



INVESTIGATION OF THE PRESERVATION TECHNIQUES FOR PERISHABLE FOOD COMMODITIES THROUGH A COMPARATIVE STUDY OF OKRA, TOMATO, AND FISH

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ABSTRACT

Postharvest spoilage of perishable crops such as okra (*Abelmoschus esculentus*), tomato (*Solanum lycopersicum*), and fish (*Clarias gariepinus*) contributes to significant food loss and reduced nutritional availability in Nigeria. This study aimed to evaluate drying kinetics and the effects of temperature on their nutritional composition during storage. Samples were dried at 60°C to 100°C at various residence times. Effects on protein, carbohydrate, and vitamin C contents were evaluated using standard analytical methods. Drying kinetics were assessed using first-order reaction models, and activation energy (E_a) was estimated from the Arrhenius model. The drying kinetics yielded a rate constant of 0.5737 min⁻¹ for fish, 0.7037 min⁻¹ for tomato, and 0.5066 min⁻¹ for okra at 100 °C. The evaluation of the drying rate dependence on temperature showed that activation energies E_a were 19.907 kJ/mol.K, 25.147 kJ/mol.K, and 20.2038 kJ/mol.K for fish, tomato, and okra drying, respectively. Overall, the results show that moderate drying temperatures, particularly around 60°C, can preserve key nutrients while enhancing product stability, and higher temperatures, such as 100°C, increase moisture loss but accelerate nutrient degradation.

Keywords: Drying, Moisture Content, Nutrient, Kinetics, Activation Energy

INTRODUCTION

The agricultural sector is pivotal to the economic and nutritional security of developing nations like Nigeria (Akpabio et al., 2025). Among key commodities, vegetables and fish are vital staples and sources of foreign exchange (Kafui et al., 2022; Saba et al., 2024). Vegetables such as okra (*Abelmoschus esculentus* L.) and tomato (*Solanum lycopersicum* L.) provide essential vitamins (A, B, C, and K), minerals, and bioactive compounds that reduce the risk of chronic diseases (Elkhalifa et al., 2021; El-Shaieny et al., 2022). Similarly, fish from Nigeria's freshwater and marine sectors are rich in high-quality proteins, omega-3 fatty acids, and micronutrients crucial for cardiovascular and immune health (Awuchi et al., 2022; Demelash Abera & Alefe Adimas, 2024).

Despite their value, these commodities are highly perishable. Okra, characterized by high moisture (86.1%) and a unique mucilaginous texture, often begins to wilt or decay within 24 to 48 hours of harvest under ambient tropical conditions (Kafui et al., 2022; Badmus et al., 2019). Tomatoes face similar vulnerabilities; their delicate skin and high-water activity make them susceptible to fungal attacks, bruising, and rapid over-ripening during transport (Wakene & Sharew, 2024; Beaulah et al., 2025). Likewise, fresh fish begins to deteriorate within hours of harvest due to intense microbial activity and enzymatic breakdown accelerated by high ambient temperatures (Abelti & Tekka, 2024).

In Nigeria, post-harvest losses are staggering, estimated at 30% to 50% for vegetables and 20% to 40% for fish (Iveren Blessing & Tavershima Richard, 2022; Mramba & Mkude, 2022). These losses are exacerbated by inadequate infrastructure, a lack of affordable cold chain logistics, and poor rural-urban linkages (Ahmed et al., 2025; Gouda and Duarte-Sierra, 2024). While significant research has focused on increasing production yields through improved varieties and fertilizers, far less attention has been paid to scalable post-harvest management. Consequently, a critical need exists to develop and promote practical preservation methods suitable for smallholder farmers and artisanal fishers.

The high perishability of okra, tomato, and fish remains a major bottleneck for food security in Nigeria. Systemic issues, including weak regulatory frameworks and the high cost of refrigeration, mean that much of the harvest never reaches the consumer in optimal condition. Even when preservation methods are available, they are often technically demanding or economically unfeasible for small-scale applications. Furthermore, agricultural extension services rarely prioritize post-harvest preservation, leaving a significant knowledge gap among stakeholders. This situation diminishes producer profits, discourages investment, and limits the availability of nutrient-dense foods in urban diets.

