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Research Article

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Nutritional and Anti-Nutritional Evaluation of Extrudates Developed from Rice–Sesame (*Oryza sativa–Sesamum indicum*) Composite Blends

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ABSTRACT
This study investigated how fermentation and sprouting affect the nutritional and anti-nutritional properties of rice-sesame extrudates. Different rice-to-sesame blends were created, fermented or sprouted, and then cooked via extrusion. The results showed that adding sesame, especially in moderate to high amounts, increased levels of key vitamins like thiamine, riboflavin, pyridoxine, and cobalamin. The sprouting method was more effective than fermentation at preserving these vitamins. Analysis of minerals identified phosphorus as the most prevalent, followed by calcium, magnesium, and iron, with the highest concentrations found in formulations rich in sesame. Regarding protein quality, leucine was the most abundant essential amino acid. Significant improvements were observed in lysine, methionine, and tryptophan levels, particularly in blends with a balanced rice-to-sesame ratio. Both processing techniques successfully lowered anti-nutritional factors such as tannins, phytates, and oxalates. Fermentation was more potent in reducing phytates and oxalates, while sprouting was superior for overall nutrient preservation. The research concludes that optimally processed rice-sesame composites hold significant promise for enriching extruded foods, providing a practical strategy to boost the nutritional value of plant-based diets.
Keywords: rice, sesame, extrudate, nutrient

INTRODUCTION
Extruded products made from cereals are a vital part of the human diet, especially in developing nations, because they are affordable, versatile, and have a long shelf life. Rice (*Oryza sativa* L.), a staple food worldwide, is prized for being easily digestible and a good energy source. However, its nutritional value is compromised by low-quality protein and a lack of essential micronutrients (Senarathna et al., 2024). Enhancing the nutritional quality of cereal-based foods by blending them with nutrient-rich oilseeds like sesame (*Sesamum indicum* L.) is a promising approach. Sesame is a valuable source of quality protein, essential fats, minerals, and bioactive components, yet its application in composite extruded foods has not been widely studied (Wacal et al., 2024). Pre-processing techniques such as fermentation and sprouting can significantly upgrade the nutritional value of grains and seeds. These methods boost the levels of bioavailable vitamins, minerals, and amino acids while degrading anti-nutrients that block nutrient absorption (Samtiya et al., 2020). Fermentation leverages microbial activity to synthesize vitamins and break down anti-nutritional compounds, while sprouting activates the seed's own enzymes, improving amino acid profiles and vitamin content. The subsequent extrusion cooking further enhances digestibility and reduces anti-nutrients, though it can lead to some vitamin degradation depending on the processing parameters (Salvador-Reyes et al., 2025). This research aimed to evaluate how adding sesame, along with fermentation and sprouting treatments, affects the vitamin, mineral, essential amino acid, and anti-nutrient levels in rice-sesame extrudates. The outcomes offer valuable information for creating nutrient-fortified extruded foods that could help address protein-energy malnutrition and micronutrient deficiencies.

MATERIALS AND METHODS
Sample Procurement
The paddy rice (FARO 52) and sesame seeds (NCRIBEN 04E) used in this study were sourced from

the National Cereals Research Institute (NCRI) in Badeggi, Niger State. The rice was manually cleaned to remove impurities and then milled to produce brown rice. The sesame seeds were stored under appropriate conditions until needed for processing.

Chemicals and Reagents

All chemicals and reagents employed were of analytical grade, sourced from British Drug House (BDH) and Mayer/Baker. These included sodium hydroxide, hydrochloric acid, sulphuric acid, perchloric acid, cupric sulphate, and ammonium thiocyanate, among others.

Equipment

The equipment utilized comprised an attrition mill (RM 100 model), an amino acid analyzer (Beckman system 6300 Model), a rice de-huller (Satake Tokyo M3), a single-screw extruder (Duisburg, DCE-330 model), and a muffle furnace (Carbolite, Bamford, S302AU).

Sample Processing

Rice samples were fermented using an adapted method from Jeygowri et al. (2015). The fermentation of sesame seeds followed the procedure outlined by Akusu et al. (2019). Sprouting protocols for both rice and sesame seeds were also implemented as described in the same literature.

