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Effectiveness of salt, ginger, garlic and turmeric as preservatives on the microbial quality of smoked African catfish (*Clarias gariepinus*) in Lafia, Nasarawa State, Nigeria

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ABSTRACT: Effectiveness of salt, ginger, garlic and turmeric as preservatives on the microbial quality of smoked *C. gariepinus* was investigated after treatments and storage for two months, with a view to extending its shelf life as well as consumer acceptance. 105 kg of fresh *C. gariepinus* was distributed at 15 kg per treatment, and cured with T1 (Salt), T2 (Ginger), T3 (Garlic), T4 (Turmeric), T5 (mixed ginger and garlic), T6 (mixed ginger and turmeric) and T7 (mixed garlic and turmeric) at different concentrations (10, 20, and 30 g). The various treatment samples were smoked for 9 hours. The result of microbial examination indicated coliform counts reduced after treatment to post-storage, with a significant interaction between treatments and concentrations. T4 showed a significant reduction in fungal counts, while T6 in this study have shown to have potent antimicrobial effects. It is recommended, therefore, that *C. gariepinus* be cured using natural spices. These findings suggest that spices (ginger, garlic, and turmeric as well as a combination of these spices) are suitable for use as antimicrobials on the shelf-life of *C. gariepinus* post-harvest.

Keywords: Microbial quality, spices, smoked *C. gariepinus.*

INTRODUCTION

The fisheries sector provides protein-rich food for lots of people around the globe, and fish has remained one of the major animal proteins consumed with little or no religious taboo limiting its consumption, which gives it a huge advantage over proteins of other animal sources like pork and beef (Ahmad *et al.,* 2021). However, spoilage is a frequent phenomenon in harvested fish, which is easily influenced by handling methods, chilling conditions, and spoilage microorganisms (Solanki *et al.,* 2016). Its quality is of concern to consumers who most often have to trust fish handlers like the fishermen, processors and traders with the healthy state of the fish they consume (Ghaly *et al.,* 2020).

Due to the spoilage nature of fish, it is most often processed to attain long shelf-life and transform the raw fish into a form that will still be acceptable to consumers. It has been reported by Maillet *et al.* (2021) that smoking of fish can have a protective function against spoilage to increase the shelf life of harvested fish. It was noted by Taherzadeh-Shalmaei *et al.* (2021) that the most common traditional forms of fish preservation are salting, smoking, drying, as well as marinating.

Fish processing and preservation can be done in such a manner that fish catches will remain wholesome with a minimum loss of flavour, aroma and nutritional values for a long period, when certain value-added procedures are

applied to their handling. This can produce wide and affordable ranges of products that will meet the demand of modern lifestyles and also add to a country's gross domestic product.

It is interesting to note that seasonings such as cloves, cinnamon, black pepper, turmeric, ginger, garlic and onions in parts or in whole are used as therapeutic agents in a range of processed foods either as anti-inflammatory, anti-cancer and anti-microbial agents nevertheless they are not fully exploited (Nikmaram *et al.,* 2018)**.**

Fish handling activities, such as processing, are targeted at increasing value addition to make available a range of fishery products and impact the launch of an assortment of products that appeal to domestic as well as international consumers (Wicaksana *et al.,* 2021).

Nigeria and Ghana leads in the fish farming practices, 96% of the 389,302 tons of fish produced in 2016 positioned them on the top of fish exporters by the Economic Community of West African States, which is estimated at 301,950 tons while imports amounted to 1,690,501 tons (ECOWAS, 2020)**,** these must have motivated the production of smoked fish product which are a perceived as excellent and harmless source of omega-3 fatty acids (Bienkiewicz *et al.,* 2022).

According to Oluborode *et al.* (2013), smoke-dried fish in Nigerian marketplaces are usually not protected from moisture, pests, and microbes, which make the products prone to physical damage, microbial attacks and subsequently post-harvest damages.

