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Impact of different drying techniques on the quality attributes of African catfish (*Clarias gariepinus*) in Makurdi

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Abstract

This study evaluated the effects of different drying methods on the nutritional, sensory, and mineral quality of African catfish (Clarias gariepinus), with the aim of identifying the most effective preservation technique. Fresh Clarias gariepinus specimens were obtained and processed at Joseph Sarwuan Tarka University, Makurdi. Fish were uniformly filleted and subjected to sun drying, oven drying, and smoke drying. Samples were periodically monitored for drying consistency and analyzed for proximate composition, mineral content, and sensory attributes using standard laboratory procedures. Smoke-dried samples recorded the highest crude protein (68.55%), ash (8.53%), and essential minerals, including calcium and potassium, while maintaining moderate fat levels. Oven drying resulted in the lowest moisture content (7.51%) and the highest fat content (10.49%), indicating improved shelf stability. Sun drying showed the lowest protein retention and the highest carbohydrate content. Sensory evaluation revealed smoked fish as the most preferred in flavor, aroma, and overall acceptability, followed by oven-dried samples. Smoke drying proved to be the most effective method for preserving the nutritional, sensory, and mineral qualities of Clarias gariepinus, followed by oven drying, while sun drying was least efficient. The findings provide useful guidance for fish processors and households in selecting appropriate drying methods to enhance product quality, shelf life, and consumer acceptance.

Keywords: Clarias gariepinus, Drying techniques, Oven drying, Quality attributes, Smoking, Sun-drying.

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Contents

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Contribution of this paper to the literature
This study uniquely integrates proximate, mineral, and sensory analyses to comparatively evaluate sun, oven, and smoke drying of *Clarias gariepinus* under identical processing conditions in Makurdi, Nigeria, providing location-specific, practical evidence to guide optimal fish preservation and consumer-preferred drying methods.

1. Introduction

Clarias gariepinus, commonly known as African catfish, is a vital aquatic species with significant economic importance in many regions due to its high nutritional value and suitability for aquaculture. Preservation methods play a crucial role in maintaining the quality and extending the shelf life of fish products, including drying, which is one of the oldest and most widely practiced preservation techniques globally [1]. Drying reduces water activity, inhibits microbial growth, and prevents enzymatic reactions, thereby preserving the nutritional and sensory attributes of fish [2].

Various drying methods, such as sun drying, oven drying, smoke drying, and freeze drying, have been employed to preserve fish, each with distinct effects on the quality characteristics of the final product. Sun drying, a traditional method, is cost-effective but may lead to inconsistent drying rates and quality deterioration due to exposure to contaminants and variable environmental conditions [3]. Oven drying, on the other hand, offers controlled drying conditions but may result in higher energy consumption and alterations in flavor and texture [3]. Freeze drying, characterized by low temperature and vacuum conditions, preserves the sensory and nutritional qualities of fish effectively but is often limited by its high cost and energy requirements [4].

The quality characteristics of dried *Clarias gariepinus*, including moisture content, protein content, lipid content, colour, texture, and sensory attributes, are influenced by the drying method employed [1]. Understanding these effects is crucial for optimizing drying processes and ensuring the production of high-quality dried fish products with enhanced market acceptability and nutritional value in developing countries.

2. Materials and Methods

2.1. Study Area

This research work was carried out in the Department of Fisheries and Aquaculture, Joseph Sarwuan Tarka University Makurdi, Benue State, Nigeria.

2.2. Sample Collection and Preparation

Fresh *Clarias gariepinus* specimens were carefully procured from Apex Fish Farms, a renowned fish farm in Makurdi, Benue State.

To maintain the freshness and integrity of the fish, the specimen was promptly packed in ice and transported to the Department of Fisheries and Aquaculture laboratory, Joseph Sarwuan Tarka University, Makurdi. Upon arrival at the laboratory, the fish underwent meticulous cleaning and preparation procedures followed by thorough rinsing under cold running water to remove residual debris or contaminants as described by Motsara and Roy [5]. Subsequently, the fish were carefully gutted to remove the visceral organs.

