003^{c}	$144.14 \pm 0{,}003^{e}$	79.25 ± 0.01^{j}	5.76 ± 0.01^{j}	0.02 ± 0.00^{c}	0.42 ± 0.00^{b}
RASUN 70:30	62.95 ± 0.007^{g}	72.64 ± 0.02^{h}	139.67 ± 0.07^{b}	11.07 ± 0.003^{d}	3.02 ± 0.003^{d}	0.01 ± 0.003^{a}	1.15 ± 0.003^{k}
RASF 70:30	89.13 ± 0.00^{m}	56.31 ± 0.003^{d}	152.25 ± 0.00^{h}	83.43 ± 0.007^{k}	4.89 ± 0.00^{h}	0.02 ± 0.003^{bc}	0.79 ± 0.003^{g}
RASUN 80:20	77.46 ± 0.009^{j}	76.39 ± 0.003^{i}	140.73 ± 0.09^{c}	11.47 ± 0.09^{f}	2.99 ± 0.003^{c}	0.02 ± 0.00^{c}	1.17 ± 0.003^{i}
RASF 80:20	78.11 ± 0.003^{k}	62.13 ± 0.003^{e}	156.13 ± 0.003^{i}	91.03 ± 0.003^{l}	6.89 ± 0.00^{k}	0.01 ± 0.00^{a}	0.63 ± 0.00^{d}
RASUN 90:10	83.26 ± 0.007^{l}	79.08 ± 0.006^{k}	150.17 ± 0.07^{l}	12.13 ± 0.03^{g}	2.94 ± 0.00^{b}	0.02 ± 0.00^{bc}	1.17 ± 0.003^{l}
RASF 90:10	92.32 ± 0.007^{n}	70.31 ± 0.003^{g}	170.05 ± 0.00^{k}	103.44 ± 0.003^{m}	5.23 ± 0.00^{i}	0.02 ± 0.00^{c}	0.74 ± 0.003^{f}

Data are presented as Mean±S.E (n=3). Values with the same superscript letter(s) along the same column are not significantly different ($P \leq 0.05$).

Legend : ASUN = Almond seed unfermented; ASF = Almond seed fermented; RASUN = Rice and Almond seed unfermented; RASF = Rice and Almond Seed Fermented; Na = Sodium; Ca = Calcium; K = Potassium; Mg = Magnessium; Fe = Iron; Cr = Chromium; Zn = Zinc

The Vitamin B_1 also showed a significant increase across board. Vitamin B_1 increase in rice from 1.36 mg/g before fermentation to 2.03 mg/g after fermentation while almond flour increased from 1.87 mg/g before fermentation to 2.13 mg/g after fermentation. The Vitamin B_1 content also increased across the fermentation ratios of the rice and almond flour RASF ranging from (2.01 - 2.11 mg/g). This is as presented in Table 3.

The Vitamin B_2 showed a significant increase after fermentation of the almond flour (1.84 mg/g) and rice (0.94 mg/g). This significant increase was also observed in the Vitamin B_2 content across the fermentation ratios of the rice and almond flour RASF ranging between (0.96 - 1.45 mg/g) as presented in Table 3. This significant increase could be as a result of biofortification by fermenting microorganisms. This trend aligns with the findings of Capozzi *et al.* (2011) who observed a similar increase in Vitamin B_2 of cereal based food products.

The synergies in nutrition of blended samples (RASUN and RASF series) were especially promising. The 50:50 combination produced the best ratios of macronutrients and the highest retention of phytochemicals which can be applied in the development