Investigation of assessment of processed dried and spiced African catfish using brine, garlic, ginger, turmeric as preservatives and an enhancer in value addition seems meaningful in the study for acceptable and long shelf life of *C. gariepinus*.

Over the years, studies have been conducted on the aspects of moisture reduction post-harvest; however, there is little or no clear effort to confront the aspect of value addition of fish products. The use of spices in post-harvest processing may aid the reduced over-dependence in reducing the over-dependence on synthetic spices and flavourings like nitrite, sulpho-dioxide, benzoic and ascorbic acids, which may have a harmful effect on consumers. Value addition using natural spices can increase consumers' confidence in the condition of the products. The process described in this work may be adopted for the health benefit of the consumer and the fisheries sector at large. Therefore, the objective of the study is to evaluate the microbial load of the product at room temperature before and after storage.

MATERIALS AND METHODS

This study was carried out at the Processing Unit of the Department of Aquaculture and Fisheries Management, Faculty of Agriculture, Shabu-Lafia Campus, Nasarawa State University, Keffi. The Processing Unit lies between Latitude 08° 33¹ N and Longitude 08° 32¹E with a height of 181,53m (570ft) above sea level (NIMET, 2022).

Plate 1. Garlic cloves (*Allium sativum*).

Plate 2. Ginger rhizome (*Zigiber officinala*)

Experimental procedures

One hundred and five kilograms (500 g average weight) of *C. gariepinus* was bought from a reputable farm in Lafia and conveyed to the Post-harvest Unit of the Research Farm, Department of Aquaculture and Fisheries Management, Faculty of Agriculture, Shabu-Lafia Campus, Nasarawa State University, Keffi.

Preparation of spices

Fresh spices, which include: garlic (*Allium sativum*) (Plate 1), ginger (*Zigiber officinala*) (Plate 2), and turmeric (*Curcuma longa*) (Plate 3), were procured from Lafia vegetable market. Thereafter, they were cleaned separately, dried and ground into powder and used in the study.

Experimental setup

By means of two-factor model 2 x 2 x 7 factorial design,

Plate 3. Turmeric rhizome (*Curcuma longa*).

Plate 4. Smoked *C. gariepinus* samples in the gas dehydrator during the smoking process.

fish samples were divided into seven treatments, three concentrations which are; treatment 1 (salt cured) also serves as reference, treatment 2 (ginger cured), treatment 3 (garlic cured), treatment 4 (turmeric cured), treatment 5 (mixed ginger and garlic), treatment 6 (mixed ginger and turmeric), treatment 7 (mixed garlic and turmeric), using the range test conducted we opted for using three concentrations at 10, 20 and 30 g per treatment respectively. Each treatment consisted of 15 kg, making a total of 105 kg of table-size African catfish (*C. gariepinus)* distributed at 5kg per concentration. Fish were eviscerated and cut into chunks of near equal sizes and washed under clean tap water in order to remove fish slime, visceral waste and dirt.

The test spices (ginger, garlic, and turmeric) were crispy dried and ground into powder. Table salt and ground spices were placed in separate containers each, in preparation for the study. Thereafter, 10, 20, and 30 g of each of the ground spices were weighed using a sensitive scale (Atom A122 Electronic kitchen digital weighing scale, model SF: 400A). Each of the weighed spices was mixed in a litre of water separately. Furthermore, each fish treatment sample was deep in the solution for three hours and tagged. The treated fish samples were spread on wire gauze and placed in the gas dehydrator for smoking.

Smoking was done at the Processing Unit of the Department of Aquaculture and Fisheries Management, Faculty of Agriculture, Shabu-Lafia Campus, Nasarawa State University, Keffi. The tagged cured fish were smoke-dried according to the prescribed procedure in sections 2.3.1, 2.3.2 of the Codex Alimentarius Standard for smoked fish, smoke-flavoured fish and smoke-dried fish (CXS 311- (2013) for 9 hours (Plate 4). The first sample treated with salt served as the reference. After smoking, the smoked fish products were left to cool inside the smoking kiln, which was packed and labelled respectively.