This research seeks to validate evidence-based drying and storage techniques adapted to tropical climates. Drying is the most economically viable solution to the preservation of fish, tomato, and okra. Various drying techniques are practiced in Nigeria, but most of these methods lead to the loss of basic nutrients such as proteins and carbohydrates (Kafui et al., 2022). This study, therefore, provides the scientific knowledge capable of guiding farmers to the optimum drying factors, which will have little or no negative effects on the nutritional properties of the food. By providing locally adaptable solutions, the study empowers farmers, fishers, and traders to extend the shelf life of their produce while maintaining sensory and nutritional quality. For consumers, these interventions promise increased access to safe and affordable food. Ultimately, this work contributes to national food security and enhances Nigeria's competitiveness in domestic and international markets by ensuring a consistent supply of high-quality agricultural products.

MATERIALS AND METHODS

Materials

Reagents and Raw Materials Used

Fresh samples of okra (*Abelmoschus esculentus*), tomato (*Solanum lycopersicum*), and African catfish (*Clarias gariepinus*) were purchased from Uselu local market, Benin City, Edo State, Nigeria. Selection was based on uniformity in size, color, and the absence of mechanical damage or microbial infection. Reagents used were of analytical grade,

and solutions were prepared with distilled water immediately before analysis.

Sample Preparation

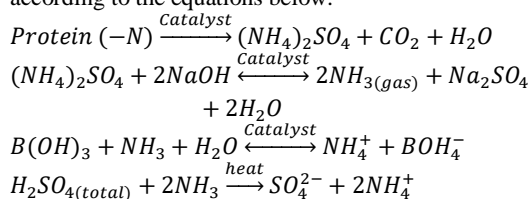
Samples were transported to the laboratory in aerated containers within one hour of purchase. Okra and tomatoes were washed with tap water, rinsed with distilled water, and dried with a muslin cloth (Mohammed et al., 2017). Fish samples were gutted, descaled, and eviscerated using sterile stainless-steel knives, then cut into uniform 5 cm fillets. The drying process was carried out in a thermostatically controlled air-dry oven (Memmert UN55) under optimized temperature conditions at fixed time and temperatures (Ajao et al., 2025). The drying continued until a constant weight was achieved, indicating equilibrium moisture content suitable for preservation. After drying, all samples were cooled to room temperature. The dried materials were then transferred into airtight glass containers and stored at ambient temperature before subsequent physicochemical analysis.

Analytical Procedures

Each analysis was performed following established standard validated through similar laboratory-based food composition studies (Ahmed et al., 2020; Mohammed et al., 2017). Detailed step-by-step procedures for each analysis are described below.

Crude Protein Determination

Crude Protein (CP) was determined by the Kjeldahl method according to Ahmed et al. (2020), Mohammed et al. (2017). Mass of sample in a 250ml conical flask was digested with 20ml H_2SO_4 and 5g $CuSO_4$ as a catalyst using a hot plate at maximum temperature for several minutes until a clear solution is obtained. It was cooled and diluted with 100 mL of distilled water. The content was stirred with a glass rod, and the tube containing the diluted sample was connected to the distillation unit, and a conical flask containing 25ml of 4% boric acid solution was attached to the condenser outlet. 50ml of 40% NaOH was dispensed into the conical flask, and distillation was carried out for 10 minutes. The ammonium borate solution formed was titrated with 0.1M HCl to a purplish-grey endpoint using methyl red as an indicator according to the equations below.



$$\%Crude\ Protein = \frac{(S - B)N(1.4007)}{w}$$

N is the normality of acid, S is the titre value of the sample, and B is the titre value of the blank