Composite Flour Preparation

Ten different composite flour blends were formulated from the processed samples. These were categorized into two series: Fermented Rice-Sesame (FRS) and Sprouted Rice-Sesame (SRS). Each series included blends where sesame replaced rice at levels of 10%, 20%, 30%, 40%, and 50%, coded as FR90S10, FR80S20...SR60S40, SR50S50. A control sample of 100% untreated rice (R100) was also prepared. The specific compositions are detailed in Table 1.0.

Table 1. Percentage Composition of Rice-Sesame Composite Flours

Composite Code	Rice Flour (%)	Sesame Flour (%)
Fermented (FRS)		
FR90S10	90	10
FR80S20	80	20
FR70S30	70	30
FR60S40	60	40
FR50S50	50	50
Sprouted (SRS)		
SR90S10	90	10
SR80S20	80	20
SR70S30	70	30
SR60S40	60	40
SR50S50	50	50
Control		
R100	100	0

Extrusion Process

The composite flours were processed using a laboratory-scale single-screw extruder. The moisture content of each flour was standardized to 25% as per the method of Anuonye et al. (2012). The feed was introduced manually at a rate of 30 rpm to ensure consistent screw filling. The barrel temperature was maintained at 120°C. Extrudates were collected after the process reached a steady state, dried at 60°C, ground into a powder, and stored in a desiccator for subsequent analysis.

Analytical Determination

B-Vitamins: The concentrations of vitamins B_1, B_2, B_6, and B_{12} were quantified using standard spectrophotometric techniques (AOAC, 2011).

Amino Acids: The amino acid profile was determined following AOAC (2012) guidelines, involving defatting, acid hydrolysis, and analysis with a Technicon sequential Multi-Sample Amino Acid Analyzer (TSM).

Minerals: The levels of calcium (Ca), magnesium (Mg), potassium (K), sodium (Na), phosphorus (P), iron (Fe), and zinc (Zn) were measured according to AOAC (2012) methods.

Anti-nutrients: Phytate, oxalic acid, and tannin contents were determined using the methods of Soetan (2012), Day and Underwood (1986), and Price and Butler (1977), respectively.

Statistical Analysis

All experimental data were analyzed using Analysis of Variance (ANOVA) in the Statistical Package for Social Sciences (SPSS) version 16.0. Differences between means were considered statistically significant at a 95% confidence interval ($p < 0.05$).

RESULTS AND DISCUSSION

The vitamin content in the extrudates varied primarily due to the processing technique used and the amount of sesame added. As sesame seeds are a natural source of several B-vitamins, using more of them in the blends directly led to higher vitamin measurements. The sprouting process was effective at preserving and even increasing vitamin levels. This occurs because germination activates enzymes that release bound vitamins and can also trigger the production of new vitamins within the seed, a finding supported by Caroca-Cáceres et al. (2025) in their work on germinated grains. Conversely, fermentation altered vitamin content through a combination of microbial production and breakdown. Microbes like lactic acid bacteria can generate vitamins such as riboflavin and cobalamin (Rastogi et al., 2024), accounting for the higher levels found in actively fermented blends. However, this process can also reduce certain vitamins through leaching, enzymatic destruction, or oxidation (Kohli et al., 2024). The fact that sprouting and fermentation each boost different vitamins stems from their unique biological mechanisms. Sprouting activates the seed's own enzymatic pathways, while fermentation depends on the metabolic activity of microorganisms. This complementary nature of the two processes in enhancing the micronutrient quality of composite flours has been noted by Obianwuna et al. (2024) and Niyigaba et al. (2025).

Mineral composition

The mineral content of the rice-sesame extrudates was significantly affected by the amount of sesame added and the processing technique employed. Since sesame seeds are a dense source of minerals like phosphorus, calcium, magnesium, and zinc (Owheruo et al., 2025), their increasing share in the blends led to a corresponding rise in mineral levels. The notably high phosphorus readings align with research by Sarkar et al. (2025), which identified sesame as containing significant phosphorus, mainly bound in phytate complexes. Formulations with more sesame exhibited elevated levels of calcium, magnesium, and zinc, underscoring the seed's more robust mineral composition compared to rice. Blends that were sprouted typically demonstrated higher mineral concentrations. This is likely because the process triggers enzymatic breakdown of anti-nutrients like phytates, which frees up minerals and makes them more bioavailable (Enemali et al., 2025). The fermentation process similarly boosted mineral levels. This improvement occurs through the action of microbial phytases, a process that has been thoroughly described for the lactic acid fermentation of cereal and legume mixtures (Massaro et al., 2025).