The fish were expertly filleted to separate the meat from the bones. This filleting process was conducted with precision to obtain uniform fillets of consistent size and thickness, thereby standardizing the samples for the subsequent drying experiments as described by Oladapo et al. [6].

To ensure homogeneity and comparability across all experimental samples, the fillets were further standardized to uniform size and weight using calibrated equipment and precise measurements, as explained by Abdulraheem et al. [7].

2.3. Drying Methods

Three distinct drying methods were selected for evaluation: sun drying, oven drying and smoke drying.

2.3.1. Sun Drying

Sun drying, a traditional method widely practiced in many regions, involves exposing fish fillets to direct sunlight for drying. This method capitalizes on solar energy to remove moisture from the fish, relying on natural air circulation and solar radiation.

Fish fillets were evenly arranged on drying racks or trays, ensuring adequate spacing for air circulation and uniform exposure to sunlight throughout the drying process [8].

2.3.2. Oven Drying

Oven drying, a controlled method commonly used in industrial settings, employs a laboratory-scale drying oven to dehydrate fish fillets at elevated temperatures. Fish fillets are placed on trays or racks inside the drying oven, with the temperature set at a controlled level of 60°C to facilitate moisture removal while minimizing thermal degradation and flavor loss, as described by Sathivel [9]. The duration of oven drying is carefully monitored and adjusted to achieve the desired moisture content and texture in the dried fish products, with periodic sampling and analysis to assess drying progress and quality attributes.

2.3.3. Smoke Drying

Smoke drying, also known as "smoke curing," is a traditional method of food preservation that combines drying and smoking techniques to prolong shelf life and enhance flavor. Fresh fish fillets were placed on the racks in a smoking kiln, and smoke fires were set underneath using charcoal with a temperature range between 65°C to 85°C to allow an even distribution of heat, as described by Oladapo et al. [6]. The smoke contains antimicrobial compounds, such as formaldehyde and phenols, which inhibit the growth of spoilage microorganisms and pathogens.

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2.4. Analysis of Quality Characteristics

Following the completion of the drying process, dried fish samples obtained from each drying method were meticulously collected and subjected to comprehensive analysis to assess various quality characteristics. The evaluation encompassed several parameters, including nutritional composition, sensory attributes, and mineral composition, utilizing standard analytical methods and sensory evaluation techniques.

The nutritional composition of the dried fish samples was determined using the method of the Association of Official Analytical Chemists (AOAC) as described by Oladapo et al. [6].

Mineral analysis of the dried fish sample was determined by the spectrophotometric method described by Jame [10] using a Jenway digital spectrophotometer.

Sensory evaluation was conducted by trained sensory panelists to assess the quality of dried fish samples, including flavor, texture, aroma, and overall acceptability. Sensory scoring scales and descriptive analysis techniques were used to quantitatively evaluate sensory characteristics as described by Abdulraheem et al. [7]. The assessments provided valuable insights into the sensory profile and consumer acceptability of the dried fish products.

2.5. Statistical Analysis

The data obtained from the study were subjected to a T-test analysis for significant differences using Predictive Analytical Software for statistical analysis (version 18.0).

3. Result

Smoke drying has the highest crude protein (68.55%, superscript "a"), followed by oven drying (64.01%, "b"), and sun drying (60.11%, "c"). Oven drying has the highest fat content (10.49%, "a"), followed by smoke drying (9.53%, "b"), and sun drying (8.03%, "c"). Sun drying has the highest crude fiber (1.64%, "a"), followed by smoke drying (1.37%, "b"), and oven drying (1.19%, "c"). Sun drying has the highest ash content (9.02%, "a"), followed by smoke drying (8.53%, "b"), and oven drying (8.01%, "c"). Sun drying retains the most moisture (10.06%, "a"), followed by smoke drying (8.94%, "b"), and oven drying (7.51%, "c"). Sun drying has the highest carbohydrate content (4.42%, "a"), followed by oven drying (2.04%, "b"), and smoke drying (1.83%, "c") (Table 1).

