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## Research Article

# Biochemical Assessment and Oxidative Stability of Garlic Fortified Silver Catfish, *Chrysichthys nigrodigitatus*

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### ABSTRACT

This study investigated the effect of garlic fortification as a natural preservative and functional additive on the biochemical composition and oxidative stability of hot-smoked Silver Catfish (*Chrysichthys nigrodigitatus*) subjected to hot smoking. Fresh, non-fortified hot-smoked and garlic-fortified hot-smoked samples were analysed for proximate composition, nutrient-energy contribution, mineral content, lipid oxidation indices and correlation between proximate and mineral parameters. Moisture content was highest in fresh fish ( $77.03 \pm 0.37\%$ ) but declined significantly after smoking to  $9.65 \pm 0.22\%$  and  $9.27 \pm 0.15\%$  in non-fortified and garlic-fortified samples respectively. Crude protein increased markedly, reaching the highest value in garlic-fortified fish ( $53.61 \pm 0.60\%$ ), while crude fat and ash also increased following smoking. Energy value rose substantially from about 372 kJ/100 g in fresh samples to over 1200 kJ/100 g in smoked products, with protein energy contribution exceeding 58% in fortified samples. Mineral concentrations also increased after processing; for example, calcium rose from  $18.6 \pm 1.5$  mg/100 g in fresh fish to  $152.7 \pm 6.1$  mg/100 g in garlic-fortified samples, while potassium increased from  $278.6 \pm 10.5$  mg/100 g to  $533.4 \pm 18.2$  mg/100 g. Garlic fortification improved oxidative stability, as indicated by a higher iodine value (6.57%) and lower peroxide and thiobarbituric acid values compared with non-fortified smoked fish. Strong positive correlations ( $r \approx 0.98-1.00$ ) were observed between proximate and mineral parameters in smoked samples. The results demonstrate that garlic fortification enhances the nutritional quality and oxidative stability of hot-smoked *C. nigrodigitatus*.

**Keywords:** Lipid Oxidation; Marine Fish; Nutrient-energy profile; Oxidative; Spoilage

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### INTRODUCTION

Fish remains a vital component of the human diet, offering high-quality protein, essential fatty acids, vitamins, and minerals (Balami *et al.*, 2019). Its nutritional richness contributes significantly to food security, especially in developing countries where fish serves as a major source of animal protein. However, the high moisture and polyunsaturated fatty acid (PUFA) content of fresh fish make it highly perishable, leading to rapid spoilage through microbial proliferation and lipid degradation (Abraha *et al.*, 2018; Moruf *et al.*, 2021a). To mitigate post-harvest

losses and preserve nutritional integrity, effective preservation techniques are essential. Smoking is a traditional and widely accepted preservation method that enhances flavor, improves texture, reduces microbial load, and extends the shelf life of fish products (Adeyeye and Oyewole, 2016). Despite these advantages, hot smoking exposes lipids to high temperatures, which can accelerate lipid oxidation, resulting in the deterioration of sensory quality and nutrient loss, particularly in PUFA-rich species (Puke and Galoburda, 2020).

Previous studies have documented the dual role of smoking in fish preservation, showing significant moisture reduction and microbial inhibition but also increased susceptibility to oxidative deterioration (Messina *et al.*, 2021; Li *et al.*, 2026). Similarly, Islam *et al.* (2023) reported that although smoking improves shelf stability, it may compromise lipid quality due to thermal oxidation of unsaturated fatty acids. In Nigeria, Moruf *et al.* (2021a) also observed that smoked fish products exhibited improved protein concentration but reduced oxidative stability over storage, highlighting the need for antioxidant interventions.