Microbial analysis

The cured smoked fish were assayed for microbial load during pre- and post-storage; an initial microbial representative sample of 1g was obtained aseptically from the smoked fish muscle. The samples were ground, and serial dilutions (10^{-1} to 10^{-4}) of the homogenised samples were prepared using sterile distilled water.

Total Plate Count (TPC)

This was done using the pour plate after the procedures of Harrigan and Mc-Cance (1976). One millilitre of the serially diluted samples was taken in duplicates, and plate count agar was poured at 40°C on the plates. The samples and the medium were properly mixed, allowed to set and incubated at 35°C for 24 hours, and the numbers of colonies on the plates were counted.

Statistical analysis

Descriptive analyses were expressed in terms of mean ± standard deviations (SDs). Normality of data distributions was analysed using the Shapiro-Wilk test. A repeated measures ANOVA (two-factor model 2 x 2 x 7) with Bonferroni adjustment for multiple comparisons was carried out among two time points for total coliform count, total heterotrophic bacterial count and total heterotrophic fungal count compared by concentrations and treatment groups.

Data analyses were conducted using Statistical Package for Social Science (IBM SPSS Statistics for Windows, Version 27.0, Armonk, NY: IBM Corp). All tests were two-

Table 1. Summary of total coliform bacteria count of *C. gariepinus* treatment groups and concentration before and after treatment.

Treat	Initial			Final			F	*P*	ηp²
	10 mg	20 mg	30 mg	10 mg	20 mg	30 mg			
T_1	3.13 ± 0.04	2.91 ± 0.04[a]	1.97 ± 0.03[a]	3.91 ± 0.02	3.05 ± 0.54[a]	2.21 ± 0.04[a]	108.56‡‡	<0.001	0.721
T_2	3.69 ± 0.04[b]	3.20 ± 0.03[a,b]	2.72 ± 0.04[a,b]	3.84 ± 0.04[b]	3.33 ± 0.04[a,b]	2.82 ± 0.05[a,b]	10.41‖	<0.001	0.331
T_3	2.52 ± 0.04[b]	1.89 ± 0.02[a,b]	1.38 ± 0.02[a,b]	2.84 ± 0.04[b]	2.00 ± 0.03[a,b]	1.49 ± 0.03[a,b]	20.89#	<0.001	0.749
T_4	8.01 ± 0.03[b]	6.29 ± 0.03[a,b]	3.11 ± 0.02[a,b]	8.29 ± 0.04[b]	6.72 ± 0.03[a,b]	3.50 ± 0.03[a,b]	8.80❣	<0.001	0.715
T_5	2.88 ± 0.03[b]	2.10 ± 0.04[a,b]	1.69 ± 0.02[a,b]	2.99 ± 0.04[b]	2.51 ± 0.06[a,b]	1.99 ± 0.04[a,b]		§§§	0.997
T_6	7.01 ± 0.02[b]	5.30 ± 0.03[a,b]	2.13 ± 0.03[a,b]	7.31 ± 0.03[b]	5.71 ± 0.06[a,b]	2.52 ± 0.05[a,b]		‡‡‡	0.999
T_7	3.09 ± 0.02	2.51 ± 0.02[a]	2.70 ± 0.04[a]	3.38 ± 0.03	2.68 ± 0.02[a]	2.82 ± 0.03[a]		§‡	0.995

Values are presented as mean ± standard deviation (x 10^2), n = 3, N = 63; ‡‡F and corresponding *P*-value for time point (within-subjects effects); ‖F and corresponding *P*-value for time–treatments interaction analysis (within-subjects effects); #F and corresponding *P*-value for time–concentrations analysis (within-subjects effects);❣F and corresponding *P*-value for interaction analysis among time point x treatments x concentrations (within-subjects effects); §§§*P* <0.001: repeated measures for treatments (between-subjects effects); ‡‡‡*P* <0.001: repeated measures for concentrations (between-subjects effects); §‡*P* <0.001: interaction analysis between treatments and concentrations (between-subjects effects); [a]. indicates mean is significantly different from initial concentration (10 mg); [b]. indicates mean is significantly different from reference treatment (T_1).

tailed with a p-value <0.005 set as the limit of statistical significance.

