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EFFECT OF GINGER (*Zingiber officinale*) AND TURMERIC (*Curcuma longa*) AS NATURAL PRESERVATIVES ON THE PROXIMATE COMPOSITION OF SMOKED-DRIED *Clarias gariepinus* and *Chrysichthys nigrodigitatus* PROCESSED WITH RICE HUSK BRIQUETTES

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Abstract
Fish is an important source of high-quality protein, essential amino acids, vitamins, and minerals for human nutrition. However, fish is highly perishable, particularly in tropical environments where high temperatures accelerate microbial activity and biochemical deterioration. This study evaluated the influence of natural spice preservatives on the proximate composition of smoked-dried Clarias gariepinus *and* Chrysichthys nigrodigitatus *processed using rice husk briquettes. Fresh fish samples were treated with ginger (*Zingiber officinale*), turmeric (*Curcuma longa*), a combination of both spices, and an untreated control. Mineral analysis showed increased calcium, phosphorus, iron, zinc, and potassium in treated samples, while vitamin retention, particularly vitamins A, D, and E, was higher in spice-treated fish due to the antioxidant activities of curcumin and gingerol compounds. Fish were immersed in spice solutions (20 g L^{-1}) for 15 minutes prior to smoking in a traditional drum kiln using rice husk briquettes as fuel. The smoked fish were stored at ambient temperature for three months. Proximate composition (moisture, crude protein, lipid, and ash) was determined using standard analytical methods. Data were analyzed using analysis of variance (ANOVA) at a 5% significance level. Results indicated that spice treatments significantly improved nutrient retention and reduced moisture content during storage ($p < 0.05$). The combined ginger–turmeric treatment produced the highest protein retention and the lowest moisture content in both species.* Clarias gariepinus *exhibited slightly higher protein content compared with* Chrysichthys nigrodigitatus*. The findings demonstrate that natural spices combined with rice husk briquette smoking enhance the nutritional quality and stability of smoked fish. The adoption of natural preservatives and sustainable biomass fuels may contribute to improved fish preservation and reduced post-harvest losses in tropical fisheries.*

Keywords: smoked fish, natural preservatives, ginger, turmeric, rice husk briquettes, proximate composition

Introduction

Fish constitutes one of the most important sources of animal protein globally and plays a vital role in food security, especially in developing countries. It provides high-quality protein, essential amino acids, vitamins such as A, D, and B-complex, and minerals including calcium, phosphorus, iron, zinc, and selenium Food and Agriculture Organization (FAO, 2022). In addition, fish is rich in omega-3 polyunsaturated fatty acids, which are associated with reduced risk of cardiovascular diseases and improved human health (Huss, 1995; Mohanty *et al.,* 2019).

Despite its nutritional benefits, fish is one of the most highly perishable food commodities due to its high moisture content, neutral pH, and the presence of autolytic enzymes that accelerate spoilage after harvest (Gram & Huss, 1996; Abbas *et al.,* 2008). In tropical regions such as Nigeria, poor post-harvest handling practices, inadequate preservation facilities, and high ambient temperatures often lead to rapid deterioration of fish quality. Post-harvest losses of fish in developing countries have been estimated to range from 30% to 50%, resulting in significant economic losses and reduced food availability (Akinneye *et al.,* 2007).

Smoking is one of the most widely used traditional methods of fish preservation. The process involves the combined effects of heat, drying, and exposure to smoke compounds, which inhibit microbial growth and extend shelf life while enhancing flavour, aroma, and colour (Doe, 1998). However, traditional fish smoking often relies heavily on firewood, contributing to deforestation, environmental pollution, and greenhouse gas emissions (Onah *et al.,* 2022).

Recently, attention has been directed toward the use of biomass briquettes, such as rice husk briquettes, as alternative smoking fuels. Rice husk is an abundant agricultural by-product that can be converted into renewable fuel, reducing reliance on fuelwood and promoting sustainable fish processing (Olorunnisola, 2007). The use of rice husk briquettes has also been reported to improve combustion efficiency and reduce environmental degradation associated with traditional fuelwood utilization (Njenga *et al.,* 2019).

In addition to improved smoking technologies, the use of natural plant-based preservatives has gained increasing interest in food preservation. Spices such as ginger (*Zingiber officinale*) and turmeric (*Curcuma longa*) contain bioactive compounds with strong antioxidant and antimicrobial properties. Ginger contains gingerols and shogaols, which exhibit antimicrobial and antioxidant activities (Shan et al., 2005). Turmeric contains curcumin, a polyphenolic compound known for its antioxidant, anti-inflammatory, and antimicrobial properties (Prasad & Aggarwal, 2011; Hewlings & Kalman, 2017). These compounds can help reduce oxidative deterioration, microbial spoilage and improve shelf-life stability in food products.

Two commercially important freshwater species in Nigeria are *Clarias gariepinus* (African catfish) and *Chrysichthys nigrodigitatus* (silver catfish). These species are widely consumed due to their high protein content, good taste, rapid growth, and economic value (Fagbenro & Adebayo, 2005). However, their high perishability poses significant challenges for storage and distribution.

Although several studies have examined the preservation of smoked fish, limited information exists on the combined effects of natural spices and rice husk briquette smoking on the nutritional composition, sensory quality, microbial stability, fatty acid profile, and shelf-life of smoked fish. Therefore, this study aimed to evaluate the effects of ginger and turmeric treatments on the proximate composition of smoked-dried *Clarias gariepinus* and *Chrysichthys nigrodigitatus* processed using rice husk briquettes.

