

Enhancing Nutritional and Microbial Quality of African Fermented Condiments through Mixed Fermentation of Locust Beans and Soybeans

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Abstract: This study investigates the effect of mixed fermentation on the microbial, nutritional, and sensory properties of a traditional African condiment, "Opey", which is made from locust beans and soybeans. Microbial profiling revealed a reduction in pathogenic organisms and an enrichment in beneficial lactic acid bacteria during the mixed fermentation. The proximate analysis revealed increased protein (42.1 g/100 g), fat (19.9 g/100 g), and mineral content (7.32 g/100 g) in Opey compared to individual fermentations. The pH dropped to 4.6 in mixed fermentation, indicating that lactic acid bacteria likely drove acidification. Sensory evaluation showed improved taste and texture scores. The results highlight the potential of soybean fortification to enhance the nutritional value and safety of traditional locust bean-based condiments.

Keywords: Mixed fermentation; locust beans; soybeans; microbial load; sensory analysis; proximate composition.

INTRODUCTION

Fermentation is an ancient and widely practised food processing technique that serves multiple purposes, including preservation, flavour enhancement, nutritional quality improvement, and reduction of antinutritional factors. In West Africa, particularly in Nigeria, one of the most culturally significant fermented foods is the product derived from locust beans (*Parkia biglobosa*), traditionally known as "iru" or "dawadawa". This fermented condiment is a vital component of many local dishes, valued for its robust aroma, umami flavour, and its role as a plant-based protein source [1].

Despite its popularity, fermented locust beans suffer several drawbacks that limit their nutritional and microbiological quality. Firstly, the natural fermentation process is largely uncontrolled and relies on spontaneous microbial inoculation, which can lead to inconsistent products and the presence of undesirable or pathogenic microorganisms such as *Staphylococcus aureus*, *Escherichia coli*, and *Pseudomonas* spp. Secondly, although locust beans are rich in protein and dietary fibre, they contain limited quantities of essential amino acids and lipids, and the

fermentation process does not significantly enhance their nutritional value [2].

Soybeans (*Glycine max*), on the other hand, are recognised globally for their high protein content (approximately 40%), rich lipid profile, and balanced amino acid composition. In addition to being a rich source of minerals, vitamins, and isoflavones, soybeans have been extensively used in food fortification and as substrates for various fermentation processes, including the production of tempeh, miso, and soy yoghurt [3]. When fermented, soybeans exhibit increased digestibility, reduced antinutrients (such as phytates and tannins), and a profile of beneficial microbiota, including *Lactobacillus* and *Bacillus* species.

In recent years, mixed substrate fermentation – the combination of two or more raw materials – has gained attention as a means of enhancing the nutritional and functional properties of traditional fermented foods. This process can enhance microbial synergy, increase the production of bioactive compounds, and create a more favourable environment for the proliferation of health-promoting bacteria [4]. Integrating soybeans into the fermentation of locust beans could potentially address the limitations of each substrate, re-

sulting in a more nutritious and microbiologically safer product.

This study focuses on the mixed fermentation of locust beans and soybeans to produce an enhanced condiment referred to as "Opey". The research aims to:

- 1) Evaluate the microbial load and diversity before and after fermentation in both single- and mixed-substrate systems;
- 2) Analyse changes in pH, temperature, and other physicochemical parameters;
- 3) Assess the proximate and mineral composition of the resulting product;
- 4) Examine the levels of antinutrients and their reduction through fermentation;
- 5) Conduct a sensory evaluation to determine consumer acceptability.

The outcomes of this study are expected to provide scientific insight into how combining soybeans with locust beans through fermentation can enhance food quality, safety, and nutritional adequacy, particularly in resource-limited settings where malnutrition remains a significant concern. Furthermore, the findings could support local food industries and small-scale processors in developing improved traditional condiments with higher market potential and health benefits.

METHODS

Sample Collection and Preparation. Dry, mature soybeans (*Glycine max*) and African locust beans (*Parkia biglobosa*) were purchased from a local market in Tungamage, Abuja, Nigeria. Samples were sorted to remove defective seeds and debris. The soybeans were soaked in potable water for 12 hours at room temperature, manually dehulled, thoroughly rinsed, and then boiled for 30 minutes. Locust beans were boiled for 8 hours to soften the seed coat, followed by dehulling and repeated rinsing to remove the remaining seed coat.