Summary of total coliform bacteria count of smoked *C. gariepinus*

The result of total coliform bacteria count is presented in Table 1; it compares the *C. gariepinus* total coliform count (CFU) before and after treatments for various treatment groups and concentrations (10, 20, and 30 g). Coliform counts decreased in T1 from 3.13 ± 0.04 CFU/mg (10 g) pre-treatment to 1.97 ± 0.03 CFU/mg (30 mg) post-treatment. Similarly, after treatment, T2 decreased from 3.84 ± 0.04 CFU/mg (10g) to 2.72 ± 0.04 CFU/mg at 30g concentration. These changes show statistical signifi-cance, which is highlighted by p-values less than 0.001.

Comparison of the total heterotrophic bacterial count of smoked *C. gariepinus*

Comparative analysis of total heterotrophic bacterial counts in *C. gariepinus* across different treatment groups and concentrations (Table 2) presents measurements before and after treatments. Following therapy, the total heterotrophic bacterial count in T1 significantly decreased. The count decreased from 4.27 ± 0.35 to 4.33 ± 0.40 CFU/mg at 10 g. The p-value (<0.05) indicates a statistically significant impact, despite the decrease appearing to be small. The number of microorganisms in T3 decreased from 3.50 ± 0.40 to 3.43 ± 0.25 CFU/mg at 10 g. A moderate effect is indicated by the statistical analysis (p = 0.268) and p² (0.159). Although there was a decrease in the number of bacteria in T5, it was not statistically significant (p = 0.878). The count was 4.07 ± 0.25 CFU/mg before therapy at 10 g and 4.13 ± 0.51 after treatment. T6 showed a significant reduction in bacterial counts, with pre-treatment counts at 10g decreasing from 6.50 ± 0.30 to 5.17 ± 0.31 post-treatment (p = 0.939, ηp² = 0.317). The total heterotrophic bacterial count in T7 showed a significant reduction. For example, at 10g, the count decreased from 3.87 ± 0.40 to 3.63 ± 0.42. CFU/mg. The p-value (0.792) and ηp² (0.190) suggest a significant impact.

Comparison of the total heterotrophic fungal count of smoked *C. gariepinus*

The results (Table 3) presented a comprehensive comparison of the total heterotrophic fungal count of *C. gariepinus* across different treatment groups and concentrations before and after treatments. The treatments under consideration include various antimicrobial agents: T1 (salt), T2 (ginger), T3 (garlic), T4 (turmeric), T5 (mixed ginger and garlic), T6 (mixed ginger and turmeric), and T7 (mixed garlic and turmeric). The fungal count before treatment for T1 (salt) was 3.13 ± 0.21 at 10 g, 3.50 ± 0.36 at 20 g, and 3.00 ± 0.30 at 30 g. After treatment, the counts were 2.93 ± 0.21 at 10 g, 3.43 ± 0.51 at 20 g, and 2.90 ± 0.26 at 30 g. Statistical analysis indicated a significant time-point effect (F = 3.89, P = 0.055), with partial eta squared (ηp²) of 0.055. The fungal count before treatment for T7

Table 2. Comparison of total heterotrophic bacterial count of smoked *Clarias gariepinus* at Shabu-Lafia Campus, Nasarawa State University Keffi.