Materials and Methods

Sample Collection

Fresh samples of *Clarias gariepinus* (268 to 273g) and *Chrysichthys nigrodigitatus* (246 to 250g) were obtained from a good fish farm in Abakaliki, Ebonyi State, Nigeria. The fish were purchased early in the morning to ensure freshness and transported to the laboratory in ice-packed containers.

Preparation of Fish Samples

In the laboratory, fish were beheaded, gutted, and eviscerated. The samples were thoroughly washed with distilled water to remove slime, blood, and surface contaminants.

Preparation of Spice Preservatives

Fresh rhizomes of ginger (*Zingiber officinale*) and turmeric (*Curcuma longa*) were purchased from Margaret Umahi International Market, Ebonyi State. The rhizomes were washed, peeled, sliced, dried, and milled into fine powder using a laboratory grinder according to the method described by Amoah *et al*. (2020) and Emelike (2020), with modifications to suit the present study. The powdered spices were stored in airtight containers until use.

Experimental Design and Spice Treatment

The experiment consisted of four treatments with three replicates; T1 (Control) with no spice, T2 treated with ginger, T3 spiced with turmeric and T4 treated with ginger and turmeric. The spice treatment procedure was adapted from Kefas *et al*. (2022). The combined spice treatment was prepared by mixing ginger powder and turmeric powder in a 1:1 ratio. Equal quantities of each spice were thoroughly blended to obtain a homogeneous mixture. For T1, T2 and T3, 20g of spice powder were dissolved in one liter of water. Fish samples were immersed in the spice solution for 15 minutes and then drained for 30 minutes on a wire mesh to allow spice penetration.

Preparation of Rice Husk Briquettes

Rice husk was collected from Abakaliki Rice Mill, Ebonyi State. The rice husk briquettes were produced following the method described by Sani *et al.* (2019**)**. Rice husk was cleaned, dried, mixed with a starch binder, compressed into briquettes using a briquetting mould, and dried to constant weight before use as smoking fuel. The use of rice husk briquettes provided sustainable heat generation and reduced dependence on firewood

Smoking Process

Fish samples were smoked using a traditional drum smoking kiln with a capacity of 400 L (90 cm length and 58 cm diameter). Rice husk briquettes served as the smoking fuel. The smoking process lasted approximately 5–6 hours daily for three consecutive days until the fish were adequately dried.

Storage Conditions

After smoking, the fish were sealed in labelled zip-lock polyethylene bags and stored at ambient temperature (29^{o}C) for three months.

Proximate and Chemical Analysis

Proximate composition analyses were carried out according to standard methods of the Association of Official Analytical Chemists (AOAC, 2019**)**. Mineral elements including calcium, phosphorus, iron, potassium, magnesium, and zinc were analyzed using standard laboratory procedures (AOAC, 2019). Vitamins A, D, and E were determined using spectrophotometric method (AOAC, 2019).

Statistical Analysis

Data obtained from the analyses were subjected to Analysis of Variance (ANOVA) to determine significant differences among treatments and species. Mean separation was performed using Duncan's Multiple Range Test at a significance level of $p < 0.05$**.**

Results

The proximate composition of smoked-dried fish samples showed significant differences among treatments and storage periods (Tables 1 and 2).

Moisture content decreased significantly in the spiced samples compared with the control ($p < 0.05$). The combined ginger–turmeric treatment exhibited the lowest moisture levels during the three-month storage period.

Protein content remained relatively stable in all samples but was highest in the combined spice treatment. *Clarias gariepinus* generally recorded slightly higher protein levels than *Chrysichthys nigrodigitatus*.

Lipid content showed minor variations among treatments, while ash content remained relatively stable throughout the storage period.

Overall, the combined spice treatment demonstrated the most effective preservation of the nutritional quality of smoked fish.

Table 1: Silver Catfish Mean Proximate Composition (Month 0, 1, 2 and 3)

Month Zero	(Month 0)					One Month Storage					Two Month Storage					Three Month Storage				
proximate	T1 (Control)	T2 (Turmeric)	T3 (Ginger)	T4 (Turmeric + Ginger)	±SEM	T1 (Control)	T2 (Turmeric)	T3 (Ginger)	T4 (Turmeric + Ginger)	±SEM	T1 (Control)	T2 (Turmeric)	T3 (Ginger)	T4 (Turmeric + Ginger)	±SEM	T1 (Control)	T2 (Turmeric)	T3 (Ginger)	T4 (Turmeric + Ginger)	±SEM
Crude Protein (%)	. . . . .	68.53^{c}	. . . . .	. . . . .	0.46	. . . . .	68.47^{b}	68.30^{b}	70.26^{a}	0.23	61.70^{c}	67.50^{b}	67.13^{b}	69.00^{a}	0.19	60.10^{c}	67.40^{b}	66.00^{b}	68.44^{a}	0.12
Moisture (%)	5.08^{a}	3.34^{b}	3.26^{b}	3.10^{c}	0.21	5.17^{a}	3.36^{b}	3.30^{b}	3.13^{c}	0.04	7.40^{a}	4.65^{b}	4.25^{b}	3.68^{c}	0.11	8.13^{a}	4.95^{b}	4.69^{b}	4.18^{c}	0.08
Lipid (%)	8.43^{a}	7.02^{b}	6.94^{b}	5.33^{c}	0.27	8.68^{a}	7.10^{b}	6.98^{b}	5.36^{c}	0.03	9.71^{a}	7.98^{b}	7.60^{b}	5.78^{c}	0.14	10.03^{a}	8.70^{b}	8.33^{b}	6.54^{c}	0.09
Ash (%)	14.21^{c}	15.31^{b}	15.77^{a}	15.13^{b}	0.21	14.00^{c}	15.31^{b}	15.76^{a}	15.13^{b}	0.12	12.15^{c}	14.98^{b}	15.38^{a}	14.85^{b}	0.12	11.80^{c}	14.28^{b}	14.79^{a}	14.24^{b}	0.07
Crude Fibre (%)	1.65c	1.86^{b}	1.92^{a}	1.62^{c}	0.07	1.70^{c}	1.86^{b}	1.93^{a}	1.61^{c}	0.03	1.80^{b}	1.93^{a}	1.85^{b}	1.76^{c}	0.05	1.88^{b}	1.98^{a}	1.90^{b}	1.65^{c}	0.05