Table 2. Selected Vitamin B Content of Extrudates (mg/100 g)

Sample	Vit B1	Vit B2	Vit B6	Vit B12
FR90S10	0.88±0.14[a]	0.14±0.14[e]	0.08±0.14[c]	0.34±0.12[d]
FR80S20	0.89±0.14[a]	0.27±0.14[d]	0.10±0.14[c]	0.43±0.23[c]
FR70S30	0.91±0.14[a]	0.35±0.14[c]	0.18±0.14[b]	0.65±0.00[b]
FR60S40	0.92±0.14[a]	0.40±0.14[b]	0.21±0.10[b]	0.68±0.23[b]
FR50S50	0.93±0.14[a]	0.47±0.21[a]	0.27±0.14[a]	1.11±0.24[a]
SR90S10	0.91±0.28[a]	0.40±0.21[d]	0.30±0.07[d]	0.25±0.12[b]
SR80S20	0.87±0.14[a]	0.42±0.21[d]	0.36±0.14[c]	0.25±0.12[b]
SR70S30	0.88±0.14[a]	0.49±0.14[c]	0.41±0.21[b]	0.28±0.71[b]
SR60S40	0.86±0.42[a]	0.61±0.07[b]	0.45±0.14[b]	0.30±0.94[b]
SR50S50	0.88±0.07[a]	0.79±0.21[a]	0.66±0.14[a]	0.58±0.24[a]
R100	0.37±0.10	0.08±0.12	0.05±0.02	0.17±0.11

Means in the same column with different superscripts are significantly different ($p < 0.05$)

Iron content was also significantly greater in blends with higher sesame proportions, supporting prior findings by Naimisha et al. (2025) on sesame's ability to increase the iron density of composite flours. The general rise in mineral availability in fermented products is probably a result of several concurrent factors, including acidification, enzymatic action, and the partial degradation of cell walls, all of which help to solubilize minerals (Sawant et al., 2025). The distinct biochemical pathways in fermentation and sprouting account for their different impacts on mineral enhancement. Sprouting works mainly by activating the plant's own enzymes to break down compounds that bind minerals. In contrast, fermentation relies on microbial metabolism, which not only diminishes anti-nutritional factors but can also generate organic acids that chelate minerals, thereby improving their mobility (Ospankulova et al., 2025).

Essential Amino Acid Profile

The balance of essential amino acids in the rice-sesame extrudates depended on how much sesame was used and how the mixture was processed. Leucine was the most abundant amino acid in every blend, which matches its known high levels in both rice and sesame proteins (Eze et al., 2025; Mostashari et al., 2024). Changes in leucine and other branched-chain amino acids like isoleucine and valine indicate that adding sesame can create a better amino acid balance in rice-based foods, potentially boosting their ability to support muscle protein synthesis and other metabolic functions (Rani et al., 2025). The increased lysine content seen with a moderate amount of sesame is significant because rice is naturally low in lysine (Eze et al., 2025). While sesame itself is not as rich in lysine as legumes, it still helps improve the overall amino acid profile when mixed with cereals. Higher levels of methionine and tryptophan in some blends are consistent with the work of Kurek et al. (2022), who noted that oilseeds like sesame are good sources of sulfur-containing and aromatic amino acids, which are typically scarce in plant-based diets. The manufacturing techniques were equally important. The sprouting process increased the availability of amino acids, likely due to proteolytic enzymes breaking down storage proteins into free amino acids and small peptides (Barakat et al., 2024). Similarly, fermentation boosted amino acid levels via the action of microbial proteases; lactic acid bacteria in particular are known to release bioactive peptides and raise the essential amino acid content in fermented cereal-legume blends (Du et al., 2024). The differences seen between the various blends show that adding sesame, especially in moderate to high amounts, can make up for the amino acids that rice lacks. At the same time, using sprouting or fermentation further improves how well these amino acids can be used by the body. These results advocate for rice-sesame combinations in creating well-rounded extruded foods, particularly for communities that depend mostly on plant-based diets.