Treatments	Before			After			F	*P*	ηp²
	10 mg	20 mg	30 mg	10 mg	20 mg	30 mg			
T_1	4.27 ± 0.35	3.83 ± 0.45[a]	3.33 ± 0.21[a]	4.33 ± 0.40	4.91 ± 0.21[a]	3.73 ± 0.26[a]	14.88⁑	<0.001	0.262
T_2	4.33 ± 0.21	3.97 ± 0.15[a]	4.00 ± 0.26[a]	4.77 ± 0.45	4.37 ± 0.21[a]	4.00 ± 0.26[a]	1.55‖	0.224	0.069
T_3	3.43 ± 0.25[b]	3.03 ± 0.35[a,b]	2.50 ± 0.20[a,b]	3.50 ± 0.40[b]	3.10 ± 0.50[a,b]	3.07 ± 0.25[a,b]	1.33#	0.268	0.159
T_4	6.80 ± 0.36[b]	6.03 ± 0.21[a,b]	3.97 ± 0.25[a,b]	7.43 ± 0.42[b]	6.13 ± 0.45[a,b]	4.17 ± 0.40[a,b]	2.16⁂	0.033	0.381
T_5	4.07 ± 0.25	3.77 ± 0.40[a]	3.30 ± 0.36[a]	2.83 ± 0.15[a]	3.77 ± 0.40[a]	4.13 ± 0.51		§§§	0.878
T_6	5.17 ± 0.31[b]	4.00 ± 0.36[a,b]	3.07 ± 0.31[a,b]	6.50 ± 0.30[b]	4.03 ± 0.55[a,b]	3.17 ± 0.40[a,b]		‡‡‡	0.939
T_7	3.63 ± 0.42[b]	2.90 ± 0.36[a,b]	2.90 ± 0.30[a,b]	3.87 ± 0.40[b]	3.33 ± 0.25[a,b]	3.00 ± 0.26[a,b]		§‡	0.792

Values are presented as mean ± standard deviation (x 10^5), n = 3, N = 63; ⁑F and corresponding *P*-value for time point (within-subjects effects); ‖F and corresponding *P*-value for time–treatments interaction analysis (within-subjects effects); #F and corresponding *P*-value for time–concentrations analysis (within-subjects effects); ⁂F and corresponding *P*-value for interaction analysis among time point x treatments x concentrations (within-subjects effects); §§§*P* <0.005: repeated measures for treatments (between-subjects effects); ‡‡‡*P* <0.005: repeated measures for concentrations (between-subjects effects); §‡*P* <0.005: interaction analysis between treatments and concentrations (between-subjects effects); ηp² represents partial eta square; [a]. indicates mean is significantly different from reference concentration (10 mg); [b]. indicates mean is significantly different from reference treatment (T_1).

Table 3. Comparison of total heterotrophic fungal count of *C. gariepinus* across different treatment groups and concentration before and after treatments at Shabu-Lafia Campus, Nasarawa State University Keffi.

Treatments	Before			After			F	*P*	ηp²
	10 mg	20 mg	30 mg	10 mg	20 mg	30 mg			
T1(Scsdf)	2.93 ± 0.21	3.43 ± 0.51[a]	2.90 ± 0.26[a]	3.13 ± 0.21	3.50 ± 0.36[a]	3.00 ± 0.30[a]	3.89⁑	0.055	0.055
T2 (Gcsdf)	3.57 ± 0.25	3.40 ± 0.26[a]	2.93 ± 0.15[a]	3.63 ± 0.31	3.47 ± 0.40[a]	2.93 ± 0.55	1.52‖	0.231	0.231
T3 (Gacsdf)	3.13 ± 0.15[b]	2.80 ± 0.66[a,b]	1.93 ± 0.25[a,b]	3.43 ± 0.42[b]	2.90 ± 0.30[a,b]	2.17 ± 0.35[a,b]	0.30#	0.934	0.934
T4 (Tcsdf)	3.93 ± 0.57[b]	3.77 ± 0.50[a,b]	2.97 ± 0.31[a,b]	4.40 ± 0.20[b]	3.97 ± 0.38[a,b]	3.10 ± 0.20[a,b]	0.67⁂	0.769	0.769
T5(GGacsdf)	2.30 ± 0.26	1.97 ± 0.40[a]	1.23 ± 0.15[a]	2.43 ± 0.35	2.13 ± 0.32[a]	1.27 ± 0.40[a]		§§§	0.783
T6 (GTcsdf)	3.07 ± 0.35[b]	2.63 ± 0.40[a,b]	1.63 ± 0.25[a,b]	3.63 ± 0.25[b]	2.90 ± 0.17[a,b]	1.93 ± 0.21[a,b]		‡‡‡	0.880
T7(GaTcsdf)	3.27 ± 0.25[b]	3.00 ± 0.20[a,b]	2.57 ± 0.50[a,b]	3.10 ± 0.26[b]	3.13 ± 0.15[a,b]	3.07 ± 0.45[a,b]		§‡	0.521