Table 3 | Vitamin Composition of Fermented and Unfermented Rice and Almond Flour

Samples	Vitamin B12 µg/100g	Vitamin C mg/100g	Vitamin D mg/g	Vitamin E mg/g	Vitamin B1 mg/g	Vitamin B2 mg/g
ASUN	9.82 ± 0.003^{g}	2.49 ± 0.007^{g}	0.07 ±0.06^{ab}	0.01 ± 0.00^{a}	1.87 ±0.003^{g}	0.63 ± 0.003^{bc}
ASF	10.75 ± 0.003^{n}	8.17 ± 0.00^{n}	0.19 ± 0.003^{ab}	3.91 ± 0.003^{i}	2.13 ± 0.003^{l}	1.84 ± 0.00^{j}
RUN	9.30 ± 0.01^{d}	1.06 ± 0.007^{a}	0.04 ± 0.00^{a}	0.02 ± 0.00^{b}	1.36 ± 0.02^{a}	0.80 ± 0.00^{a}
RF	10.41 ± 0.00^{k}	6.24 ± 0.00^{j}	0.20 ± 0.003^{ab}	0.22 ± 0.00^{c}	2.03 ± 0.003^{h}	0.94 ± 0.00^{d}
RASUN 50:50	9.56 ± 0.00^{f}	1.75 ± 0.003^{f}	0.03 ± 0.00^{a}	0.01 ± 0.00^{a}	1.63 ± 0.003^{f}	0.72 ± 0.00^{c}
RASF 50:50	10.60 ± 0.003^{m}	7.22 ± 0.003^{m}	0.29 ± 0.003^{c}	2.07 ± 0.006^{h}	2.11 ± 0.003^{k}	1.45 ± 0.003^{h}
RASUN 60:40	9.32 ± 0.00^{e}	1.69 ± 0.00^{e}	0.04 ± 0.003^{a}	0.01 ± 0.00^{a}	1.51 ± 0.00^{e}	0.49 ± 0.21^{b}
RASF 60:40	10.37 ± 0.003^{j}	6.72 ± 0.003^{k}	0.47 ± 0.26^{c}	1.90 ± 0.003^{g}	2.09 ± 0.003^{j}	1.22 ± 0.003^{ef}
RASUN 70:30	8.40 ± 0.003^{c}	1.67 ± 0.00^{d}	0.67 ± 0.00^{d}	0.01 ± 0.00^{a}	1.47 ± 0.003^{d}	0.69 ± 0.003^{c}
RASF 70:30	10.34 ± 0.009^{i}	6.77 ± 0.00$_{l}$	0.21 ± 0.003^{ab}	1.84 ± 0.00^{f}	2.08 ± 0.003^{i}	1.31 ± 0.007^{fg}
RASUN 80:20	8.11 ± 0.00^{b}	1.51 ± 0.00^{c}	0.09 ± 0.003^{ab}	0.01 ± 0.003^{a}	1.42 ± 0.003^{c}	0.66 ± 0.003^{bc}
RASF 80:20	10.55 ± 0.006 l	6.70 ± 0.003^{j}	0.19 ± 0.00^{ab}	0.72 ± 0.003^{e}	2.07 ± 0.003^{i}	1.12 ± 0.00^{e}
RASUN 90:10	6.01 ± 0.003^{a}	1.43 ± 0.003^{b}	0.09 ± 0.08^{ab}	0.02 ± 0.00^{b}	1.39 ± 0.003^{b}	0.54 ± 0.00^{bc}
RASF 90:10	10.26 ± 0.003^{h}	6.12 ± 0.003^{h}	0.18 ± 0.006^{ab}	0.46 ± 0.00^{d}	2.01 ± 0.003^{h}	0.96 ± 0.003^{d}

Data are presented as Mean±S.E (n=3). Values with the same superscript letter(s) along the same row are not significantly different (P≤0.05).

Legend: ASUN = Almond seed unfermented; ASF = Almond seed fermented; RASUN = Rice and Almond seed unfermented; RASF = Rice and Almond seed Fermented

of functional food. This is in addition to existing food to food fortification approaches that are suggested by FAO (2023) to deal with micronutrient deficiencies in developing areas. Fermentation of such blends was found to continue to enhance not only the micronutrient content but also probably bioavailability and thus, it can be used in nutritional intervention programs.

4. | Conclusion

These findings show that fermentation increased the nutritional and mineral bioavailability, and increase in essential vitamin content. The 228% vitamin C and 39,000% vitamin E rise in fermented almond flour is a remarkable evidence of the potential revolution of microbial fermentation in food valorisation.

The 50:50 blend of rice and almond flour was optimized to become a nutritionally balanced product with the high carbohydrate levels of rice and the high fat, fibre and mineral levels of almond flour. Such results are in line with international endeavors to come up with nutrient enriched food products by using bioprocessing technologies to make these foods sustainable. Anti-nutritional factors (e.g., alkaloids) are also reduced by the fermentation, which also improves the safety and bioavailability of these substrates to human consumption.

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