Antinutritional Factors

The levels of anti-nutritional factors in the rice-sesame extrudates changed due to the interplay between the amount of sesame added and the processing techniques used. The minor rise in tannins when more sesame was included aligns with the natural polyphenols found in sesame seed coats (Anyiam et al., 2025). Despite this, total tannin quantities were low in all samples, indicating that extrusion, fermentation, and sprouting are proficient at diminishing these compounds. Phytate content was typically more reduced in sprouted blends than in fermented ones. This is because the germination process activates the seed's native phytase enzymes, which break down phytic acid and liberate minerals that were previously bound (Enemali et al., 2025). Fermentation also lowered phytate levels via the action of microbial phytases, though the effect was somewhat less pronounced, a result that agrees with studies on cereal-legume blends by Siddik et al. (2024) and Green et al. (2024). The decrease in oxalate content, especially in blends with less sesame, is likely a result of processing that breaks down soluble oxalates. Sprouting maintained somewhat higher oxalate levels than fermentation, potentially because of its shorter duration and lack of the acidic conditions in fermentation that help dissolve oxalates (Zayed et al., 2025).

Table 3. Mineral Composition of Extrudates

Sample	Na (g/100g)	K (g/100g)	Ca (g/100g)	Mg (g/100g)	P (g/100g)	Fe (mg/100g)	Zn (mg/100g)
$FR_{90}S_{10}$	0.49 ± 0.01^{cd}	0.31 ± 0.04^{d}	0.13 ± 0.01^{e}	0.29 ± 0.74^{c}	1.20 ± 0.85^{e}	2.83 ± 0.01^{e}	0.38 ± 0.01^{e}
$FR_{80}S_{20}$	0.48 ± 0.01^{d}	0.50 ± 0.03^{c}	0.37 ± 0.04^{d}	0.33 ± 0.01^{c}	1.28 ± 1.43^{d}	4.12 ± 0.01^{d}	0.56 ± 0.01^{d}
$FR_{70}S_{30}$	0.50 ± 0.02^{c}	0.62 ± 0.01^{b}	0.50 ± 0.03^{c}	0.51 ± 0.02^{b}	1.70 ± 0.86^{c}	7.21 ± 0.01^{c}	0.80 ± 0.00^{b}
$FR_{60}S_{40}$	0.53 ± 0.03^{b}	0.65 ± 0.00^{b}	0.56 ± 0.02^{b}	0.51 ± 0.02^{b}	2.30 ± 1.56^{a}	7.89 ± 0.13^{b}	0.94 ± 0.01^{a}
$FR_{50}S_{50}$	0.67 ± 0.02^{a}	0.74 ± 0.03^{a}	0.68 ± 0.03^{a}	0.58 ± 0.03^{a}	2.26 ± 2.19^{a}	9.42 ± 0.06^{a}	0.67 ± 0.01^{c}
$SR_{90}S_{10}$	0.58 ± 0.04^{c}	0.51 ± 0.01^{d}	0.53 ± 0.03^{e}	0.37 ± 0.13^{e}	1.90 ± 1.65^{e}	3.51 ± 0.01^{e}	0.66 ± 0.01^{e}
$SR_{80}S_{20}$	0.53 ± 0.03^{c}	0.65 ± 0.01^{c}	0.66 ± 0.06^{d}	0.45 ± 0.01^{d}	2.03 ± 0.85^{d}	3.64 ± 0.03^{d}	0.73 ± 0.01^{d}
$SR_{70}S_{30}$	0.62 ± 0.01^{b}	0.73 ± 0.01^{b}	0.74 ± 0.04^{c}	1.05 ± 0.06^{c}	2.36 ± 0.07^{c}	4.14 ± 0.04^{c}	0.81 ± 0.01^{c}
$SR_{60}S_{40}$	0.63 ± 0.03^{b}	0.84 ± 0.03^{a}	0.99 ± 0.08^{b}	1.35 ± 0.05^{b}	2.95 ± 0.14^{b}	5.68 ± 0.04^{b}	1.71 ± 0.02^{a}
$SR_{50}S_{50}$	1.09 ± 0.02^{a}	0.86 ± 0.00^{a}	1.58 ± 0.05^{a}	2.06 ± 0.04^{a}	3.42 ± 0.00^{a}	9.07 ± 0.01^{a}	1.20 ± 0.01^{b}
R_{100}	0.15 ± 0.01	0.17 ± 0.00	0.09 ± 0.01	0.19 ± 0.01	0.54 ± 0.00	1.83 ± 0.03	0.11 ± 0.01