Mean values with different superscripts across the same row differ significantly ($p < 0.05$),

African Catfish Mean Proximate Composition
The proximate composition showed clear improvements with spice treatments. Crude protein increased from 68.88% in the control to a maximum of 71.15% in the turmeric with ginger treatment, with turmeric and ginger alone also enhancing protein levels compared to the control. Moisture and lipid contents decreased progressively with treatment, indicating improved dryness and reduced fat, as moisture declined from 6.25% to 3.90% and lipid from 10.23% to 7.80% in T_4. Ash content increased from 11.77% to 13.18%, reflecting higher mineral concentration, while crude fibre varied slightly (1.72–2.09%), with ginger recording the highest value. Nitrogen-free extract was lowest in turmeric-treated samples (1.70%) and highest in ginger-treated samples (2.59%).

Similar to the Silver Catfish, the African Catfish samples showed superior stability in the treated groups. The T1 (Control) moisture content increased significantly to 9.61% by Month 3, indicating reabsorption of atmospheric moisture. In contrast, the T4 treatment maintained a low moisture content (4.58%) and retained the highest crude protein (69.83%) compared to the control (62.25%), highlighting the synergistic effect of ginger and turmeric in maintaining nutrient density.

Table 2: African Catfish Mean Proximate Composition (Month 0, 1, 2 and 3)

Month Zero	Month 0					One Month Storage				
proximate	T1 (Control)	T2 (Turmeric)	T3 (Ginger)	T4 (Turmeric + Ginger)	±SEM	T1 (Control)	T2 (Turmeric)	T3 (Ginger)	T4 (Turmeric + Ginger)	±SEM
Crude Protein (%)	68.88^{d}	70.93^{b}	70.20^{c}	71.15^{a}	0.33	67.59^{d}	70.82^{b}	70.17^{c}	71.14^{a}	0.36
Moisture (%)	6.25^{a}	4.77^{b}	4.37^{c}	3.90^{d}	0.23	6.40^{a}	4.86^{b}	4.39^{c}	3.93^{d}	0.32
Lipid (%)	10.23^{a}	8.52^{b}	8.06^{c}	7.80^{d}	0.32	10.35^{a}	8.28^{b}	8.15^{c}	7.90^{d}	0.04
Ash (%)	11.77^{d}	12.40^{c}	12.93^{b}	13.18^{a}	0.29	11.60^{d}	12.40^{c}	12.93^{b}	13.18^{a}	0.25
Crude Fibre (%)	1.72^{c}	2.01^{b}	2.09^{a}	1.70^{c}	0.08	1.81^{c}	2.02^{b}	2.11^{a}	1.69^{d}	0.03

Month Zero	Two Month Storage					Three Month Storage				
proximate	T1 (Control)	T2 (Turmeric)	T3 (Ginger)	T4 (Turmeric + Ginger)	±SEM	T1 (Control)	T2 (Turmeric)	T3 (Ginger)	T4 (Turmeric + Ginger)	±SEM
Crude Protein (%)	63.58^{d}	69.70^{b}	68.99^{c}	70.68^{a}	0.23	62.25^{d}	68.69^{b}	68.33^{c}	69.83^{a}	0.14
Moisture (%)	8.21^{a}	5.20^{b}	4.98^{c}	4.03^{d}	0.12	9.61^{a}	5.88^{b}	5.35^{c}	4.58^{d}	0.08
Lipid (%)	11.89^{a}	8.96^{b}	8.60^{c}	7.98^{d}	0.12	12.30^{a}	9.40^{b}	8.98^{c}	8.57^{d}	0.07
Ash (%)	9.70^{d}	12.05^{c}	12.57^{b}	13.00^{a}	0.12	8.50^{d}	11.51^{c}	12.04^{b}	12.48^{a}	0.05
Crude Fibre (%)	1.90^{c}	1.95^{b}	2.00^{a}	1.80^{d}	0.05	1.95^{c}	2.08^{b}	2.15^{a}	1.69^{d}	0.04

Mean values with different superscripts (a, b, c, d) within the same row differ significantly ($p < 0.05$),