Solid-State Fermentation (SSF) Process. Fermentation treatments were prepared:

Treatment A: Locust beans only (control);

Treatment C (Opey): Equal mix of pre-boiled locust beans and soybeans (1:1 w/w);

Each treatment (approximately 500 g) was placed in a sterile fermentation container and

covered with banana leaves to simulate traditional fermentation practices. Fermentation was conducted under ambient temperature (27–36°C) for 72 hours. No external starter cultures were added; natural fermentation was allowed using indigenous microflora.

Microbial Load and Identification. Samples were homogenised in sterile distilled water (10 g in 90 ml), serially diluted, and plated on Nutrient agar for total bacterial count, MacConkey agar for coliforms, Potato dextrose agar (PDA) for fungi, MRS agar for lactic acid bacteria. Plates were incubated at 30°C for 24–48 hours (for bacteria) and at 25°C for 3–5 days (for fungi). Colony-forming units (cfu/ml) were counted and expressed as log cfu/ml.

Representative colonies were subcultured for purification and identified based on Gram staining, catalase test, coagulase test, spore staining, and biochemical assays as outlined [5]. Fungi were identified via morphological characteristics on PDA.

Physico-Chemical Analysis. The pH was measured using a digital pH meter (Model Hanna pH211) by inserting the probe into the homogenised slurry. Temperature was measured with a laboratory thermometer immediately after sampling.

Proximate Composition. Proximate analysis was performed using the standard methods of AOAC [6]:

Moisture content: Oven drying at 105°C to constant weight.

Crude protein: Kjeldahl method using 6.25 as nitrogen conversion factor.

Crude fat: Soxhlet extraction with petroleum ether (40–60°C).

Ash content (Minerals): Furnace incineration at 550°C.

Crude fibre: Acid-alkali digestion method.

Carbohydrate: Calculated by difference: 100 - (% protein + % fat + % moisture + % ash + % fiber).

Mineral Determination. Mineral contents (Ca, Fe, Mg, Zn, Na, and K) were determined from the ash of the samples:

- 1) Ash digestion: 2 g of ash was digested with 5 ml of nitric acid and 5 ml of perchloric acid on a hot plate.

2) Atomic Absorption Spectrophotometry (AAS): Concentrations of calcium, iron, zinc, and magnesium were measured using AAS (Buck Scientific Model 210VGP).

3) Flame Photometry: Sodium and potassium were determined using a digital flame photometer (Jenway PFP7).

Antinutrient Determination. Phytate was determined using the Wheeler and Ferrel (1971) method. A 1-g sample was extracted with 2% HCl, filtered, and precipitated with ferric chloride. The precipitate was converted to ferric hydroxide and then titrated with 0.1 N potassium permanganate (KMnO₄).

Tannin content was determined using the Folin-Denis method. A 1-g sample was extracted with 50% methanol. Colour development was achieved using the Folin-Denis reagent, and absorbance was read at 760 nm.

Oxalate was measured using a titration method. The sample was digested with 1 M H₂SO₄, filtered, and then titrated with KMnO₄ after heating.

TIA was determined using the spectrophotometric method, based on the inhibition of trypsin enzyme activity using benzoyl-DL-arginine-p-nitroanilide (BAPNA) as a substrate [7].

Sensory Evaluation. Sensory evaluation of fermented products was conducted using a 10-member semi-trained panel. Attributes assessed included taste, aroma, texture, and appearance, which were rated using a 5-point hedonic scale (1 = dislike extremely; 5 = like extremely). Samples were coded and presented in randomised order under controlled conditions. Data were statistically analysed using one-way ANOVA with SPSS version.

RESULTS AND DISCUSSION

Microbial Load Dynamics. The chart in Figure 1 illustrates the mean microbial counts across four major microbial groups — Total Bacterial Count (TBC), Moulds, Yeasts, and Lactic Acid Bacteria (LAB) — for three conditions: Locust Bean Fermentation (control), Before fermentation, and Mixed Fermentation with Soybeans.