Moisture Content

Moisture was determined using the oven-drying method at 110 °C. Approximately 5g of sample was weighed into an evaporating dish and dried until a constant weight was recorded (Ajao et al., 2025). Moisture content was calculated as:

$$\%Moisture = \frac{W_m - W_d}{W_m} \times 100 \quad (1)$$

W_m = weight of moist sample, W_d = weight of dry sample

Carbohydrate Determination by Dinitro Salicylic Acid (DNS) Method

Carbohydrate content of the various food samples was estimated by the DNS method according to Ahmed et al. (2020) and Mohammed et al. (2017). 1g of sample was digested with 250ml 0.5M NaOH in a 500ml conical flask. The solution was therefore neutralized using HCl solution and then made up to 1000ml with distilled water. 5ml of the neutral solution was measured into a 50ml boiling tube, and 2.0 ml of DNS reagent was added. The mixture was then placed in boiling water for 10 minutes, after which there was a complete reaction between the digested carbohydrates and the DNS. The mixture was allowed to cool, and its absorbance was measured with the aid of a UV-Vis spectrophotometer at 690nm. The exact sugar content was estimated from a standard glucose curve.

Vitamin-C Determination

Standard vitamin C solution (ascorbic acid) was prepared in different concentrations of 250, 500, 750, and 1000mg/L. Exactly 10ml of sample was measured into a 250ml conical flask, and 100ml of distilled water. The mixture was swirled gently, and 1.0ml starch solution was added and swirled to mix properly. The mixture was immediately titrated using 0.005M iodine solution prepared by adding 1.3g iodine mixed with 2g potassium iodide in 1000ml distilled water. The endpoint of the titration is identified as the first permanent trace of a dark blue-black colour due to the starch-iodine complex. Standard calibration was conducted by the titration of standard solutions of ascorbic acid, aliquot solutions, and noting the titration volume (Ahmed et al., 2020; Mohammed et al., 2017).

Drying Kinetics

The drying rate (R) was calculated as the change in moisture content over time:

$$R = -\frac{M_s}{A} \left(\frac{dX}{dt} \right) \quad (2)$$

Where M_s is the mass of the dried sample, A is the exposed drying surface area, dX is the change in moisture content (dry basis), and dt is the change in time.

Effects of Rate Constant Dependence on Temperature

The drying curve describes the relationship between moisture ratio and drying time for fish, okra, and tomato samples under varying temperature conditions. The drying rate constant (k) for each temperature was obtained from the exponential form of the moisture ratio equation expressed as:

$$MR = e^{-kt} \quad (3)$$

where MR is the moisture ratio (dimensionless), k is the drying rate constant (min^{-1}), and t is the drying time (min). The slope of the linearized plot of $\ln MR$ against time (t) yielded the k-values for each drying temperature. The temperature dependence of the drying rate constant was further analyzed using the Arrhenius-type relationship, which correlates the rate constant with absolute temperature (T) as follows:

$$K = k_0 e^{E_a/RT} \quad (4)$$

where k_0 is the pre-exponential factor, E_a is the activation energy (kJ/mol), R is the universal gas constant (8.314 J/mol·K), and T is the absolute temperature (K). A plot of $\ln(k)$ against $1/T$ produced a straight line, and the slope ($-E_a/R$) was used to determine the activation energy for the drying process.

RESULTS AND DISCUSSION

Effect of Drying on Nutritional Composition

The nutritional profile of okra, tomato, and fish showed significant changes following thermal treatment at 60°C. This temperature was selected to balance moisture removal with the preservation of thermolabile compounds (Ahmed et al., 2020).

Crude Protein Content

From Table 1, crude protein content increased slightly across all samples: fish, 24.72% to 25.61%, okra, 2.73% to 2.75%,

and tomato, 1.62% to 1.65%. This trend does not represent the synthesis of new protein but rather a "concentration effect" caused by the removal of water, which increases the relative proportion of nitrogenous matter in the remaining dry mass (Mohammed et al., 2017). The stability of these values suggests that 60°C is sufficiently mild to avoid significant protein denaturation or Maillard reactions, which typically occur at temperatures exceeding 80°C (Ajao et al., 2025).