Table 3 summarizes the effect of turmeric, ginger, and their combination on the vitamin composition of silver catfish during 0–3 months of storage and reveals significant treatment and storage related differences ($p < 0.05$) for most vitamins. At Month 0, vitamin A was significantly higher in turmeric (15.27) and ginger (14.96) treatments than in the control (13.85), while the combined treatment showed a lower value (13.21), indicating better vitamin A retention with single spice application; vitamin E and vitamin B3 were also significantly enhanced by spice treatment, with the highest values recorded in the turmeric with ginger samples (0.99 and 1.80, respectively), whereas vitamins D (4.15–4.30) and B1 (1.35–1.42) did not differ significantly ($p > 0.05$) among treatments. As storage progressed, a general decline in vitamin content was observed across all samples; however, spiced fish consistently retained higher levels than the control. After one month, vitamin A (15.49–15.13), vitamin E (0.84–0.95), and vitamin B3 (1.53–1.77) remained significantly higher in spiced treatments, while vitamins D and B1 continued to show no significant differences. By Month 3, marked reductions occurred, particularly in the control sample, yet turmeric- and ginger-treated fish still exhibited significantly higher ($p < 0.05$) retention of vitamins A, E, and B3, with vitamin D remaining relatively stable and vitamin B1 only slightly affected. Overall, the results demonstrate that turmeric and ginger, applied singly or in combination, significantly ($p < 0.05$) improved the retention of key vitamins in silver catfish during storage, with the most pronounced protective effects observed for vitamins A, E, and niacin (B3).Storage degraded vitamins in the control samples significantly. Vitamin E (tocopherol), a natural antioxidant, was depleted in T1 (0.30 IU) as it fought oxidation, whereas T2 (Turmeric) and T4 retained significantly higher levels (0.89 and 0.86 IU), suggesting a sparing effect where the spice antioxidants protected the endogenous vitamins.

Table 3: Silver Catfish Mean Vitamin Composition (Month 0-3)

	Month 0					One Month Storage				
Vit.	T1 (Control)	T2 (Turmeric)	T3 (Ginger)	T4 (Turmeric + Ginger)	±SEM	T1 (Control)	T2 (Turmeric)	T3 (Ginger)	T4 (Turmeric + Ginger)	±SEM
Vit. A	13.85^{c}	15.27^{a}	14.96^{b}	13.21^{d}	0.25	14.03^{b}	15.49^{a}	15.13^{a}	13.02^{c}	0.20
Vit. D	4.15^{ns}	4.20^{ns}	4.23^{ns}	4.30^{ns}	0.10	4.07^{ns}	4.13^{ns}	4.18^{ns}	4.25^{ns}	0.08
Vit. E	0.75^{d}	0.91^{b}	0.87^{c}	0.99^{a}	0.03	0.73^{c}	0.89^{b}	0.84^{b}	0.95^{a}	0.04
Vit. B1	1.38^{ns}	1.35^{ns}	1.36^{ns}	1.42^{ns}	0.03	1.40ns	1.33^{ns}	1.37ns	1.41^{ns}	0.03
Vit. B2	1.01^{a}	0.98^{b}	0.95^{b}	0.59^{c}	0.02	0.99^{a}	0.97^{a}	0.97^{a}	0.55^{b}	0.06
Vit. B3	1.48^{d}	1.63^{a}	1.55^{c}	1.80^{a}	0.03	1.50^{c}	1.61^{b}	1.53^{c}	1.77^{a}	0.04

	Two Month Storage					Three Month Storage				
Vit.	T1 (Control)	T2 (Turmeric)	T3 (Ginger)	T4 (Turmeric + Ginger)	±SEM	T1 (Control)	T2 (Turmeric)	T3 (Ginger)	T4 (Turmeric + Ginger)	±SEM
Vit. A	13.77^{b}	15.39^{a}	15.00^{b}	12.98^{c}	0.19	13.20^{b}	15.10^{a}	14.74^{b}	12.70^{c}	0.11
Vit. D	3.85^{ns}	4.05^{ns}	4.04^{ns}	4.19^{ns}	0.07	3.48^{ns}	3.71^{ns}	3.65^{ns}	4.03^{ns}	0.05
Vit. E	0.61^{c}	0.90^{b}	0.84^{b}	0.95^{a}	0.04	0.30^{c}	0.89^{a}	0.73^{b}	0.86^{a}	0.03
Vit. B1	1.20^{c}	1.25^{b}	1.24^{b}	1.36^{a}	0.03	1.33^{b}	1.05^{c}	0.93^{c}	1.25^{a}	0.05
Vit. B2	0.67^{c}	0.88^{b}	0.85^{b}	0.50^{d}	0.05	1.35^{a}	0.57^{c}	0.40^{d}	0.45^{d}	0.04
Vit. B3	1.32^{c}	1.55^{a}	1.48^{b}	1.61^{a}	0.04	1.10^{c}	1.50^{a}	1.37^{b}	1.45^{a}	0.05

Means within the same row with different superscripts are significantly different ($p < 0.05$). ns = not significant

African Catfish Mean Vitamin Composition

Based on the data, dietary supplementation significantly enhanced vitamin retention in African catfish during storage. The T2 (Turmeric) consistently maintained the highest Vitamin A levels, measuring 12.68IU 12.54, 12.43lu, and 12.20IU from months 0 to 3, respectively, and was significantly superior. The T4 (Turmeric with Ginger) demonstrated a powerful synergistic effect for Vitamin D, retaining significantly higher levels (5.69, 5.74, 5.66, 5.30) than all others treatment at each month. All spice treatments preserved Vitamin E; by month 3, T_1 (Control) fell sharply to 0.54, while T_2 and T4 retained levels at 1.10. For B vitamins, T4 showed the strongest protection for B1 (1.39IU at month 2) and B2 (0.36 to control's 0.10 at month 3), while T2 best supported B3 (1.88 at month 0 to 1.60 at month 3). The spice enhanced diets, especially T4, effectively mitigated vitamin degradation. The T4 treatment showed remarkable retention of Vitamin D in African Catfish (5.30 IU vs 2.92 IU in Control). This suggests the spice matrix may stabilize the sterol structure of Vitamin D against oxidative breakdown during storage.