Table 1. Proximate composition (%) of smoked, sun-dried, and oven-dried *Clarias gariepinus*.

Drying methods	Crude protein	Fat	Crude fiber	Ash	Moisture	Carbohydrate
Smoke dry	68.55 ± 0.02^{a}	9.53 ± 0.01^{b}	1.37 ± 0.05^{b}	8.53 ± 0.01^{b}	8.94 ± 0.03^{b}	1.83 ± 0.02^{c}
Sun dry	60.11 ± 0.01^{c}	8.03 ± 0.03^{c}	1.64 ± 0.04^{a}	9.02 ± 0.01^{a}	10.06 ± 0.01^{a}	4.42 ± 0.01^{a}
Oven dry	64.01 ± 0.01^{b}	10.49 ± 0.03^{a}	1.19 ± 0.04^{c}	8.01 ± 0.02^{c}	7.51 ± 0.01^{c}	2.04 ± 0.02^{b}

Note: Means in the same row with different superscript differs significantly.

Smoke drying has the highest flavor (8.5, superscript "a"), followed by oven drying (7.8, "b"), and sun drying (6.9, "c"). Smoke drying scores highest for texture (8.2, "a"), followed by oven drying (7.5, "b"), and sun drying (7.0, "c"). Smoke drying has the highest aroma score (8.4, "a"), followed by oven drying (7.6, "b"), and sun drying (6.8, "c"). Smoke drying is the most preferred for overall acceptability (8.3, "a"), followed by oven drying (7.7, "b"), and sun drying (7.0, "c") (Table 2).

Table 2. Sensory evaluation of smoked, sun-dried, and oven-dried *Clarias gariepinus*.

Drying Method	Flavor (Mean ± SD)	Texture (Mean ± SD)	Aroma (Mean ± SD)	Overall Acceptability (Mean ± SD)
Oven dried	7.8 ± 0.4^{b}	7.5 ± 0.5^{b}	7.6 ± 0.3^{b}	7.7 ± 0.4^{b}
Smoked dried	8.5 ± 0.3^{a}	8.2 ± 0.4^{a}	8.4 ± 0.2^{a}	8.3 ± 0.3^{a}
Sun dried	6.9 ± 0.5^{c}	7.0 ± 0.6^{c}	6.8 ± 0.5^{c}	7.0 ± 0.5^{c}

Note: Means in the same row with different supper script differs significantly.

Oven drying leads in calcium (180.5, "a"), magnesium (135.2, "a"), potassium (220.8, "a"), sodium (75.4, "a"), iron (8.5, "a"), zinc (4.2, "a"), and phosphorus (250.7, "a"), followed by sun drying (170.7, 130.6, 215.4, 74.3, 8.1, 4.0, 245.6, all "b"), and smoke drying (165.3, 128.5, 210.1, 72.6, 7.8, 3.9, 240.3, all "c") Table 3).

Table 3. Minerals composition of smoked, sun-dried, and oven-dried Clarias gariepinus.

Mineral	Smoked (mg/100g) ± SD	Sun-Dried (mg/100g) ± SD	Oven-Dried (mg/100g) ± SD
Calcium (Ca)	180.5 ± 5.2^{a}	165.3 ± 4.9^{c}	170.7 ± 5.0^{b}
Magnesium (Mg)	135.2 ± 4.3^{a}	128.5 ± 3.8^{c}	130.6 ± 4.1^{b}
Potassium (K)	220.8 ± 6.1^{a}	210.1 ± 5.7^{c}	215.4 ± 5.9^{b}
Sodium (Na)	75.4 ± 2.8^{a}	72.6 ± 2.6^{c}	74.3 ± 2.7^{b}
Iron (Fe)	8.5 ± 0.6^{a}	7.8 ± 0.5^{c}	8.1 ± 0.5^{b}
Zinc (Zn)	4.2 ± 0.3^{a}	3.9 ± 0.3^{c}	4.0 ± 0.3^{b}
Phosphorus (P)	250.7 ± 7.5^{a}	240.3 ± 6.9^{c}	245.6 ± 7.2^{b}

Note: Means in the same row with different supper script differs significantly.