*Chrysichthys nigrodigitatus*, commonly known as the Silver Catfish, is a commercially important freshwater species in West Africa due to its taste, size, and availability. It is often processed by traditional hot smoking methods to enhance storability and market value. However, the oxidative stability of its lipid-rich flesh remains a major concern during and after processing, as lipid peroxidation leads to rancidity, off-flavors, and diminished nutritional quality (Ogunbambo, 2020). There is therefore a growing interest in developing cost-effective, natural interventions to improve the shelf life and oxidative stability of smoked fish products. One promising approach involves the use of bioactive plant-based additives that possess antioxidative and antimicrobial effects, thereby complementing conventional processing methods.

Several authors have explored the use of plant-derived antioxidants in fish processing. El-Saber *et al.* (2020) demonstrated that natural spices significantly reduced peroxide and thiobarbituric acid values in smoked fish. Likewise, Ozma *et al.* (2023) reported that plant extracts rich in phenolic compounds effectively inhibited lipid oxidation and prolonged shelf life in seafood products. In a related study, Olatunde and Benjakul (2018) showed that natural additives improved both nutritional retention and oxidative stability in processed fish, supporting their application as functional preservatives.

Recent trends in food preservation advocate the use of natural antioxidants to counteract lipid peroxidation and enhance the functional quality of processed fish. Garlic (*Allium sativum*) has garnered attention for its rich content of sulfur-containing compounds such as allicin, diallyl disulfide, and ajoene, which exhibit potent antioxidant, antimicrobial, and lipid-stabilizing properties (Ozma *et al.*, 2023). Several studies have reported that garlic supplementation in meat and fish products can retard lipid oxidation, maintain unsaturated fatty acids, and

preserve sensory attributes (El-Saber *et al.*, 2020; Ozma *et al.*, 2023). Its application in hot smoked fish processing could offer dual benefits—nutritional enhancement and oxidative protection. This study, therefore, examined the effect of garlic fortification on the nutritional stability and lipid oxidation indices of hot smoked *C. nigrodigitatus*, with the aim of providing an evidence-based strategy to improve the quality and shelf-life of smoked freshwater fish products.

## **MATERIALS AND METHODS**

### **Sample Collection and Preparation**

Fresh specimens of *C. nigrodigitatus* (average weight:  $350 \pm 25$  g) were sourced from a reputable fish landing site in Lagos, Nigeria. The fish were immediately transported on ice to the laboratory, where they were washed, degutted, and divided into three groups: (i) fresh (un-smoked) (ii) a control group, which was hot smoked without garlic treatment, and (iii) treated group, which was hot smoked after marination in a 10% garlic paste solution for 30 min.

### **Smoking Procedure and Storage Conditions**

Both smoked groups were previously subjected to hot smoking using a traditional drum kiln. The smoking was carried out at 70–90 °C for 6 hours using hardwood as fuel, until the internal temperature of the fish reached 65 °C. Smoked fish samples were cooled to ambient temperature ( $27 \pm 2$  °C). All samples were stored at ambient conditions ( $27 \pm 2$  °C; relative humidity: 60–70%) for a period of 14 days.

### **Laboratory Analysis**

The proximate composition, iodine value, peroxide value, thiobarbituric acid (TBA) value, and free fatty acid (FFA) content were determined using standard AOAC (2019) methods. The energy value of fish samples was calculated using the Atwater general factor system-Protein: 4 kcal/g, Fat: 9 kcal/g and Carbohydrate: 4 kcal/g. Lipid extracts were analyzed spectrophotometrically to assess oxidative and hydrolytic rancidity.

Mineral components were evaluated from solution obtained by first wet-ashing the samples and dissolving the ash with de-ionized water and concentrated hydrochloride acid in standard flask.

The solution was analyzed for mineral content using Atomic Absorption Spectrophotometer. Phosphorus was analyzed by employing the method of Vanado Molybdate and read on colourimeter (Santoso, 2006).

### **Statistical Analysis**

Data were analyzed using SPSS version 25.0 to perform two-way ANOVA among means, which were

separated using Tukey’s HSD test at a significance level of  $p < 0.05$ .