Table 4: African Catfish Mean Vitamin Composition (Month 0-3)

	Month 0					One Month Storage				
Vit.	T1 (Control)	T2 (Turmeric)	T3 (Ginger)	T4 (Turmeric + Ginger)	±SEM	T1 (Control)	T2 (Turmeric)	T3 (Ginger)	T4 (Turmeric + Ginger)	±SEM
Vit. A	10.72^{c}	12.68^{a}	11.39^{b}	11.05^{b}	0.07	10.58^{d}	12.54^{a}	11.25^{b}	10.91^{c}	0.16
Vit. D	3.45^{c}	3.58^{b}	3.91^{b}	5.69^{a}	0.09	3.41^{c}	3.49c	3.86b	5.74a	0.22
Vit. E	0.89^{c}	1.12^{b}	1.07^{b}	1.20^{a}	0.02	0.87^{c}	1.10^{b}	1.05^{b}	1.18a	0.05
Vit. B1	1.39	1.34	1.36	1.47	0.03	1.37^{ns}	1.35^{ns}	1.34^{ns}	1.45	0.03
Vit. B2	0.63^{a}	0.59^{b}	0.55^{c}	0.50^{d}	0.02	0.61^{ns}	0.58^{ns}	0.54^{ns}	0.49ns	0.04
Vit. B3	1.63^{c}	1.88^{a}	1.78^{b}	1.81^{b}	0.03	1.61b	1.85^{a}	1.77^{ns}	1.77^{ns}	0.05

	Two Month Storage					Three Month Storage				
Vit.	T1 (Control)	T2 (Turmeric)	T3 (Ginger)	T4 (Turmeric + Ginger)	±SEM	T1 (Control)	T2 (Turmeric)	T3 (Ginger)	T4 (Turmeric + Ginger)	±SEM
Vit. A	10.48^{d}	12.43^{a}	11.10^{b}	10.70^{c}	0.16	10.00^{c}	12.20^{a}	10.80^{b}	10.50^{c}	0.11
Vit. D	3.23^{c}	3.36^{b}	3.36^{b}	5.66^{a}	0.21	2.92^{c}	3.19^{b}	3.10^{b}	5.30^{a}	0.14
Vit. E	0.80^{a}	1.10^{c}	1.05^{d}	1.18^{b}	0.05	0.54^{c}	1.10^{a}	0.97^{b}	1.10^{a}	0.05
Vit. B1	1.16^{c}	1.21^{b}	1.19^{c}	1.39^{a}	0.03	0.90^{c}	1.02^{b}	0.94^{c}	1.15^{a}	0.04
Vit. B2	0.36^{b}	0.40^{a}	0.35^{b}	0.40^{a}	0.04	0.10^{c}	0.38^{a}	0.30^{b}	0.36^{a}	0.03
Vit. B3	1.50^{ns}	1.79^{a}	1.55^{ns}	1.57^{ns}	0.05	1.23^{c}	1.60^{a}	1.49^{b}	1.49^{b}	0.05

Means within the same row with different superscripts are significantly different ($p < 0.05$). ns = not significant

Silver Catfish Mean mineral Composition

All spiced samples showed significantly higher mineral contents than the control, with calcium increasing from 202.69 mg/100 g in the control to 269.49 mg/100 g (turmeric), 252.18 mg/100 g (ginger), and peaking at 284.60 mg/100 g in the turmeric with ginger treatment, while phosphorus rose from 98.86 mg/100 g in the control to about 107.5 mg/100 g in ginger and combined treatments; magnesium also increased from 70.60 mg/100 g in the control to approximately 76–77 mg/100 g in spiced samples. Iron was significantly higher in turmeric (10.98 mg/100 g) and turmeric with ginger (10.78 mg/100 g) treatments compared with the control (8.50 mg/100 g), whereas zinc values were highest in the control (13.40 mg/100 g) and combined treatment (13.30 mg/100 g) and lowest in ginger-treated fish (10.90 mg/100 g). As storage progressed to Month 3, a significant decline ($p < 0.05$) in all minerals was observed across treatments, with more pronounced losses in the control; however, spiced samples consistently retained higher mineral levels, as shown by calcium values of 187.44 mg/100 g (control) versus 268.77–284.42 mg/100 g (spiced), phosphorus 85.67 mg/100 g versus up to 107.16 mg/100 g, magnesium 64.10 mg/100 g versus 75.21 mg/100 g, iron 6.00 mg/100 g versus 10.67 mg/100 g, and zinc 8.10 mg/100 g versus 13.32 mg/100 g. the results demonstrate that turmeric and ginger, particularly in combination, significantly ($p < 0.05$) improved mineral retention and nutritional stability of silver catfish during storage.Treated samples consistently exhibited higher mineral concentrations than the control. T4 Silver Catfish contained 284.42 mg/100g of Calcium compared to 187.44 mg/100g in the control. This is likely due to the concentration effect (lower moisture in T4) and the mineral contribution from the spices themselves.