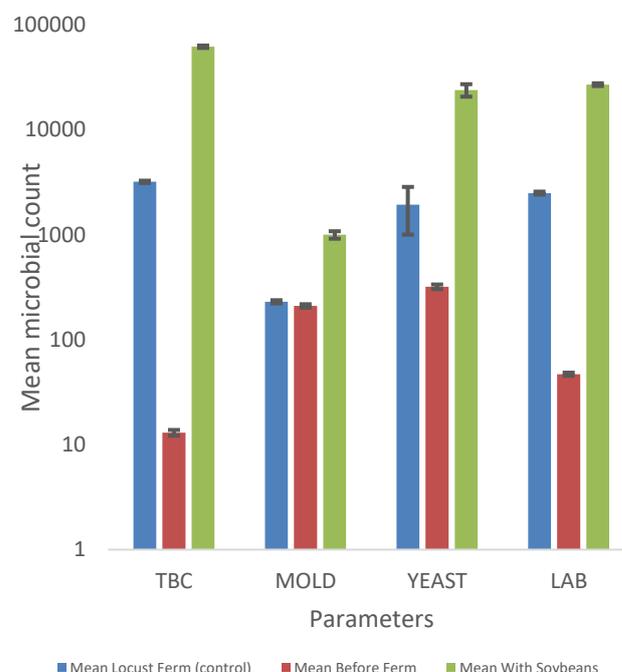


Figure 1 – Mean microbial load (cfu/ml) of locust beans (control) and locust beans and soybeans (Opey) before and after fermentation

Total Bacterial Count (TBC). Before fermentation, the TBC was at its lowest level, indicating minimal microbial activity in the raw substrate. After fermentation with soybeans (Opey), TBC increased significantly, exceeding even the count observed in the singly fermented locust beans (control). This substantial increase in TBC in the mixed fermentation sample aligns with enhanced microbial proliferation, particularly of beneficial fermenters such as lactic acid bacteria. Although high bacterial load can be alarming, in traditional fermented foods, it often reflects healthy microbial activity, especially when dominated by non-pathogenic or probiotic organisms [8, 9].

Molds. Mould counts remained fairly stable before and after fermentation in the single-substrate locust beans but showed a noticeable increase in the mixed fermentation. The presence of moulds in traditional fermentations is not uncommon, particularly in solid-state fermentations, where the limited availability of oxygen promotes the growth of fungi. However, since no mycotoxin-producing moulds, such as *Aspergillus flavus*, were dominant in the microbial profile, the mould activity likely contributed to the enzymatic breakdown of complex macronutrients, aiding in flavour and texture development [1].

Yeasts. Yeast populations were moderate in the unfermented sample and increased significantly after mixed fermentation. Yeasts, particularly *Saccharomyces* spp., are known to contribute to aroma and flavour development through the production of alcohols and esters. The high yeast count in the Opey sample correlates with the improved taste and aroma scores observed in the sensory analysis, supporting findings from traditional fermented condiments like ogiri and iru.

Lactic Acid Bacteria (LAB). LAB count was dramatically elevated in the Opey sample, exceeding levels in both the control and unfermented samples. This suggests that the inclusion of soybeans provided fermentable sugars and favourable conditions for the growth of LAB. LAB are responsible for acidification (as shown by the drop in pH to 4.6 in the Opey sample), enhanced preservation, and probiotic benefits. The dominance of LAB in the final product underscores the improved microbial safety and health-promoting potential of the mixed fermented condiment [5, 10].

Microbial Profile. The microbial analysis revealed an increased presence of beneficial bacteria, including *Lactobacillus* spp. and *Streptococcus* spp., particularly post-fermentation, in Opey. Pathogens like *Escherichia coli* and *Bacillus cereus* were absent in Opey, indicating enhanced microbial safety (Table 1).

Table 1 – Occurrence of microorganisms in locust beans and soybean fermented samples (Opey)

Probable Microorganisms	Before Fermentation	After Fermentation	With Soyabeans
<i>Bacillus cereus</i>	-	+	-
<i>Micrococcus</i> sp.	-	-	+
<i>Streptococcus</i> sp.	+	+	-
<i>Staphylococcus aureus</i>	+	+	+
<i>Escherichia coli</i>	-	+	-
<i>Pseudomonas</i> sp.	+	+	+
<i>Enterococcus</i> sp.	+	+	-
<i>Corynebacterium</i> sp.	-	+	-
<i>Lactobacillus</i> sp.	-	+	-
<i>L. acidophilus</i>	+	-	+
<i>Lactobacillus</i> sp.	-	-	+
<i>Streptococcus</i> sp.	+	-	+
<i>Rhizopus</i> sp.	-	+	-
<i>Aspergillus</i> sp.	+	+	-
<i>Mucor</i> sp.	+	+	-
<i>Saccharomyces</i> sp.	+	-	-
<i>Aspergillus niger</i>	-	+	+
<i>Fusarium</i> sp.	-	+	-