Table 1: Protein Content of Fresh and Dried Samples

Sample	Fresh (%)	Dried (%)
Fish	24.72	25.61
Okra	2.731	2.748
Tomato	1.621	1.647

Vitamin C Content

In contrast to macronutrients, Vitamin C (ascorbic acid) exhibited a sharp decline, with losses ranging from 40% to 80% (Table 2). The most significant reduction occurred in fish, 0.722% to 0.125%, while okra and tomato retained higher absolute levels despite substantial percentage losses. This degradation is attributed to the highly thermolabile nature of

Vitamin C, which undergoes rapid oxidation and hydrolysis in the presence of heat and residual moisture (Pratama et al., 2023). However, the retention of approximately 11.7%–13.4% in the vegetables indicates that low-temperature drying remains a viable method for preserving a portion of the antioxidant capacity compared to high-heat alternatives (Giannakourou & Taoukis, 2021).

Table 2: Vitamin-C Content of Fresh and Dried Samples

Sample	Fresh (%)	Dried (%)
Fish	0.722	0.125
Okra	19.64	11.712
Tomato	21.034	13.422

Carbohydrate Content

Carbohydrate levels remained nearly constant (Table 3), with negligible changes in okra 1.204% to 1.207%, and tomato, 5.113% to 5.114%. This confirms that polysaccharides are

thermally stable under the employed parameters, provided that moisture control prevents enzymatic browning or caramelization (Afolabi et al., 2022).

Table 3: Carbohydrate Content of Fresh and Dried Samples

Sample	Fresh (%)	Dried (%)
Fish	3.29	3.29
Okra	1.204	1.207
Tomato	5.113	5.114

Drying Rate Constants and Moisture Removal

The moisture loss profiles for fish, tomato, and okra (Figures 1, 2, and 3) illustrate that drying efficiency is a function of both temperature and time. At 60°C, a maximum moisture removal of 33%, 34%, and 28% for fish, tomato, and okra, respectively achieved at 150 minutes, whereas at 100 °C, the moisture removal was 78.8%, 91.8%, and 75.7% for fish,

tomato, and okra, respectively. The drying process followed first-order kinetics, as evidenced by the linear relationship in Figures 1 to 3, and it is consistent with Newton’s law of drying, which assumes that internal moisture diffusion is the dominant mechanism controlling water removal (Mohammed et al., 2017; Ahmed et al., 2020).