Table 5: Silver Catfish Mean Mineral Composition (Month 0, 1, 2 and 3)

	Month 0					One Month Storage					
Min	T1 (Control)	T2 (Turmeric)	T3 (Ginger)	T4 (Turmeric + Ginger)	±SEM	T1 (Control)	T2 (Turmeric)	T3 (Ginger)	T4 (Turmeric + Ginger)	±SEM	T1 (Control)
Ca	202.69^{d}	269.49^{b}	252.18^{c}	284.60^{a}	11.6	193.43^{d}	269.89^{b}	251.67^{c}	284.48^{a}	7.35	188.36^{d}
P	98.86^{d}	103.26^{c}	107.53^{b}	107.48^{a}	0.6	93.87^{d}	102.11^{c}	107.28^{b}	107.31^{a}	0.88	87.08^{d}
Mg	70.60^{d}	76.49^{b}	76.87^{a}	75.85^{c}	0.6	68.18^{d}	76.34^{b}	76.79^{a}	75.81^{c}	0.56	65.13^{c}
Fe	8.50^{c}	10.98^{a}	7.70^{d}	10.78^{b}	0.35	7.13^{c}	10.08^{b}	7.50^{c}	10.78^{a}	0.30	6.28^{c}
Zn	13.40^{a}	12.27^{b}	10.90^{c}	13.30^{a}	0.25	11.78^{c}	12.22^{b}	10.86^{d}	13.30^{a}	0.26	9.61^{c}

	Two Month Storage				Three Month Storage				
Min	T2 (Turmeric)	T3 (Ginger)	T4 (Turmeric + Ginger)	±SEM	T1 (Control)	T2 (Turmeric)	T3 (Ginger)	T4 (Turmeric + Ginger)	±SEM
Ca	268.80^{b}	252.27^{c}	284.46^{a}	1.74	187.44^{d}	268.77^{b}	251.83^{c}	284.42^{a}	0.14
P	101.40^{c}	107.00^{b}	107.25^{a}	0.68	85.67^{d}	101.40^{c}	106.80^{b}	107.16^{a}	0.20
Mg	76.28^{b}	76.69^{a}	75.72^{b}	0.18	64.10^{c}	76.23^{b}	76.67^{a}	75.21^{b}	0.09
Fe	10.00^{a}	7.44^{d}	10.68^{b}	0.28	6.00^{c}	9.90^{b}	7.41^{c}	10.67^{a}	0.08
Zn	12.19^{b}	12.18^{b}	13.30^{a}	0.17	8.10^{c}	12.19^{b}	10.84^{c}	13.32^{a}	0.09

Means within the same row with different superscripts (a–d) are significantly different ($p < 0.05$).

African Catfish Mean mineral Composition

The mineral composition of African catfish was significantly influenced by spice treatment (turmeric, ginger, and their combination) and storage duration, as indicated by the data in Table 12 ($P < 0.05$). Across all storage periods, the T4 treatment (Turmeric + Ginger) consistently recorded the highest concentrations of calcium (Ca), phosphorus (P), and magnesium (Mg), highlighting the synergistic effect of combining these spices in preserving mineral content. For instance, at Month 0, Ca was highest in T4 (252.90 mg/100 g) compared to the control T1 (178.67 mg/100 g), and this trend persisted through Month Three (252.77 mg/100 g vs 167.16 mg/100 g in control), indicating that the rice husk–smoking process combined with antioxidant-rich spices effectively reduced mineral leaching during storage.

Phosphorus (P) content followed a similar trend, with T4 again showing superior retention (180.63–181.40 mg/100 g) compared to the control (101.02–91.73 mg/100 g) across storage months. This suggests that spices, particularly in combination, may protect phosphate-containing compounds in the fish from oxidative degradation. Magnesium (Mg) was also better retained in spiced samples, with T2–T4 consistently above 90 mg/100 g, whereas control samples declined progressively with storage, possibly due to mineral solubilization during moisture changes and lipid oxidation.

Iron (Fe) and zinc (Zn) exhibited slight variations across treatments but maintained higher levels in spiced fish compared to control, emphasizing the protective effect of spice phenolics and antioxidant activity. For example, Fe in T4 remained relatively high (9.61 mg/100 g at Month 0 to 9.50 mg/100 g at Month Three), while T1 decreased from 7.35 to 4.92 mg/100 g. Zn values were also preserved in T2–T4 (14.37–14.48 mg/100 g) throughout storage.

Table 6: African Catfish Mean Mineral Composition (Month 0 - 3)

	Month 0					One Month Storage				
Mineral	T1 (Control)	T2 (Turmeric)	T3 (Ginger)	T4 (Turmeric + Ginger)	±SEM	T1 (Control)	T2 (Turmeric)	T3 (Ginger)	T4 (Turmeric + Ginger)	±SEM
Ca (mg/100g)	178.67^{d}	238.50^{b}	220.43^{c}	252.90^{a}	17.5	171.87^{d}	236.11^{b}	220.08^{c}	252.19^{a}	8.60
P (mg/100	101.02^{d}	109.50^{c}	112.15^{b}	180.63^{a}	3.5	94.47^{d}	109.47^{c}	112.00^{b}	182.10^{a}	4.77
Mg (mg/100g)	81.55^{d}	90.38^{b}	91.41^{a}	91.48^{a}	0.5	79.11^{d}	90.27^{b}	91.44^{a}	91.47^{a}	1.37
Fe (mg/100g)	7.35^{b}	5.86^{c}	9.23^{a}	9.61^{a}	0.4	6.20^{c}	5.66^{d}	9.00^{b}	9.58^{a}	0.38
Zn (mg/100g)	13.08^{b}	14.48^{a}	13.48^{b}	14.48^{a}	0.3	11.08^{c}	14.48^{a}	13.48^{b}	14.48^{a}	0.30