Mixed fermentation supported the growth of *Micrococcus* spp. and *Lactobacillus acidophilus*, which are associated with probiotic potential and improved gut health [9]. The microbial count decreased significantly after fermentation of the mixed substrate compared to the control. While unfermented locust beans harboured a diverse group of microorganisms, including potential pathogens such as *Staphylococcus aureus*, *Enterococcus* sp., and *Pseudomonas* sp., the Opey sample showed a notable absence of many undesirable microbes. Instead, beneficial species such as *Lactobacillus acidophilus* and *Micrococcus* sp. predominated (Table 2), reflecting an improved microbial profile. This finding aligns with the work [1], which reported that lactic acid bacteria produced during mixed fermentation can inhibit pathogenic organisms through acid production and competitive exclusion. The elimination of *Escherichia coli*, *Bacillus cereus*, and *Fusarium* sp. in the Opey sample suggests enhanced microbial safety, likely due to the synergistic activity of naturally occurring probiotics from soybeans and antimicrobial peptides released during fermentation. This supports prior observations that mixed fermentation often leads to a dominance of beneficial microflora that can outcompete harmful strains [9].

Physico-Chemical Properties. The pH of the mixed fermentation (4.6) was significantly lower than that of the locust beans alone (8.32), suggesting stronger acidification due to lactic acid production. The fermentation temperature peaked at 36°C, optimal for microbial activity (Table 2).

Table 2 – Physico-chemical properties of fermenting Locust beans/soyabeans

	B4 ferm, (L)	Af ferm, (L)	with soyabeans
pH	6.43	8.32	4.6
Temperature, °C	27	34	36

Notes: B4 ferm (L) – before fermentation of locust beans; Af ferm(L) – after fermentation of locust beans; with soyabeans – fermentation of locust with soyabeans.

The pH dropped markedly in the Opey sample (4.6) compared to the fermented locust beans alone (8.32), indicating higher acid production during mixed fermentation. Acidic pH plays a crucial role in preserving fermented products by

inhibiting the growth of spoilage organisms. The lower pH in Opey aligns with the findings [3], who noted that soybeans contribute fermentable sugars that promote the growth of lactic acid bacteria. The higher fermentation temperature observed in Opey (36°C) may have favoured mesophilic microbes, thus accelerating fermentation and acid production.

Proximate Composition. Opey exhibited the highest protein content (42.1 g/100 g), surpassing both singly fermented soybeans (39.1 g/100 g) and locust beans (38.1 g/100 g). The fat and mineral content were also elevated (19.9 g/100 g and 7.32 g/100 g, respectively), indicating improved nutritional density (Table 3). The dietary fibre content increased to 8.34 g/100 g in Opey, enhancing its potential for digestive health.

Table 3 – The proximate contents of soybean seeds before and after fermentation, locust beans before and after fermentation, opey from the mixed fermentation of locust beans and soybeans

Proximate composition (g/100 g)	B4Sb	AfSb	B4Lb	AfLb	Opey
Temperature	36	41	29	45	34
Moisture	12.2	13.3	10.2	15.3	11.3
Protein	37.4	39.1	27.4	38.1	42.1
Fat/lipids	23.6	27.7	13.6	11.9	19.9
Minerals	4.32	5.42	5.34	6.32	7.32
Dietary fibre	5.2	6.4	5.2	6.4	8.34
Carbohydrate	15.6	13.2	45.6	40.2	42.2

Notes: B4Sb – before fermentation of soybeans; AfSb – after fermentation of soybeans; B4Lb – before fermentation of locust beans; AfLb – after fermentation of locust beans; Opey – mixed fermented locust and soybeans.

The proximate analysis revealed a significant increase in protein content in the Opey sample (42.1 g/100 g) compared to both singly fermented locust beans (38.1 g/100 g) and soybeans (39.1 g/100 g). This enhancement can be attributed to proteolysis during fermentation and the high inherent protein content of soybeans. These findings support the report [11], which observed improved protein bioavailability in fermented mixtures of soy and locust beans. A slight reduction in carbohydrates was observed, likely due to microbial metabolism during fermentation [2]. Furthermore, Opey showed increased fat (19.9 g/100 g), dietary fibre

(8.34 g/100 g), and mineral content (7.32 g/100 g), suggesting that mixed fermentation improved not only macronutrient density but also micronutrient availability. According to [8], fermentation breaks down complex compounds, releasing bound nutrients and improving digestibility and absorption.