## RESULTS AND DISCUSSION

### Nutrient and Nutrient Energy Composition

The proximate composition of *C. nigrodigitatus* showed significant variations across treatments. Moisture content was highest in fresh samples ( $77.03 \pm 0.37\%$ ) and significantly reduced in both hot smoked ( $9.65 \pm 0.22\%$ ) and garlic-fortified hot smoked samples ( $9.27 \pm 0.15\%$ ), consistent with the moisture-reducing effect of smoking reported by Adepoju et al. (2018), who observed similar reductions in milkfish. Crude protein increased markedly in smoked samples, with garlic-fortified fish showing the highest value ( $53.61 \pm 0.6\%$ ), likely due to concentration effects from dehydration and the possible proteolytic activity of garlic, aligning with the findings of Barros et al. (2023) on fortified smoked fish. Crude fat content was significantly higher in smoked samples compared to fresh, although slightly reduced in garlic-fortified fish ( $5.85 \pm 0.05\%$ ) relative to the non-fortified ( $6.43 \pm 0.55\%$ ), suggesting garlic’s potential antioxidative effect on lipid preservation, as supported by Khan et al. (2020). Ash content followed a similar trend, increasing after smoking, which is attributed to mineral concentration from moisture loss, aligning with reports by Msuku and Kapute (2018). Carbohydrate values remained low and statistically similar, indicating minimal influence from smoking or garlic treatment. These results collectively affirm that hot smoking and garlic fortification enhance nutrient density by reducing moisture and concentrating essential nutrients.

Furthermore, the observed increase in protein and ash contents directly translated into higher nutrient-energy density in the smoked products, as reflected in the substantial rise in total energy values compared to fresh samples. This is primarily due to the

reduction in water content, which concentrates macronutrients and increases caloric value per unit weight, a trend widely reported in thermally processed fish (Olatunde and Benjakul, 2018). In addition, the slight reduction in lipid content in garlic-treated samples, despite increased energy density, indicates that garlic may help modulate fat stability while preserving essential nutrients. This aligns with reports that natural plant additives not only enhance oxidative stability but also maintain the functional and nutritional integrity of fish products during processing (El-Saber et al., 2020).

The compositional energy values presented in Table 2 indicate a significant increase in total energy content from fresh (372 kJ/100 g) to hot smoked (1199–1206 kJ/100 g) *C. nigrodigitatus*, with garlic-fortified samples exhibiting slightly higher values. This increase is attributed to moisture loss during smoking, which concentrates macronutrients, especially protein and fat (Salami et al., 2024). The proportion of energy derived from protein (PEP) rose markedly from 19.6% in fresh samples to over 58% in fortified smoked fish, aligning with findings by Moruf et al. (2021b), who reported protein-dominated energy profiles in grilled crab. Fat-derived energy (PEF) also increased from 3.2% to around 15%, consistent with the lipid concentration effect during smoking (Han et al., 2023). Garlic fortification had minimal effect on total energy but slightly enhanced protein energy utilization (UEDP%), suggesting a potential protective effect of garlic on protein stability during heat processing, as similarly observed by Hussein et al. (2023), who reported that garlic-treated Nile tilapia exhibited reduced lipid oxidation indices, with peroxide values ranging from 2.10–2.85 meq/kg and thiobarbituric acid (TBA) values between 0.45–0.72 mg MDA/kg, compared to higher values in untreated samples.

**Table 1: Proximate composition of Fresh and Garlic-Fortified Hot Smoked *Chrysichthys nigrodigitatus***

Parameters (%)	Fresh	Non-Fortified Hot Smoked	Garlic-Fortified Hot Smoked
Moisture	$77.03 \pm 0.37^a$	$9.65 \pm 0.22^b$	$9.27 \pm 0.15^b$
Crude Protein	$17.53 \pm 0.51^a$	$51.34 \pm 1.38^b$	$53.61 \pm 0.6^b$
Crude Fat	$1.31 \pm 1.05^a$	$6.43 \pm 0.55^b$	$5.85 \pm 0.05^b$
Ash	$2.64 \pm 0.01^a$	$27.41 \pm 0.00^b$	$26.67 \pm 0.02^b$
Carbohydrates	$1.49 \pm 0.56^a$	$5.17 \pm 0.61^a$	$4.60 \pm 0.26^a$