Means in the same column with different superscripts are significantly different ($p < 0.05$)

Table 4. Essential Amino Acid Composition of Extrudates

Samples	Leucine (mg/100g)	Isoleucine (mg/100g)	Lysine (mg/100g)	Methionine (mg/100g)	Valine (mg/100g)	Histidine (mg/100g)	Phenylalanine (mg/100g)	Arginine (mg/100g)	Threonine (mg/100g)	Tryptophan (mg/100g)
$FR_{90}S_{10}$	7.42 ± 0.38^{c}	4.52 ± 0.70^{a}	3.74 ± 0.44^{d}	2.49 ± 0.28^{b}	4.19 ± 0.40^{b}	0.89 ± 0.19^{d}	3.71 ± 0.52^{a}	3.51 ± 0.12^{e}	4.16 ± 0.05^{d}	2.51 ± 0.17^{b}
$FR_{80}S_{20}$	8.00 ± 0.19^{a}	4.11 ± 0.01^{b}	4.55 ± 0.67^{c}	2.92 ± 0.07^{a}	3.22 ± 0.10^{c}	1.02 ± 0.16^{c}	3.59 ± 0.44^{ab}	3.68 ± 0.36^{d}	4.47 ± 0.24^{b}	2.52 ± 0.13^{b}
$FR_{70}S_{30}$	6.95 ± 0.78^{d}	3.98 ± 0.08^{d}	5.03 ± 0.14^{b}	2.10 ± 0.01^{d}	4.73 ± 0.06^{a}	1.47 ± 0.20^{b}	3.15 ± 0.06^{bc}	4.08 ± 0.01^{c}	4.11 ± 0.03^{d}	2.52 ± 0.13^{b}
$FR_{60}S_{40}$	7.74 ± 0.53^{b}	4.07 ± 0.05^{c}	5.59 ± 0.64^{a}	2.10 ± 0.01^{d}	2.09 ± 0.02^{d}	1.70 ± 0.16^{a}	2.88 ± 0.21^{c}	4.70 ± 0.05^{b}	4.70 ± 0.16^{a}	2.92 ± 0.41^{a}
$FR_{50}S_{50}$	6.37 ± 0.35^{c}	3.77 ± 0.57^{e}	5.06 ± 0.62^{b}	2.20 ± 0.02^{c}	4.15 ± 0.06^{b}	1.41 ± 0.16^{b}	2.69 ± 0.12^{d}	5.16 ± 0.05^{a}	4.17 ± 0.07^{c}	2.96 ± 0.11^{a}
$SR_{90}S_{10}$	8.04 ± 0.24^{b}	4.95 ± 0.15^{a}	4.47 ± 0.64^{c}	2.71 ± 0.29^{b}	4.03 ± 0.04^{a}	0.74 ± 0.13^{d}	3.95 ± 0.34^{a}	3.73 ± 0.06^{d}	3.71 ± 0.16^{d}	2.55 ± 0.10^{b}
$SR_{80}S_{20}$	9.11 ± 0.64^{a}	3.10 ± 0.02^{e}	4.03 ± 0.06^{e}	3.45 ± 0.58^{a}	2.70 ± 0.56^{b}	1.43 ± 0.11^{b}	3.73 ± 0.06^{b}	3.95 ± 0.05^{c}	4.39 ± 0.32^{b}	2.13 ± 0.02^{d}
$SR_{70}S_{30}$	7.08 ± 0.38^{d}	4.57 ± 0.15^{b}	4.73 ± 0.33^{b}	2.74 ± 0.12^{b}	4.00 ± 0.02^{a}	1.52 ± 0.02^{a}	3.59 ± 0.41^{c}	3.91 ± 0.11^{c}	4.11 ± 0.23^{c}	2.24 ± 0.17^{cd}
$SR_{60}S_{40}$	7.40 ± 0.57^{c}	4.23 ± 0.02^{c}	4.37 ± 0.25^{d}	2.18 ± 0.01^{d}	4.05 ± 0.05^{a}	1.30 ± 0.12^{c}	3.14 ± 0.04^{d}	4.29 ± 0.32^{b}	4.92 ± 0.06^{a}	2.66 ± 0.01^{a}
$SR_{50}S_{50}$	9.15 ± 1.16^{a}	4.09 ± 0.02^{d}	5.23 ± 0.19^{a}	2.48 ± 0.1^{c}	3.49 ± 0.60^{ab}	1.46 ± 0.20^{b}	3.13 ± 0.02^{d}	4.58 ± 0.05^{a}	4.11 ± 0.01^{c}	2.30 ± 0.17^{c}
R_{100}	2.93 ± 0.14	1.52 ± 0.07	0.66 ± 0.13	0.72 ± 0.03	1.78 ± 0.09	0.67 ± 0.02	2.30 ± 0.05	2.26 ± 0.08	2.17 ± 0.11	0.93 ± 0.01

