Effect of Brine Pretreatment on the Thin-Layer Drying Characteristics and Moisture Diffusivity of Blue Whiting (*Micromesistius poutassou*) Fillets

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ABSTRACT: Blue whiting (Micromesistius poutassou) is a highly perishable fish whose preservation by conventional open-air drying often results in slow moisture removal and inconsistent product quality. This study evaluated the effects of brine pretreatment on the drying kinetics, moisture diffusivity, mathematical modelling, and colour characteristics of blue whiting fillets during hot-air drying. Fillets were immersed in sodium chloride solutions (0–200 g/L) for 30 min and dried at 60–100 °C. Moisture ratio data were fitted to six thin-layer drying models, effective moisture diffusivity was determined using Fick's second law, and colour changes were quantified in the CIE Lab* colour space. Drying rate increased with both temperature and brine concentration. Effective moisture diffusivity increased from 5.59×10^{-10} – 5.29×10^{-9} m²/s in unbrined fillets to 4.96×10^{-8} m²/s following pretreatment with 200 g/L NaCl, while the drying activation energy was 17.94 kJ/mol. Among the models evaluated, the Two-term Exponential model provided the best description of drying behaviour (R^2 = 0.9987–0.9997; RMSE ≤ 0.0081). Brining also significantly influenced colour development, with the greatest changes observed at 50–100 g/L NaCl. These findings demonstrate that controlled brine pretreatment enhances moisture transport and enables more efficient and predictable hot-air drying, providing a practical basis for optimizing industrial processing of blue whiting and related fish products.

KEYWORDS: *Blue whiting; Brine pretreatment; Thin-layer drying; Moisture diffusivity; Drying kinetics modelling; Colour parameters*

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I. INTRODUCTION

Fish and fishery products are essential components of global nutrition, providing high-quality proteins, essential fatty acids, vitamins, and minerals. However, their inherent high moisture content and enzymatic activity render them highly perishable, necessitating effective preservation strategies to maintain quality, extend shelf life, and reduce post-harvest losses (Mohanty *et al.*, 2019). Drying, particularly hot air drying, is widely employed in fish processing to lower water activity and inhibit microbial and enzymatic spoilage, thereby enhancing storability and consumer safety (Abraha *et al.*, 2017; Ali *et al.*, 2022).

Blue whiting (*Micromesistius poutassou*) is a small pelagic species predominantly found in the North-East Atlantic Ocean and is frequently imported into Nigeria. Locally known as *panla* in the southwestern region, it has become a significant and affordable protein source for many households, particularly amidst the rising costs of red meat and poultry (Amusan *et al.*, 2019; Ogunyebi and Osibona, 2022). Despite its economic and nutritional relevance, blue whiting is highly susceptible to rapid spoilage due to its delicate muscle structure and high moisture content, necessitating the use of appropriate processing and preservation techniques (Ogunyebi and Osibona, 2022).

Pre-drying treatments such as brining, which involves immersing fish fillets in sodium chloride solutions, are commonly used to influence the drying behaviour of fish muscle (Sobukola and Olatunde, 2011; Rasul *et al.*, 2022; Mebratu *et al.*, 2024). Brining induces osmotic dehydration and facilitates salt uptake, which can alter moisture content and enhance water removal during drying, thereby affecting drying kinetics and effective moisture diffusivity. However, the specific effects of brine concentration on the thin-layer drying behaviour and colour attributes of blue whiting under hot-air drying conditions remain underexplored.

Hot air oven drying is a widely used, cost-effective method that provides controlled and uniform drying conditions (Inyang *et al.*, 2017). Evaluating the influence of brining on the drying characteristics of blue whiting fillets in such systems is crucial for optimizing drying parameters and ensuring product quality. This study, therefore, aims to investigate the effect of brining on the hot air drying behavior of blue whiting fillets. The results are expected to inform the development of improved processing protocols expected to enhance the quality, stability, and shelf life of *panla*, thereby supporting its continued role as a vital, low-cost protein source in Nigeria

II. MATERIALS AND METHOD

A. Materials and Sample Acquisition

Fresh frozen blue whiting (*Micromesistius poutassou*) samples were procured from a licensed cold storage facility in Ile-Ife, Osun State, Nigeria. To ensure the integrity of the fish, samples were transported to the Biochemical Engineering Laboratory, Department of Chemical Engineering, Obafemi Awolowo University, in polystyrene (Styrofoam) boxes packed with flaked ice. Upon arrival, biometric measurements were taken. The average length and mass of the fish were 23.69 ± 1.42 cm and 197.26 ± 10.31 g, respectively.