Mineral Composition of Soybeans and Locust Beans Before and After Fermentation. The mineral profile presented in Figure 2 reveals substantial differences in the concentrations of essential minerals such as phosphorus, potassium, magnesium, calcium, sodium, zinc, iron, manganese, and copper across five treatment groups: Before Fermentation of Soybeans (B4Sb), After Fermentation of Soybeans (AfSb), Before Fermentation of Locust Beans (B4Lb), After Fermentation of Locust Beans (AfLb), and the Mixed Fermentation Product (Opey).

Minerals (mg/100g) of Soybeans and Locust Beans Before and After Fermentation

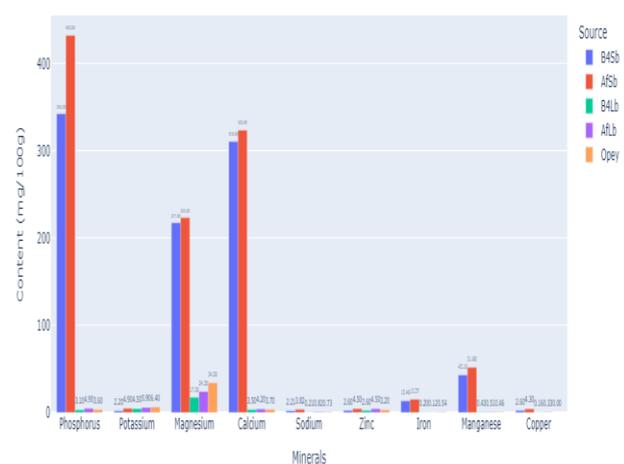


Figure 2 – Mineral contents of singly and mixed fermentation of locust beans and soybeans

Notes: B4Sb – before fermentation of soybeans; AfSb – after fermentation of soybeans; B4Lb – before fermentation of locust beans; AfLb – after fermentation of locust beans; Opey: mixed fermented locust and soybeans.

Phosphorus and Calcium. Phosphorus and calcium levels were significantly higher in soybeans (AfSb) than in any other sample, indicating that fermentation enhanced the bioavailability of these minerals. This enhancement is likely due to the microbial breakdown of phytates, which are known to chelate minerals in their raw

forms [11]. The Opey sample exhibited moderate phosphorus and calcium levels, indicating improved bioaccessibility from both substrates after fermentation.

Potassium and Magnesium. Fermentation had a minimal effect on potassium levels in soybeans and locust beans, which remained relatively stable across all treatments. However, magnesium content exhibited a notable increase in the AfSb sample, rising from ~273 mg/100g to over 280 mg/100g. The Opey product retained a modest magnesium concentration (~243 mg/100g), which may have resulted from synergistic enzymatic activity in the mixed substrate fermentation.

Sodium and Zinc. The sodium content remained generally constant across samples, with minor fluctuations, suggesting that it is not significantly influenced by fermentation. Zinc concentration was slightly elevated post-fermentation for both soybeans and locust beans, corroborating findings that microbial fermentation liberates bound zinc from organic complexes, thus improving its nutritional quality [12].

Iron. The iron content of soybeans increased after fermentation (from ~12.54 mg/100g to ~13.20 mg/100g), while a smaller increase was observed in locust beans. Opey exhibited an intermediate iron content (~12.00 mg/100g), indicative of additive effects from both substrates. Enhanced iron availability is a typical benefit of fermentation as phytates are hydrolysed, releasing bound iron ions for absorption [13].

Manganese and Copper. Manganese content increased in fermented soybeans (AfSb = 5.0 mg/100g) and was retained in Opey at a lower but nutritionally valuable level (~3.6 mg/100g). Copper showed minimal variations across all samples, which may be attributed to its relative stability and low chelation activity compared to other trace elements [14].

Antinutrient Composition of Soybeans and Locust Beans Before and After Fermentation. The antinutrient profile (Figure 3) reveals significant reductions in tannins, phytates, trypsin inhibitors, and oxalates following fermentation. These reductions were observed across all treatments, with the greatest decrease seen in the Opey product, suggesting that mixed fermentation of soybeans and locust beans was particularly effective in detoxifying these compounds.