4. Discussion

The proximate composition of *Clarias gariepinus* (African catfish) varies significantly based on the drying method used, namely, smoke drying, sun drying, and oven drying. These methods influence the nutritional content of the fish, affecting factors such as crude protein, fat, crude fiber, ash, moisture, and carbohydrate levels. The variations in these parameters are critical for understanding the nutritional and preservation qualities of dried fish products.

Smoke drying yielded the highest crude protein content ($68.55 \pm 0.02\%$) in *C. gariepinus*, followed by oven drying ($64.01 \pm 0.01\%$) and sun drying ($60.11 \pm 0.01\%$). The elevated protein content in smoke-dried samples is likely due to low moisture content and the protective effects of smoke compounds, which inhibit microbial degradation and

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protein breakdown [11]. The Maillard reaction during smoking may also enhance protein nitrogen retention [12]. Sun drying, with prolonged exposure to sunlight and air, promotes protein denaturation and oxidative losses, resulting in the lowest protein content [13]. Oven drying, with controlled temperature and humidity, minimizes protein denaturation compared to sun drying but is less effective than smoke drying in preserving protein [14].

Oven-dried samples exhibited the highest fat content (10.49 ± 0.03%), followed by smoke-dried (9.53 ± 0.01%) and sun-dried samples (8.03 ± 0.03%). Controlled oven conditions minimize lipid oxidation, preserving higher fat levels [15]. Smoke drying retains surface fats, contributing to flavor but resulting in slightly lower fat content than oven drying [16]. Sun drying, with extended exposure to air and sunlight, accelerates lipid oxidation, leading to the lowest fat content [17].

Sun-dried samples showed the highest crude fiber content (1.64 ± 0.04%), followed by smoke-dried (1.37 ± 0.05%) and oven-dried samples (1.19 ± 0.04%). The slight increase in fiber content in sun-dried fish may result from a concentration effect due to moisture loss, though differences are minimal [18]. Oven drying, with higher temperatures, may cause minor structural degradation of fiber [19].

Sun-dried samples had the highest ash content (9.02 ± 0.01%), followed by smoke-dried (8.53 ± 0.01%) and oven-dried samples (8.01 ± 0.02%). The elevated ash content in sun-dried fish likely results from moisture reduction, concentrating minerals, and potential environmental contamination [20]. Smoke drying deposits mineral-rich smoke particles, increasing ash content [21]. Oven drying preserves inherent minerals without external inputs, resulting in moderate ash levels.

Oven-dried samples had the lowest moisture content (7.51 ± 0.01%), followed by smoke-dried (8.94 ± 0.03%) and sun-dried samples (10.06 ± 0.01%). Low moisture in oven-dried fish enhances microbial stability and shelf life [22]. Smoke drying, being less intensive, retains higher moisture, potentially reducing shelf stability but enhancing flavor [23]. Sun drying, with inconsistent conditions, results in the highest moisture content, increasing spoilage risk [19].

Sun-dried samples exhibited the highest carbohydrate content (4.42 ± 0.01%), followed by oven-dried (2.04 ± 0.02%) and smoke-dried samples (1.83 ± 0.02%). Higher carbohydrate levels in sun-dried fish may indicate residual non-protein, non-fat components, with less efficient conversion compared to other methods. Oven drying retains carbohydrates moderately, while smoke drying emphasizes protein and fat retention [14].

The drying method significantly affects the proximate composition of *C. gariepinus*, influencing its nutritional quality, preservation potential, and shelf life. Smoke drying maintains high protein and mineral content but retains more moisture compared to oven drying, which provides an optimal balance of fat and low moisture. Sun drying, while accessible, leads to higher moisture and lower protein, making it the least efficient for preservation. These findings align with previous studies, such as those by Ali et al. [11], Abdullahi et al. [13], and Bala et al. [14], which have documented similar impacts of drying techniques on fish composition.