	Two Month Storage					Three Month Storage				
Mineral	T1 (Control)	T2 (Turmeric)	T3 (Ginger)	T4 (Turmeric + Ginger)	±SEM	T1 (Control)	T2 (Turmeric)	T3 (Ginger)	T4 (Turmeric + Ginger)	±SEM
Ca (mg/100g)	165.28^{d}	236.00^{b}	219.98^{c}	252.15^{a}	4.08	167.16^{d}	235.24^{b}	219.87^{c}	252.77^{a}	1.06
P (mg/100	92.88^{d}	109.17^{c}	111.93^{b}	182.03^{a}	5.39	91.73^{d}	109.10^{c}	111.69^{b}	181.40^{a}	0.25
Mg (mg/100g)	76.38^{c}	90.18^{b}	91.36^{a}	91.37^{a}	0.25	76.00^{c}	90.05^{b}	91.23^{a}	91.33^{a}	0.15
Fe (mg/100g)	5.10^{c}	5.60^{d}	8.98^{b}	9.48^{a}	0.38	4.92^{c}	5.60^{d}	8.89^{b}	9.50^{a}	0.07
Zn (mg/100g)	9.49^{c}	14.46^{a}	14.40^{a}	14.45^{a}	0.07	9.10^{c}	14.37^{a}	14.40^{a}	14.45^{a}	0.07

Values are mean ± SEM. Means within the same row with different superscripts (a–d) are significantly different ($p < 0.05$).

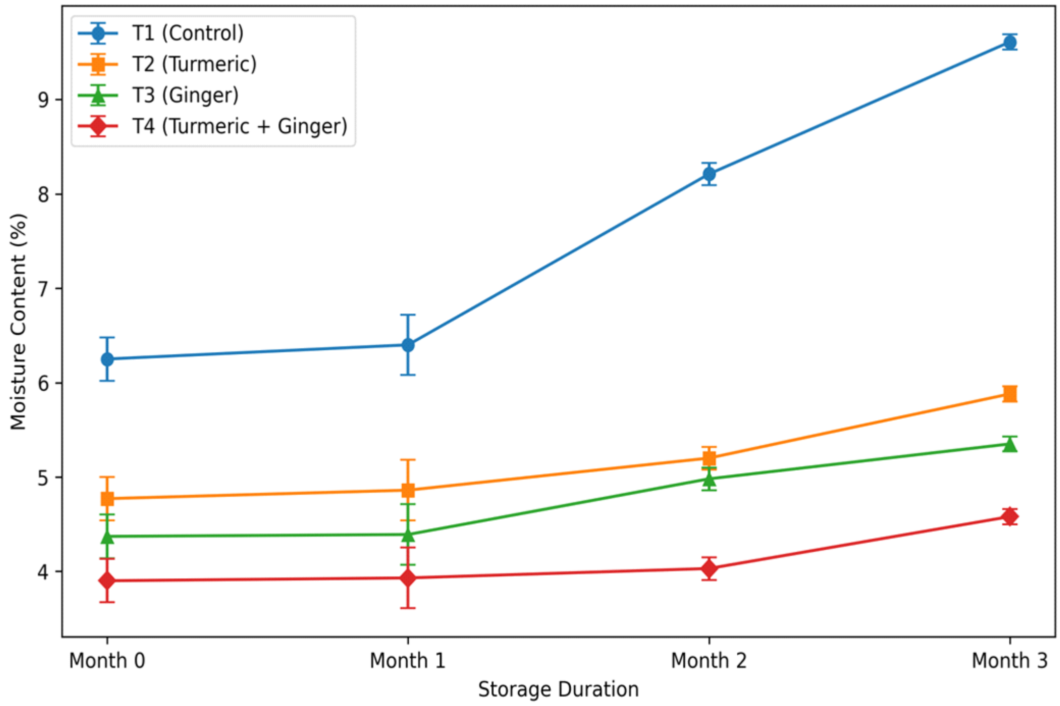

Figure 1: Kinetic Stability of Moisture Content during Storage (C. gariepinus)

The moisture stability plot (Figure 1) illustrates distinct hygroscopic behaviours between the treatments. Over the three-month period, moisture levels in the Control (T1) ascended sharply from 6.25% to 9.61%, approaching the critical 10% threshold for fungal proliferation. In contrast, the combined treatment (T4) maintained a stable moisture profile (3.90% to 4.58%), demonstrating the effectiveness of the spice paste in creating a barrier against environmental moisture reabsorption.