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Commercial-grade sodium chloride (NaCl) was obtained locally for brining and used without further purification.

B. Sample Preparation and Brining

Within one hour of arrival, fish were washed with chlorinated water (<10 ppm residual chlorine), beheaded, and eviscerated. The cleaned fish were rinsed with distilled water, drained, and manually filleted (Gang et al., 2013; Abd El-Hay, 2022). Fillets were cut into strips (~5 cm × 2 cm × 0.5 cm) using a scalpel for precision. Thickness was measured at multiple points with a vernier caliper, and any sample deviating beyond ±0.1 cm was either re-cut or discarded. Fillets were then stored at –18 °C until analysis.

For brining, fillets were randomly assigned to five groups and immersed in sodium chloride (NaCl) solutions at 0 (control), 50, 100, 150, and 200 g/L for 30 min at ambient temperature (≈27 °C) using a 1:5 fillet-to-brine mass ratio. After treatment, samples were blotted to remove surface moisture before drying or analysis. The selected salt concentrations (50–200 g/L) reflect typical brining practices in Nigerian fish processing, from mild flavour enhancement to strong osmotic dehydration, allowing systematic evaluation of their effects on thin-layer drying kinetics, effective moisture diffusivity, and colour of blue whiting fillets (Oku & Amamakoromo, 2023; Dinrifo, 2024).

C. Proximate Composition Analysis

The proximate composition of the control fillets (unbrined samples) was assessed to establish the baseline physico-chemical profile of *Micromesistius poutassou*. All analyses were conducted in triplicate on two independent batches, yielding a total of six replicates (n = 6) per parameter. Analytical procedures were based on standard methods outlined by the Association of Official Analytical Chemists, as reported by Desta *et al.* (2019).

D. Thin-Layer Drying Procedure

The drying experiments were conducted using a laboratory-scale hot air oven (UNISCOPE Model SM – 9053) operated at constant temperatures of 60, 70, 80, 90, and 100 °C. For each experimental run, approximately 50 g of brined fish fillets were arranged in a single layer on a perforated drying tray to ensure uniform exposure to the drying air. The oven was preheated to the desired set temperature before sample placement to minimize initial lag effects. The samples were weighed at 10-minute intervals over a 180-minute drying period using a digital precision balance (±0.01 g). Each drying test was performed in triplicate.

E. Moisture Content Determination

The moisture content (MC) of the fish samples was determined on a wet basis using the standard oven drying method at 105 ± 2 °C until a constant weight was achieved (Hossain *et al.*, 2017). The percentage moisture content was calculated using Equation (1):

$$MC\ (\%) = \left(\frac{W_1 - W_2}{W_1}\right) \times 100 \quad (1)$$

where W_1 is the initial weight of the sample (g), and W_2 is the final dry weight (g). For drying kinetics modelling, the dry basis moisture content at any time t, Mt (kg water/kg dry matter), was calculated using Equation (2):

$$M_t = \frac{W_t - W_d}{W_d} \quad (2)$$

where W_t is the mass of the fish sample at time t (g), and W_d is the mass of the moisture-free sample (g).