4.1. Sensory evaluation of smoked, sun-dried, and oven-dried Clarias gariepinus

The sensory evaluation of fish products provides insight into consumer preferences and acceptability, which are critical in determining the best processing methods. This study evaluates the sensory qualities flavor, texture, aroma, and overall acceptability of smoked, sun-dried, and oven-dried *C. gariepinus* based on provided data. The evaluation shows significant differences among the three drying methods, each contributing distinct qualities to the fish's sensory properties.

Smoke-dried fish achieved the highest flavor score (8.5 ± 0.3), followed by oven-dried (7.8 ± 0.4) and sun-dried fish (6.9 ± 0.5). The superior flavor of smoked fish results from the Maillard reaction and absorption of smoke compounds (e.g., phenols, carbonyls), enhancing taste intensity [24]. Oven-dried fish lacks these flavor-enhancing agents, while sun-dried fish may undergo lipid oxidation, reducing flavor appeal [25].

Smoked fish scored highest for texture (8.2 ± 0.4), followed by oven-dried (7.5 ± 0.5) and sun-dried fish (7.0 ± 0.6). The firm, chewy texture of smoked fish results from heat-induced protein structural changes [26]. Oven drying maintains acceptable texture through controlled drying, while sun drying's uneven conditions may result in overly dry or tough textures [27].

Smoked fish exhibited the highest aroma score (8.4 ± 0.2), followed by oven-dried (7.6 ± 0.3) and sun-dried fish (6.8 ± 0.5). Smoke-derived volatile compounds enhance aroma in smoked fish [28]. Oven-dried fish lacks these compounds, while sun-dried fish may develop oxidative rancidity, reducing aroma appeal [29].

Smoked fish scored highest for overall acceptability (8.3 ± 0.3), followed by oven-dried (7.7 ± 0.4) and sun-dried fish (7.0 ± 0.5). The superior sensory attributes of smoked fish, driven by flavor and aroma, align with consumer preferences in African cuisines [30]. Oven-dried fish maintains good acceptability, while sun-dried fish's lower scores reflect compromised sensory quality [31].

Calcium content was highest in smoked samples (180.5 ± 5.2 mg/100g), followed by oven-dried (170.7 ± 5.0 mg/100g) and sun-dried samples (165.3 ± 4.9 mg/100g), reflecting moisture reduction in smoked fish that concentrates minerals [32]. Potassium (220.8 ± 6.1 mg/100g in smoked vs. 210.1 ± 5.7 mg/100g in sun-dried) and magnesium (135.2 ± 4.3 mg/100g in smoked vs. 128.5 ± 3.8 mg/100g in sun-dried) followed similar trends, with smoking optimizing retention [33, 34]. Sodium (75.4 ± 2.8 mg/100g in smoked) and phosphorus (250.7 ± 7.5 mg/100g in smoked) were highest in smoked samples, while sun-drying led to losses due to environmental exposure [35]. Iron (8.5 ± 0.6 mg/100g in smoked) and zinc (4.2 ± 0.3 mg/100g in smoked) were also highest in smoked samples, with oven drying outperforming sun drying [36].

5. Conclusion

The proximate composition and sensory evaluation of *Clarias gariepinus* demonstrate that drying methods significantly influence nutritional quality, preservation, and consumer acceptability. Smoke drying yields the highest crude protein and mineral content, with enhanced sensory attributes due to flavor and aroma compounds, making it the most preferred method. Oven drying provides the highest fat retention and lowest moisture content, optimizing preservation but lacking the smoky flavor. Sun drying, while accessible, results in lower protein and higher moisture,

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reducing nutritional and sensory quality. These findings highlight the importance of selecting appropriate drying methods to balance nutritional integrity, sensory appeal, and storage potential in dried fish products.

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