**Keys:** Mean±Standard Error; Values with different superscripts across row are significantly different at ( $P < 0.05$ )

**Table 2: Compositional energy values of Fresh and Garlic-Fortified Hot Smoked *Chrysichthys nigrodigitatus***

Parameter	Unit	Fresh	Non-Fortified Hot Smoked	Garlic-Fortified Hot Smoked
Total energy	kJ 100g <sup>-1</sup>	372	1199	1206
	kcal 100g <sup>-1</sup>	88	284	285
PEF	% (kJ 100g <sup>-1</sup> )	3.2 (48)	15.9 (238)	14.2 (216)
	% (kcal 100g <sup>-1</sup> )	3.3 (12)	16.3 (58)	14.5 (53)
PEC	% (kJ 100g <sup>-1</sup> )	1.7 (25)	5.9(8.8)	5.1 (78)
	% (kcal 100g <sup>-1</sup> )	1.6 (1.7)	5.8 (21)	5.1 (18)
PEP	% (kJ 100g <sup>-1</sup> )	19.6 (298)	58.3 (873)	59.8 (911)
	% (kcal 100g <sup>-1</sup> )	19.4 (19.6)	57.8 (205)	59.2 (214)
UEDP%	kJ	11.7	35	35.9
	kcal	11.6	34.7	35.5

**Keys:** Proportion of total energy due to fat (PEF), Proportion of total energy due to carbohydrate (PEC), Proportion of total energy due to protein (PEP), utilization of energy value due to protein (UEDP%).

The mineral composition of *C. nigrodigitatus* showed significant increases following smoking and garlic fortification ( $P < 0.05$ ). Fresh fish recorded comparatively low mineral values, with calcium ( $18.6 \pm 1.5$  mg/100 g), phosphorus ( $165.4 \pm 6.2$  mg/100 g), sodium ( $58.7 \pm 3.1$  mg/100 g), magnesium ( $24.3 \pm 1.2$  mg/100 g), and potassium ( $278.6 \pm 10.5$  mg/100 g). However, the non-fortified hot-smoked samples exhibited markedly higher concentrations, such as calcium ( $145.3 \pm 5.4$  mg/100 g) and potassium ( $518.7 \pm 16.9$  mg/100 g), while garlic-fortified smoked fish recorded slightly higher values, including calcium ( $152.7 \pm 6.1$  mg/100 g) and phosphorus ( $405.8 \pm 10.7$  mg/100 g). The observed increase in mineral concentration after smoking is largely attributable to moisture reduction and nutrient concentration during thermal processing. Similar increases in mineral levels of smoked fish products have been reported in African catfish and other freshwater species by Ogunbambo *et al.* (2020) and Olopade *et al.* (2023), who noted that smoking enhances mineral density due to dehydration effects. The slightly higher mineral values in garlic-fortified samples may also be linked to the inherent mineral contribution of garlic and its ability to improve nutrient retention during processing.

In addition, the elevated mineral concentrations in smoked samples may reflect reduced leaching losses during processing, as water removal limits the dissolution and loss of soluble minerals. This concentration effect is particularly evident for macrominerals such as potassium and phosphorus, which are abundant in muscle tissues and become more pronounced after dehydration. The marginal increase observed in garlic-treated samples further suggests that garlic may exert a protective effect on mineral stability by reducing oxidative degradation and structural breakdown during heating. Similar observations have been reported by Olatunde and Benjakul (2018), who noted that plant-based additives can enhance mineral retention in thermally processed fish products. Moreover, the improved mineral density in smoked and fortified fish enhances their nutritional value, particularly in meeting recommended dietary intakes of essential elements such as calcium and phosphorus, which are vital for bone health and metabolic functions. This implies that garlic fortification, in addition to smoking, may serve as a practical strategy for improving both the micronutrient profile and functional quality of processed fish products.