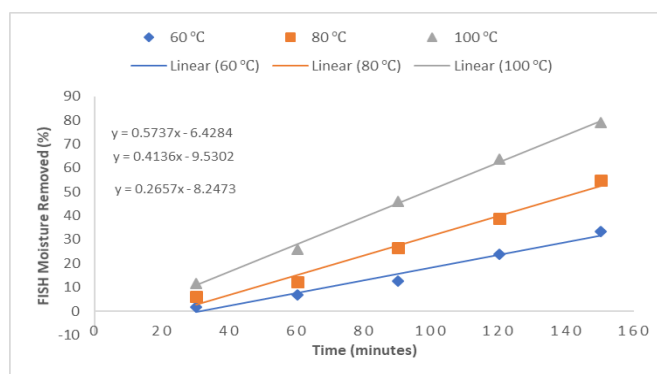


Figure 1: Fish Drying Rate Constant

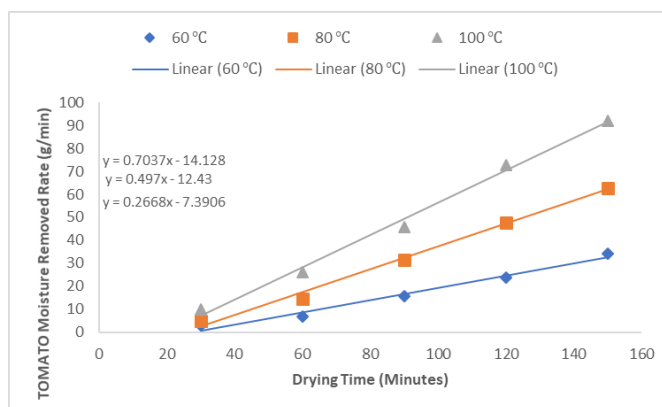


Figure 2: Tomato Drying Rate Constant

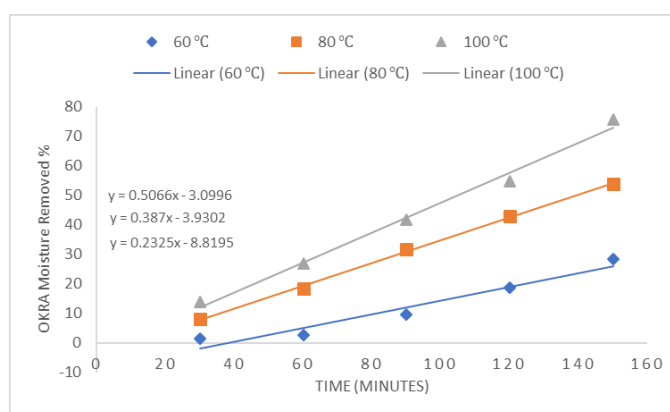


Figure 3: Okra Drying Rate Constant

The kinetic study revealed by the first-order kinetics in Figures 1 to 3 showed a consistent increase in drying rate constants (k) with temperature, 0.5737 min⁻¹, 0.4136 min⁻¹, and 0.2657 min⁻¹ at 100 °C, 80 °C, and 60 °C, respectively, in the fish drying kinetic study. Also, 0.7037min⁻¹, 0.497min⁻¹, and 0.2668min⁻¹ at 100 °C, 80 °C, and 60 °C respectively on the tomato drying kinetic study whereas, 0.5066 min⁻¹, 0.387min⁻¹, and 0.2325min⁻¹ at 100 °C, 80 °C, and 60 °C respectively for okra drying kinetics.

While k generally increases with temperature, the marginal difference between 80 °C and 100 °C suggests the onset of "case hardening." This phenomenon occurs when rapid surface drying creates a localized hard shell, restricting internal moisture diffusion, thereby slowing the overall drying rate despite higher thermal energy supply (Mohammed et al., 2017). Consequently, 60 °C provided the most favourable balance, maintaining a porous tissue structure that allowed for steady moisture migration without the structural compromises observed at 80 and 100 °C temperatures.

Drying Rate Dependence on Temperature and Activation Energy

The temperature dependence of the drying rate constant was evaluated using the Arrhenius plots (Figures 4, 5, and 6), and the activation energy was estimated to be approximately 19.907 kJ/mol.K, 25.147 kJ/mol.K, and 20.2038 kJ/mol.K for fish, tomato, and okra drying, respectively. The temperature dependence of the drying rate constant was evaluated using the Arrhenius plots (Figures 4, 5, and 6), and the activation energies were estimated to be approximately 19.907 kJ/mol.K, 25.147 kJ/mol.K, and 20.2038 kJ/mol.K for fish, tomato, and okra drying, respectively. These results indicate that the drying process for tomatoes requires the highest activation energy, followed by okra and fish. This suggests that tomatoes may have a more complex drying behavior compared to the fish and okra. This relatively moderate Ea indicates that moisture removal in these samples requires moderate energy, primarily driven by surface evaporation. This supports the use of 60 °C as a practical, energy-efficient threshold for small-scale preservation in tropical climates (Komolafe et al., 2018).