Values are expressed as mean ± Standard Deviation. Values with different superscripts on the same column are statistically different at $P < 0.05$

Table 5. Antinutrient Composition of Extrudates

Sample	Tannin (mg/mL)	Phytate (mg/mL)	Oxalate (mg/mL)
$FR_{90}S_{10}$	0.12 ± 0.02^{c}	0.98 ± 0.20^{c}	0.17 ± 0.06^{d}
$FR_{80}S_{20}$	0.23 ± 0.03^{b}	1.03 ± 0.01^{b}	1.11 ± 0.02^{c}
$FR_{70}S_{30}$	0.28 ± 0.02^{ab}	1.05 ± 0.01^{b}	1.12 ± 0.03^{c}
$FR_{60}S_{40}$	0.30 ± 0.02^{a}	1.16 ± 0.01^{a}	1.96 ± 0.10^{b}
$FR_{50}S_{50}$	0.31 ± 0.01^{a}	1.16 ± 0.00^{a}	2.28 ± 0.00^{a}
$SR_{90}S_{10}$	0.30 ± 0.02^{a}	0.58 ± 0.27^{d}	2.68 ± 0.06^{d}
$SR_{80}S_{20}$	0.26 ± 0.01^{ab}	0.84 ± 0.01^{c}	2.99 ± 0.06^{c}
$SR_{70}S_{30}$	0.24 ± 0.04^{b}	0.85 ± 0.00^{c}	3.23 ± 0.10^{b}
$SR_{60}S_{40}$	0.19 ± 0.01^{b}	0.92 ± 0.01^{b}	3.27 ± 0.03^{b}
$SR_{50}S_{50}$	0.13 ± 0.01^{c}	0.95 ± 0.01^{a}	3.54 ± 0.03^{a}
R_{100}	0.11 ± 0.01	0.53 ± 0.02	0.04 ± 0.02

Values are expressed as mean ± Standard Deviation. Values with different superscripts on the same column are statistically different at $P < 0.05$. FRS = Fermented Rice/Sesame, SRS = Sprouted Rice/Sesame, R_{100} = Rice, Subscripts = percentage substitution

CONCLUSION

The addition of sesame to rice-based extrudates markedly enhanced their nutritional value by boosting vitamin content, enriching minerals, and creating a more balanced essential amino acid profile. The sprouting process was particularly effective at increasing vitamin levels and amino acid availability. In contrast, fermentation was more successful at diminishing anti-nutritional factors like phytates and oxalates. Both techniques improved the body's ability to absorb minerals, with blends higher in sesame showing the most significant increases in key minerals such as phosphorus, calcium, magnesium, and iron. The high levels of leucine, along with substantial gains in lysine, methionine, and tryptophan, demonstrate how the combination of rice and sesame creates a more complete protein. The consistent decrease in tannins, phytates, and oxalates confirms that these processing methods successfully mitigate compounds that inhibit mineral absorption and protein digestion.

CONFLICT OF INTEREST

The author here declares there is no conflict of interest in the publication of this article.

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