**Table 3: Mineral Composition of Fresh and Garlic-Fortified Hot Smoked *Chrysichthys nigrodigitatus***

Mineral (mg/100 g)	Fresh	Non-Fortified Hot Smoked	Garlic-Fortified Hot Smoked
Calcium	$18.6 \pm 1.5^a$	$145.3 \pm 5.4^b$	$152.7 \pm 6.1^b$
Phosphorus	$165.4 \pm 6.2^a$	$392.6 \pm 12.3^b$	$405.8 \pm 10.7^b$
Sodium	$58.7 \pm 3.1^a$	$312.5 \pm 8.6^b$	$325.9 \pm 9.4^b$
Magnesium	$24.3 \pm 1.2^a$	$86.4 \pm 3.8^b$	$91.2 \pm 4.1^b$
Potassium	$278.6 \pm 10.5^a$	$518.7 \pm 16.9^b$	$533.4 \pm 18.2^b$

**Correlation coefficient among proximate and mineral components**

The correlation matrices revealed strong relationships between proximate and mineral

components of *C. nigrodigitatus*, with more pronounced associations in the smoked samples than in the fresh fish. In the fresh fish (Table 4), extremely strong positive correlations ( $r \approx 0.983-1.000$ ) were

observed among most proximate parameters and minerals; for instance, crude fat showed near-perfect correlation with phosphorus ( $r = 1.000$ ) and calcium ( $r = 0.999$ ), while moisture correlated perfectly with sodium and potassium ( $r = 1.000$ ). Similarly, the non-fortified hot-smoked (Table 5) maintained strong correlations between nutrients and minerals ( $r \approx 0.998-1.000$ ), although ash showed moderate relationships with other variables ( $r = 0.633-0.690$ ), suggesting slight compositional modification following garlic fortification. In contrast, the garlic-fortified smoked samples (Table 6) displayed

relatively weaker and more variable correlations, such as moisture with crude protein ( $r = 0.565$ ) and ash with crude fat ( $r = 0.216$ ). The stronger correlations in smoked fish likely reflect nutrient concentration due to moisture loss during smoking. Similar positive associations between proximate and mineral components in processed fish products have been reported by Odiko and Obirenfoju (2017) and Moruf *et al.* (2021b), who attributed such relationships to compositional concentration during thermal processing.

**Table 4: Correlation coefficient between proximate and mineral compositions in Fresh *Chrysichthys nigrodigitatus***

	Moisture	Crude Protein	Crude Fat	Ash	CHO	Ca	P	Na	Mg
C. Protein	0.995								
C. Fat	0.999	0.991							
Ash	1.000	0.992	1.000						
CHO	0.999	0.990	1.000	1.000					
Ca	0.997	0.983	0.999	0.998	0.999				
P	0.998	0.988	1.000	1.000	1.000	1.000			
Na	1.000	0.995	0.999	1.000	0.999	0.997	0.998		
Mg	0.995	0.981	0.998	0.998	0.999	1.000	0.999	0.995	
K	1.000	0.996	0.999	0.999	0.998	0.995	0.997	1.000	0.994

**Table 5: Correlation coefficient between proximate and mineral compositions in Non-Fortified Hot Smoked *Chrysichthys nigrodigitatus***

	Moisture	Crude Protein	Crude Fat	Ash	CHO	Ca	P	Na	Mg
C. Protein	1.000								
Crude Fat	0.998	0.999							
Ash	0.690	0.677	0.647						
CHO	1.000	1.000	1.000	0.670					
Ca	0.997	0.998	1.000	0.633	0.999				
P	1.000	1.000	1.000	0.670	1.000	0.999			
Na	1.000	1.000	0.999	0.673	1.000	0.999	1.000		
Mg	0.998	0.999	1.000	0.642	0.999	1.000	0.999	0.999	
K	0.999	1.000	1.000	0.666	1.000	0.999	1.000	1.000	0.999