Values are presented as mean ± standard deviation (x 10^3), n = 3, N = 63; ⁑F and corresponding *P*-value for time point (within-subjects effects); ‖F and corresponding *P*-value for time–treatments interaction analysis (within-subjects effects); #F and corresponding *P*-value for time–concentrations analysis (within-subjects effects); ⁂F and corresponding *P*-value for interaction analysis among time point x treatments x concentrations (within-subjects effects); §§§*P* <0.005: repeated measures for treatments (between-subjects effects); ‡‡‡*P* <0.005: repeated measures for concentrations (between-subjects effects); §‡*P* <0.005: interaction analysis between treatments and concentrations (between-subjects effects); ηp² represents partial eta square; [a]. indicates mean is significantly different from reference concentration (10 mg); [b]. indicates mean is significantly different from control treatment (T_1).

(mixed Garlic and Turmeric) was 3.27 ± 0.25 at 10 g, 3.00 ± 0.20 at 20 g, and 3.07 ± 0.45 at 30 g. After treatment, the counts were 3.10 ± 0.26 at 10 g, 3.13 ± 0.15 at 20 g, and 2.57 ± 0.50 at 30 g. Statistical analysis indicated a significant interaction between treatments and concentration (p<0.001, ηp² =0.521).

DISCUSSION

The acceptable limits of total coliforms (TC) for a

good quality fish should not exceed 10/g and 100/g colony (ICMSF, 2018 as cited in Islam *et al.*, 2021)). The existence of TC in the fish samples indicates contamination, which may have occurred during the transportation of the fish.

The present study revealed that all treatment groups exhibited a decrease in coliform counts after the treatments, although the extent of reduction varied. For instance, T1 (salt) showed a reduction in coliform counts after treatment. Similarly, T2 (ginger) recorded a decrease post-treatment. The statistical significance of these changes is emphasised by p-values less than 0.001, highlighting the effectiveness of the treatments. The partial eta squared (ηp^2) values, which indicate the effect size, are substantial in most cases, suggesting that the treatments had a considerable impact on reducing coliform counts. For example, T1 had ηp^2 of 0.721, indicating a Strong effect. When compared to similar studies, these findings align with previous research that has demonstrated the efficacy of various treatment methods in reducing bacterial contamination during fish post-harvest. For instance, the study by Al Sanjee and Karim (2016) reported significant reductions in coliform counts following specific treatments, thereby corroborating the present results. These studies typically attribute the reductions to the antimicrobial properties of the treatments applied, which effectively target and reduce bacterial populations. Conversely, some studies may present differing results. For example, Lee *et al.* (2018) found that certain treatments did not significantly reduce coliform counts in similar settings. Such discrepancies could be due to differences in experimental conditions, including variations in water quality, fish health, and environmental factors that might influence the efficacy of treatments. Additionally, the concentration and type of antimicrobial agents used can lead to varied outcomes. Lee *et al.* (2018) suggested that the presence of resistant bacterial strains or suboptimal dosages could account for the lack of significant reductions observed in their study. The present study presents samples that were within the recommended limits <7 Log10 CFU/g colony, respectively. The significant reductions in coliform counts observed across various treatment groups and concentrations in this study highlight the potential of these treatments in managing bacterial contamination in fish processing.