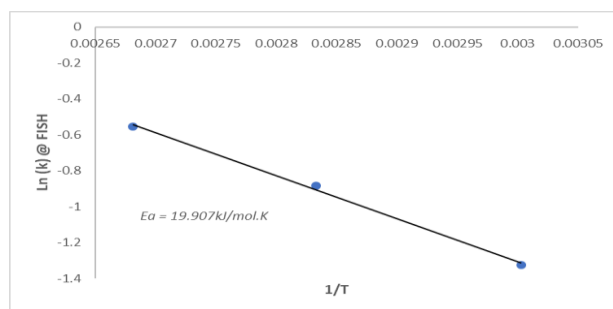


Figure 4: Arrhenius Plot of Temperature of Fish Drying Rate

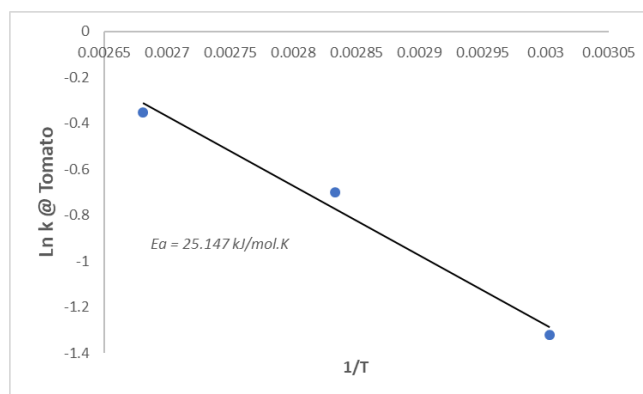


Figure 5: Arrhenius Plot of Temperature of Tomato Drying Rate

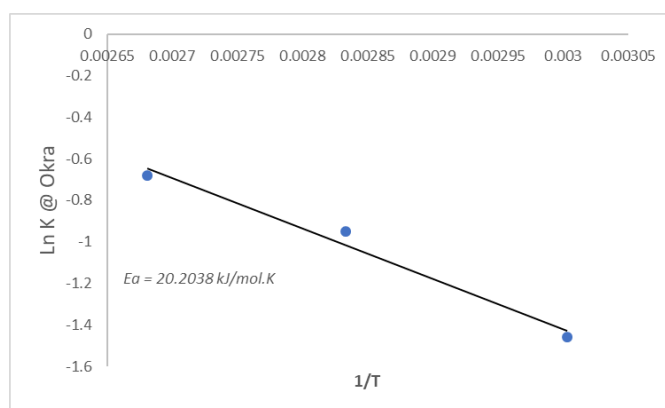


Figure 6: Arrhenius Plot of the Temperature of the Okra Drying Rate

CONCLUSION

The study showed that controlled drying of fish (*Clarias gariepinus*), okra (*Abelmoschus esculentus*), and tomato (*Solanum lycopersicum*) effectively reduced moisture content, enhancing shelf stability and preventing microbial spoilage. From the results obtained, Protein content slightly increased due to water loss concentration, vitamin C decreased owing to heat sensitivity, while carbohydrate levels remained stable for all the samples. Also, the drying kinetics showed that 60°C provided the best balance between moisture removal and nutrient preservation, confirming its suitability for maintaining the nutritional and structural integrity of dried fish, okra, and tomato under controlled laboratory conditions. The drying followed first-order kinetics, with drying rate constants (k) of 0.0153, 0.0189, and 0.0191 min^{-1} at 60°C, 80°C, and 100°C, respectively. The activation energy (E_a) of 6.093 kJ/mol indicated a moderate energy requirement for moisture diffusion, indicating that drying was governed mainly by surface evaporation and mild internal diffusion.

Recommendations

The following suggestions are recommended for future experimental work based on this study:

- Further research should examine the influence of different drying air velocities and humidity levels on drying rate, nutrient preservation, and product rehydration characteristics.
- Studies should be conducted on the application of pre-treatment techniques such as blanching, antioxidant dipping, and osmotic dehydration to improve color retention, texture, and vitamin stability.
- The drying kinetics of okra and tomato should be modeled using more advanced equations such as Page,

Henderson–Pabis, or Midilli models to better predict drying behavior and moisture diffusivity.

- Comparative analysis between solar, convective, and freeze-drying methods should be performed to assess energy efficiency and nutrient retention under tropical conditions.
- A techno-economic analysis incorporating the activation energy data should be performed to design cost-effective, energy-efficient drying systems suitable for small- and medium-scale food processors.

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