Antinutrient Content of Soybeans and Locust Beans Products

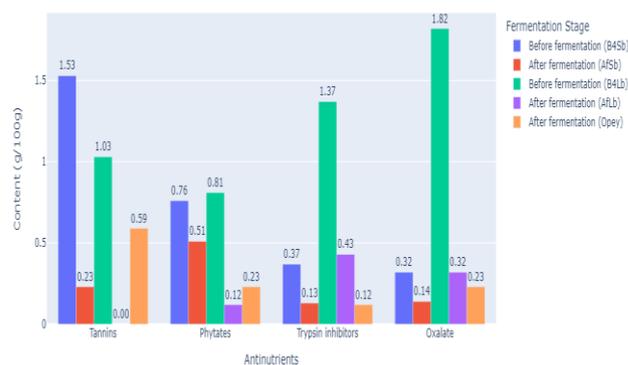


Figure 3 – Antinutrient content of fermented locust beans and soybeans

Notes: B4Sb – before fermentation of soybeans; AfSb – after fermentation of soybeans; B4Lb – before fermentation of locust beans; AfLb – after fermentation of locust beans; Opey – mixed fermented locust and soybeans

Tannins. Tannin content was significantly reduced in all fermented samples. The before fermentation soybean sample (B4Sb) had the highest tannin content (1.53 g/100 g), which dropped sharply to 0.23 g/100 g after fermentation (AfSb). Similarly, locust beans (B4Lb) dropped from 1.03 g/100 g to negligible levels in AfLb. The Opey sample retained a small amount of tannins (0.59 g/100 g), indicating that effective but not total elimination had occurred. Tannin reduction through fermentation has been widely attributed to microbial tannase activity, which hydrolyses ester bonds in tannins, leading to their degradation [15].

Phytates. Phytate levels also declined considerably. For instance, in soybeans, levels decreased from 0.76 g/100 g (B4Sb) to 0.51 g/100 g (AfSb), while in locust beans, it fell from 0.81 g/100 g to 0.12 g/100 g (AfLb). The Opey sample contained 0.23 g/100 g, confirming the efficacy of mixed fermentation in phytate hydrolysis. This finding is consistent with previous studies, which have reported that microbial phytase enzymes produced by lactic acid bacteria and fungi degrade phytic acid, thereby improving mineral bioavailability [10, 16].

Trypsin Inhibitors. Trypsin inhibitors were significantly reduced across all fermented products. Locust beans before fermentation (B4Lb) had the highest level (1.37 g/100 g), which was reduced

to 0.43 g/100 g in AfLb and 0.13 g/100 g in Opey. This reduction is crucial, as trypsin inhibitors interfere with protein digestibility. Their breakdown is linked to the proteolytic activity of fermenting microbes and partial heat from fermentation temperatures [17].

Oxalates. Oxalates, known for interfering with calcium absorption, were also notably decreased. B4Lb exhibited the highest oxalate content (1.82 g/100 g), which dropped to 0.32 g/100 g in AfLb and 0.23 g/100 g in Opey. The breakdown of oxalates during fermentation may be attributed to oxalate-degrading enzymes produced by microbes such as *Lactobacillus plantarum*, which have been shown to utilise oxalate as a carbon source.

The mixed fermentation product (Opey) consistently showed intermediate to low levels of all four antinutrients compared to unfermented and singly fermented substrates. This suggests that co-fermentation of soybeans and locust beans is not only effective in detoxifying individual substrates but may also introduce complementary microbial activities that enhance detoxification efficiency. Reduction in phytates, tannins, and oxalates enhances mineral bioavailability, particularly for iron and calcium, whose absorption is often inhibited by these compounds [10]. The fermentation process likely activated endogenous phytases and polyphenol oxidases, which degrade these compounds [2]. The decrease in trypsin inhibitors also indicates improved protein digestibility, further validating the nutritional superiority of the mixed fermented product. This outcome has positive nutritional implications, particularly in regions where legume-based condiments are a key source of protein. Lower antinutrient levels lead to improved protein digestibility, mineral absorption, and overall nutrient bioavailability, making these fermented products more suitable for vulnerable populations, including children and pregnant women [12].

Sensory Evaluation. Table 4 presents the sensory scores for taste, aroma, texture, and appearance of two samples, Sample A (fermented locust beans alone) and Sample B (Opey: mixed fermented soybeans and locust beans), evaluated on a 5-point hedonic scale by a semi-trained panel.