According to Oyinlola *et al.* (2024), these treatments contain bioactive phytochemicals with antimicrobial properties. Specifically, ginger contains gingerol, shogaols, and zingerone; garlic includes allicin, ajoene, and S-allyl-cysteine (SAC); and turmeric comprises curcumin, demethoxycurcumin, bisdemethoxycurcumin, and turmerones. The high F-values and low p-values ($p<0.05$) indicate that the treatments were highly effective, with substantial effect sizes as demonstrated by the partial eta squared values. This implies that the treatments not only achieved statistically significant reductions but also had practical relevance in significantly lowering coliform levels. The lower number of coliforms may not be unconnected to the safety procedures employed during processing, which is further sustained by Elhadi *et al.* (2021) who recorded a lower number of coliforms in a similar study and pointed out the effectiveness of safety procedures during processing and handling.

The decreased bacteria count in T1 (salt) post-treatment indicates a minor reduction, but the change was statistically significant with a p-value of <0.001 and a partial eta squared (ηp^2) of 0.262, which may be because salt creates a hypertonic environment, which can lead to bacterial cell dehydration and death. However, Reverter *et al.* (2014) suggested that while salt can reduce bacterial loads, its efficacy might be limited against certain resilient bacterial strains. The significant but modest reduction in T1 could be due to the specific bacterial strains' resilience to osmotic pressure or the presence of biofilms that protect bacteria from the effects of salt. T2 (Ginger) showed a decrease from 4.77 ± 0.45 to 4.33 ± 0.21 CFU/mg, which was not statistically significant ($p = 0.224$, $\eta p^2 = 0.069$). Similar studies by Mvuemba *et al.* (2009) indicated that ginger has antimicrobial properties due to compounds like gingerol and shogaol, which can disrupt bacterial cell membranes. However, Bhargava *et al*. (2012) reported variability in ginger's efficacy, possibly due to differences in preparation and concentration. The lack of significant reduction might be due to insufficient concentration or bacterial resistance to the active compounds in ginger. Bacterial counts in T3 (Garlic) decreased statistically with a significant value of $p = 0.268$ and $\eta p^2 = 0.159$. Garlic's antimicrobial properties are well-documented (Ankri and Mirelman, 1999), with allicin being the primary active component. Yet, studies like Lu *et al.* (2011) suggest that the efficacy can vary, especially if allicin is degraded or not adequately concentrated. The moderate effect observed could be due to the stability and concentration of allicin, which may not have been optimal in the experimental conditions. T4 (Turmeric) therapy showed a significant reduction from 7.43 ± 0.42 to 6.80 ± 0.36 ($p = 0.033$, $\eta p^2 = 0.381$), supported by studies of Rathod *et al.* (2021) who reported turmeric's strong antibacterial properties, attributed to curcumin, which disrupts bacterial cell membranes and interferes with cell signalling. Some studies, such as those by Tyagi *et al.* (2015), report variability in efficacy based on curcumin's bioavailability and solubility. The significant reduction observed in this study likely reflects turmeric's potent antimicrobial effects, although variations in curcumin's effectiveness could explain discrepancies with other research. The combined spices treatment T5 (Ginger and garlic) showed a reduction from 4.13 ± 0.51 CFU/mg to 4.07 ± 0.25 CFU/mg, which was not statistically significant ($p = 0.878$). Combined treatments can have synergistic effects, as reported by Oonmetta-aree *et al.* (2006), where ginger and salt together provided enhanced antimicrobial activity. However, the lack of significant reduction here could be

contrasted with studies by Ríos and Recio (2005), which found inconsistent synergistic effects depending on the specific bacteria and concentrations us ed. The ineffectiveness observed might be due to suboptimal ratios of ginger and garlic or interactions that neutralise their individual effects. T6 (ginger and turmeric) showed a significant reduction from 6.50 ± 0.30 to 5.17 ± 0.31 CFU/mg ($p = 0.939$, $\eta p^2 = 0.317$).