The experimental moisture data were converted into the dimensionless moisture ratio (MR), commonly expressed as:

$$MR = \frac{M_t - M_e}{M_o - M_e} \quad (3a)$$

where M_t is the moisture content at time t, M_o is the initial moisture content, and M_e is the equilibrium moisture content. However, given the fluctuating relative humidity of the drying air and the generally low values of M_e (Ertekin and Yaldiz, 2004; Toğrul and Pehlivan, 2003), the expression was simplified as:

$$MR = \frac{M_t}{M_o} \quad (4)$$

F. Determination of Effective Moisture Diffusivity

Assuming moisture movement within the fillets occurred primarily by diffusion, Fick's second law of diffusion for a slab geometry was used to estimate the effective moisture diffusivity (D_e). For long drying times, a simplified analytical solution is given by (Elshehawy and Mosad, 2022):

$$ln(MR) = ln\left(\frac{8}{\pi^2}\right) - \left(\frac{\pi^2 D_e}{4L^2}\right) t \quad (5)$$

where t is the drying time (s), L is the half-thickness of the fillet (m), and D_e is the effective moisture diffusivity (m^2/s). By plotting ln(MR) against drying time, the slope of the resulting straight line was used to compute D_e. The impact of brine concentration on D_e was also investigated at a fixed drying temperature of 100 °C.

G. Drying Kinetics Modelling

To describe and predict the drying characteristics of blue whiting fillets, the experimental MR data were fitted to selected thin-layer drying models (Lewis, Page, Henderson and Pabis, Logarithmic, 2 – term exponential and Midilli–Kucuk models) as presented in Table 1. In the model equations presented, a, b, c, k, k_o, k_1, and n are the model empirical parameters which must be determined experimentally.

Table 1 The thin layer drying models used in this study

S/N	Model Name	Model Equations	References
1	Lewis	$MR = \exp(-kt)$	Agustini *et al.* (2021)
2	Page	$MR = \exp(-kt^n)$	Natarajan *et al.* (2022)
3	Henderson and Pabis	$MR = a\exp(-kt)$	Zibokere and Egbe (2021)
4	Logarithmic	$MR = a\exp(-kt) + c$	Elshehawy and Mosad (2022)
5	Two term exponential	$MR = a\exp(-k_1t) + b\exp(-k_2t)$	Elshehawy and Mosad (2022); Sanda *et al.* (2023)
6	Midilli–Kucuk	$MR = a\exp(-kt^n) + bt$	İsmail and Kocabay (2020)

Nonlinear regression analysis was performed using the solver toolkit on Microsoft Excel 2016. The accuracy of each model was evaluated using the coefficient of determination (R^2), reduced chi-square (χ^2), and root mean square error (RMSE), defined respectively as (Okeleye *et al.*, 2021):

$$R^2 = 1 - \frac{SS_{res}}{SS_{tot}} \tag{6}$$

where

$$SS_{res} = \sum\left(MR_e - MR_p\right)^2; \tag{7}$$

and

$$SS_{tot} = \sum\left(MR_e - \overline{MR}_e\right)^2; \tag{8}$$

$$\chi^2 = \frac{\sum\left(MR_e - MR_p\right)^2}{N - n}; \tag{9}$$

and

$$RMSE = \sqrt{\frac{\sum\left(MR_e - MR_p\right)^2}{N}} \tag{10}$$

where MR_e and MR_p are the experimental and predicted moisture ratios, respectively, N is the number of observations, and n is the number of model parameters.

H. Impact of Treatment Processes on Colour Attributes of Fish Products

Colour assessment of both fresh and dried fish samples was conducted through a combination of visual inspection and instrumental colorimetric evaluation. Objective colour measurements were obtained using an Android-compatible chromameter (Research Lab Tools, Version 3.1), operating within the CIE L* a* b* colour space.

To ensure measurement reliability and comparability with conventional food colorimeters, colour determinations were performed under controlled conditions (Witjaksono *et al.*, 2017; Niakan *et al.*, 2025). The mobile device was mounted on a fixed stand and positioned normal (90°) to the sample surface, with all measurements conducted inside a light-controlled sampling chamber to eliminate ambient light interference. Illumination was provided by a constant LED light source to ensure uniform irradiance across the sample surface.

Prior to colour measurement, the chromameter was calibrated using a two-point calibration protocol involving a high-reflectance white reference and a zero-reflectance (black) reference. Calibration accuracy was verified using a diagnostic colour standard, and calibration was accepted only when the total colour difference (ΔE) between measured and reference values was less than 1.0. This tolerance is consistent with values reported in validation studies demonstrating strong agreement between smartphone-based chromameters and commercial portable colorimeters commonly used in food quality analysis (Valous *et al.*, 2009; Boruczkowska *et al.*, 2025).