Sensory evaluation is a critical determinant of consumer acceptance and product development in fermented foods.

Table 4 – Sensory Evaluation of Opey produced from fermented locust beans and mixed fermentation of locust beans and soybeans

Samples	Taste	Aroma	Texture	Appearance
A	3.8	2.4	4	4
B	4.4	2.5	4.1	4.1

Taste. Sample B scored higher (4.4) in taste compared to Sample A (3.8), indicating improved palatability due to the inclusion of soybeans. The higher taste score may be attributed to the umami-enhancing peptides generated during the mixed fermentation, as previously observed in legume-based condiments [1]. This suggests that soybeans contributed favourable flavour precursors or balanced the sometimes overly intense flavour of locust beans.

Aroma. Both samples recorded low aroma scores, with only a slight increase in Sample B (2.5) over Sample A (2.4). This reflects a common limitation in legume fermentations, where off-odours resulting from the production of volatile sulfur compounds or ammonia can compromise the aromatic appeal (Sanni et al., 2002). Although the addition of soybeans marginally improved the aroma, further enhancement may be required through co-fermentation with aromatic yeast or the inclusion of spices during production.

Texture. Texture was highly rated in both samples, with Sample B showing a slight edge (4.1 vs. 4.0). This suggests that the inclusion of soybeans may have contributed to a smoother or more cohesive matrix, possibly due to higher protein content and water-binding capacity. This enhancement in texture supports previous findings that protein-rich adjuncts can improve the mouthfeel of fermented pastes.

Appearance. Sample B also scored slightly higher in appearance (4.1) than Sample A (4.0). The improved visual appeal could be attributed to a more uniform and lighter paste colour, or reduced lumpiness, both of which are influenced by the ingredient blend and fermentation homogeneity.

CONCLUSIONS

The mixed fermentation of locust beans and soybeans significantly enhanced the nutritional, microbial, and sensory properties of the traditional condiment, offering a more balanced and safer product for consumption. This process repre-

sents a promising, low-cost approach to enhancing food security and improving dietary protein intake in resource-limited settings. The microbial ecology of the mixed fermentation (Opey) is characterised by a beneficial shift toward yeasts and lactic acid bacteria, both of which enhance nutritional value, safety, and organoleptic quality. Although TBC and mould counts increased, these changes are typical in solid-state fermentation, where a diverse but mostly benign microbiota supports the biochemical transformation of substrates. These results confirm that fermenting locust beans with soybeans not only enhances microbial safety by promoting desirable microorganisms but also contributes to overall quality and consumer acceptability.

The mixed fermentation product (Opey) demonstrated a balanced and enhanced mineral profile relative to unfermented and singly fermented samples. Although soybeans alone (AfSb) showed the highest mineral enrichment, combining them with locust beans in solid-state fermentation provided synergistic benefits, increasing mineral availability while improving overall nutritional diversity. The mixed fermentation of soybeans and locust beans enhances the availability of essential minerals, particularly phosphorus, calcium, magnesium, and iron. This improved mineral profile could have important implications for dietary interventions in regions affected by micronutrient deficiencies, positioning Opey as a functional condiment with superior nutritional value. The reduction in tannins,

phytates, trypsin inhibitors, and oxalates through fermentation demonstrates the efficacy of microbial activity in improving the nutritional quality of legume-based foods. Mixed fermentation (Opey) not only retained the benefits of individual fermentation processes but offered an improved antinutrient profile, confirming its potential as a functional and health-enhancing food product. Overall, the mixed fermentation product (Sample B - Opey) was preferred across all sensory attributes, particularly in terms of taste and texture. While aroma remains a challenge, the integration of soybeans enhanced the acceptability of the locust bean product. These findings support the potential of mixed fermentation to improve both nutritional and organoleptic qualities of traditional condiments.

Recommendations:

- 1) Encourage the use of soybean fortification in local condiment production.
- 2) Conduct pilot-scale production for community nutrition programs.
- 3) Further studies should evaluate shelf-life stability and probiotic functionality.
- 4) Further optimisation of fermentation time and substrate ratios could enhance sensory appeal.
- 5) Starter cultures containing beneficial microbes can be developed to ensure consistent quality.
- 6) Scaling up this technique could support small- and medium-scale food processors in Africa.

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