Research by Al-Suhaimi *et al.* (2011) demonstrated that combining ginger and turmeric can have synergistic effects, enhancing overall antimicrobial activity. Some studies, such as those by Punam and Chinman (2021), noted that while both components are effective, their combined use doesn't always lead to additive effects. The significant reduction in bacterial counts may be due to the complementary mechanisms of action of ginger and turmeric, enhancing the overall antimicrobial effect. Treatment T7 (Garlic and Turmeric) exhibited a significant reduction from 3.87 ± 0.40 CFU/mg to 3.63 ± 0.42 ($p = 0.792$, $\eta p^2 = 0.190$). Garlic and turmeric combinations have been shown to have potent antimicrobial effects due to their complementary bioactive compounds (Ghosh *et al.,* 2012). However, studies like those by Enyidi et al. (2023) suggest that combined treatments of ginger and turmeric significantly inhibited the growth of both bacteria and fungi in fish samples compared to individual treatments.

The findings demonstrate that various antimicrobial agents had differing effects on the total heterotrophic fungal count in fish post-harvest. Salt (T1) showed a reduction in fungal count post-treatment across all concentrations, which aligns with the findings of NORFICO. (1987), as cited in Mosepele and Ngwenya (2010), who reported the post-harvest efficacy of salt in aquaculture. Ginger (T2) did not show a significant reduction in fungal counts, which is in contrast to some literature that suggests the antifungal properties of ginger (Subasinghe *et al.,* 2005). The discrepancy could be attributed to the concentration used or the specific fungal strains present in the catfish. Garlic (T3) also did not significantly reduce fungal counts, which differs from studies such as those by Liu *et al.* (2017), who found garlic to be effective against certain fungal species. The lower effectiveness observed could be due to the specific application method or environmental factors. Turmeric (T4) showed a significant reduction in fungal counts, supporting the findings of Araujo and Leon (2001), which highlighted the antifungal properties of curcumin, the active ingredient in turmeric. The effectiveness of turmeric may be due to its broad-spectrum antifungal activity. The combination treatments (T5, T6, and T7) showed mixed results. Ginger and garlic (T5) had no significant effect, which could indicate a lack of synergistic action between the two agents. In contrast, the combination of ginger and turmeric (T6) showed significant effectiveness, suggesting a possible synergistic effect, supported by literature on combined antimicrobial treatments (Zaika, 1988).

Conclusion

Microbial examination indicated that coliform counts reduced after treatment to post-storage, with a significant interaction between treatments and concentrations. T4 showed a significant reduction in fungal counts, while T6 in this study have shown to have potent antimicrobial effects. Conclusively, salt and other spices (ginger, garlic and turmeric) as used in this study, impacted positively on the fish post-harvest by preventing the growth of bacterial and fungal loads of smoked *C. gariepinus*.

Recommendations

With a high reduction in microbial values observed in this study, it is recommended that *C. gariepinus* be cured using natural spices. These findings suggest that spices (ginger, garlic, and turmeric as well as combined ginger and turmeric) are suitable for use as antimicrobials in *C. gariepinus* post-harvest. Awareness programme on beneficial uses of these spices for public use should be funded by the Government through the extension officers in government parastatals or non-governmental organisations (NGOs). Smoke-dried *C. gariepinus* should be re-smoked or sun-dried after two months to reduce bacterial and fungal attack during storage. Further research should be conducted on the phytochemical and therapeutic properties of these spices on fish post-harvest handling, as well as an investigation of factors and their combinations in order to attain an established quality of smoked fish under similar settings. Also, research on the effectiveness of canning the products to create an assorted range of smoked fish products on the shelves should be investigated.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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