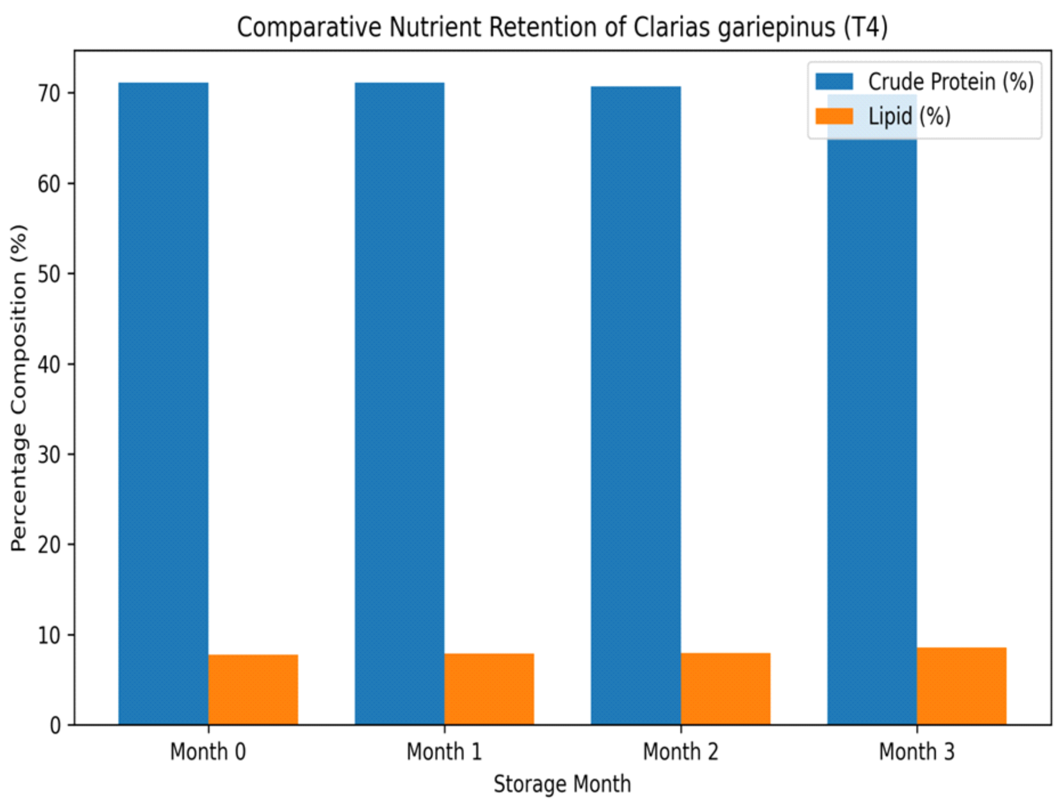

Figure 2: Comparative Nutrient Retention at Month 3 (C. gariepinus)

Figure 2 highlights the protective capacity of the treatments regarding macronutrients. At the end of the storage period, the T4 treatment retained significantly higher crude protein levels (69.83%) compared to the control (62.25%). Additionally, the lipid profile in T4 appeared more balanced (8.57%), whereas the control showed an apparent increase in lipid percentage due to the loss of protein mass (concentration effect).

Discussion

The reduction in moisture content observed in the spiced samples may be attributed to the combined effects of smoking and spices treatment which enhance drying efficiency. Reduced moisture content is important for prolonging shelf life because it limits microbial growth (Doe, 1998).

The higher protein retention observed in the combined ginger–turmeric treatment may be due to the reduced moisture content of the samples and the bioactive compounds in the spices. Gingerols and curcuminoids have been reported to inhibit oxidative reactions and protein degradation in food products (Shan *et al.,* 2005; Prasad & Aggarwal, 2011).

The slightly higher protein content observed in *Clarias gariepinus* compared with *Chrysichthys nigrodigitatus* may be related to species-specific physiological differences and initial nutrient composition.

The use of rice husk briquettes as smoking fuel represents a sustainable alternative to fuelwood. Biomass briquettes provide consistent heat energy while reducing environmental impacts associated with deforestation (Olorunnisola, 2007).

These findings support previous studies which reported that natural plant extracts can improve the nutritional stability of smoked fish products during storage (Akinneye *et al*., 2007).

The mineral composition of smoked-dried Chrysichthys nigrodigitatus and Clarias gariepinus showed significant improvements in spice-treated samples compared with the control. African catfish generally recorded higher ash values than silver catfish, indicating greater mineral concentration and retention during smoking and storage. The turmeric + ginger treatment enhanced the retention of important minerals such as calcium, phosphorus, iron, zinc, potassium, and magnesium in both fish species.

The increased mineral retention observed in treated samples agrees with the findings of Adeyeye *et al*. (2019), who reported that spice application improves mineral stability during fish processing and storage. Similarly, Rybicka *et al*. (2022) observed that antioxidant-rich plant additives improve mineral stability in smoked foods.

Higher ash content observed in treated samples further confirms increased mineral concentration. According to Food and Agriculture Organization (FAO, 2020), smoking processes that effectively reduce moisture help concentrate minerals and improve nutritional density.

The improved iron and zinc contents in treated samples may also be linked to reduced oxidative degradation during storage. Similar findings were reported by Rybicka *et al*. (2022), who observed improved micronutrient retention in fish processed with natural antioxidants.

Vitamin revealed improved retention of vitamins A, D, and E in turmeric- and ginger-treated samples compared with the control. The antioxidant activity of curcumin and gingerol likely protected these vitamins from thermal and oxidative degradation during smoking and storage.

This finding agrees with Prasad and Aggarwal (2011), who reported that turmeric enhances oxidative stability and preserves fat-soluble vitamins in food systems.

Vitamin E retention was significantly higher in treated samples due to its synergistic interaction with antioxidant compounds present in turmeric and ginger. Similar observations were reported by Sivaraman *et al.* (2021), who found that natural spices improve vitamin stability in smoked and dried fish products.

The higher vitamin retention in turmeric + ginger-treated samples suggests a synergistic preservative effect. This agrees with the report of Fitriyanto *et al*. (2025), who noted that combined plant antioxidants are more effective in preserving nutrients than single-spice treatments. African catfish treated with turmeric and ginger demonstrated slightly superior Vitamin retention compare with silver catfish as seen in table 3 and 4, although both species benefited significantly from spice application.

Conclusion

The study demonstrated that ginger and turmeric treatments significantly improved the nutritional stability of smoked-dried *Clarias gariepinus* and *Chrysichthys nigrodigitatus*. The combined ginger–turmeric treatment provided the best results in terms of moisture reduction and protein retention during storage. The use of natural spice preservatives in combination with rice husk briquette smoking represents a sustainable and effective strategy for improving smoked fish preservation in tropical regions. Adoption of this method may help reduce post-harvest losses and enhance food security.

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