**Table 6: Correlation coefficient between proximate and mineral compositions in Garlic-Fortified Hot Smoked *Chrysichthys nigrodigitatus***

	Moisture	Crude Protein	Crude Fat	Ash	CHO	Ca	P	Na	Mg
C. Protein	0.565								
Crude Fat	0.951	0.793							
Ash	0.508	0.423	0.216						
CHO	0.787	0.954	0.939	0.132					
Ca	0.588	1.000	0.810	0.398	0.962				
P	0.301	0.957	0.582	0.669	0.825	0.948			
Na	0.351	0.971	0.624	0.628	0.854	0.964	0.999		
Mg	0.315	0.961	0.594	0.657	0.834	0.953	1.000	0.999	
K	0.348	0.970	0.621	0.631	0.852	0.963	0.999	1.000	0.999

**Oxidative Stability**

The results in Table 7 show that garlic fortification significantly influenced the lipid oxidation profile of C.

*nigrodigitatus* during hot smoking. While the non-fortified hot smoked samples exhibited the lowest iodine value (1.60%), indicating higher degradation of unsaturated fatty acids, the garlic-fortified samples retained a value (6.57%) closer to that of fresh fish (7.07%), suggesting better preservation of lipid unsaturation. Similar trends were observed for peroxide and TBA values, where garlic-treated samples had notably lower levels (3.38 meq/kg and 6.04 mg/100g, respectively) compared to non-fortified smoked fish (5.30 meq/kg and 8.08 mg/100g), reflecting reduced primary and

secondary lipid oxidation. This aligns with the findings of Khan *et al.* (2020), who reported that natural antioxidants, including garlic, slow down lipid peroxidation in smoked fish products. However, FFA values were not significantly different among the treatments ( $p > 0.05$ ), which agrees with the observation of Nadeem *et al.* (2017) that FFA content is less sensitive to antioxidant treatments in short-term storage. Overall, garlic fortification demonstrated a protective effect against oxidative rancidity, enhancing the lipid stability of smoked fish.

**Table 7: Lipid Oxidation Indices of Fresh and Garlic-Fortified Hot Smoked *Chrysichthys nigrodigitatus***

Parameters (%)	Fresh	Non-Fortified Hot Smoked	Garlic-Fortified Hot Smoked
Iodine Value	7.07±0.07 <sup>a</sup>	1.60±0.14 <sup>b</sup>	6.57±0.03 <sup>a</sup>
Peroxide Value (MEq/kg)	0.67±0.05 <sup>a</sup>	5.30±0.06 <sup>b</sup>	3.38±0.01 <sup>b</sup>
Thiobarbituric Acid Value (mg/100g)	1.38±0.04 <sup>a</sup>	8.08±0.08 <sup>b</sup>	6.04±0.31 <sup>b</sup>
Free Fatty Acid (MgKOH/g)	1.11±0.02 <sup>a</sup>	1.87±0.03 <sup>a</sup>	2.17±0.05 <sup>a</sup>

**Keys:** Mean±Standard Error; Values with different superscripts across row are significantly different at ( $P < 0.05$ )

## CONCLUSION

Hot smoking significantly improved the nutritional density of *Chrysichthys nigrodigitatus* through moisture reduction and concentration of nutrients and minerals. Garlic fortification further enhanced the biochemical quality of the smoked fish, as reflected by higher protein content, improved mineral levels such as calcium and potassium and better oxidative stability indicated by a higher iodine value and lower peroxide indices. Strong correlations between proximate and mineral components in smoked samples suggest that dehydration during processing contributes to nutrient concentration and inter-relationships among nutrients. Overall, garlic-fortified hot-smoked *C. nigrodigitatus* represents a nutritionally improved and more stable fish product with potential for extended shelf life.

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