The evaluated parameters included L* (lightness), a* (red-green chromaticity), and b* (yellow-blue chromaticity). The overall colour difference (ΔE) resulting from the drying treatments was quantified using the standard Euclidean distance formula in the L*a*b* space, as presented in Equation (11) (Shrestha *et al.*, 2020):

$$\Delta E = \sqrt{(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2} \tag{11}$$

where: $\Delta L = L^* - L_o^*$; $\Delta a = a^* - a_o^*$ and $\Delta b = b^* - b_o^*$. The subscript '*o*' refers to the initial colour parameters of each sample at the beginning of the drying experiment. Additionally, chroma (C*) and hue angle (h°), which provide insight into the saturation and perceived colour tone of the samples, respectively, were computed using Equations (12) and (13) (Shrestha *et al.*, 2020):

$$C^* = \sqrt{a^2 + b^2} \tag{12}$$

$$h = \tan^{-1}\left(\frac{b}{a}\right) \tag{13}$$

III. RESULTS AND DISCUSSION

A. Physico-chemical Characteristics of the Fish Samples

The proximate composition of *Micromesistius poutassou* (Table 2) indicates a high moisture content (79.78 ± 1.01%), typical of fresh pelagic fish. The protein level (29.46 ± 1.13%) confirms its nutritional richness, aligning with previous findings by Egerton *et al.* (2020) on pelagic species. With a crude fat content of 4.24 ± 1.14%, the species is classified as lean, in accordance with standard fat-based fish classifications. The ash content (6.23 ± 0.97%) suggests a significant mineral contribution. These attributes make *M. poutassou* a suitable candidate for processing and preservation studies.

Table 2: Physicochemical attributes of the fresh fish samples

Physicochemical attributes	Value
Moisture content (% wet basis)	79.78 ± 1.01
Crude Protein (%)	29.46± 1.13
Crude Fat (%)	4.24 ± 1.14
Ash	6.23± 0.97

B. Drying Kinetics and Model Evaluation for the unsalted fillets

The experimental moisture ratio (MR) data for the thin-layer drying of the unsalted *Micromesistius poutassou* fillets at five different temperatures (60–100 °C) were fitted to six established drying models: Lewis, Page, Henderson and Pabis, Logarithmic, Two-term Exponential, and Midilli-Kucuk. Model performance was assessed using the coefficient of determination (R^2), chi-square (χ^2), and root mean square error (RMSE) as statistical indicators (Table 3). In accordance with standard model selection criteria, models yielding R^2 values above 0.95 and concurrently low χ^2 and RMSE values were considered to provide satisfactory predictive accuracy (Akpinar, 2006; Ertekin and Yaldız, 2004).

Among the tested models, the Two-term Exponential model consistently outperformed others across all drying temperatures, exhibiting the highest R^2 values (0.9987–0.9997) and the lowest χ^2 (1.661×10^{-5} – 7.811×10^{-5}) and RMSE (0.00372–0.00807) values. These findings confirm the model's superior capability in capturing the drying behavior of *M. poutassou* fillets and accurately describing moisture transfer kinetics during thermal processing. The Midilli-Kucuk and Page models also demonstrated strong fits, particularly at lower temperatures, but their performance was marginally less robust compared to the Two-term Exponential model. Similar trends have been reported in previous studies on fish and agricultural products, further validating the utility of the Two-term Exponential model in thin-layer drying applications (Doymaz, 2004; Jain and Pathare, 2007).

1. Effect of Drying Temperature

The effect of drying temperature on moisture removal from *Micromesistius poutassou* fillets is shown in Figure 1. The drying curves indicate that moisture ratio decreased rapidly at the beginning of the drying process. This initial stage corresponds to the removal of free water from the surface of the fillets. As drying progressed, the rate of moisture loss slowed down, likely due to the decreasing availability of free moisture and the slower movement of water from inside the fillets to the surface. This suggests that the internal structure of the fillets may limit moisture migration, possibly due to low porosity or compact muscle fibres.

The drying rate increased with temperature, showing that higher drying temperatures led to faster moisture removal.

Figure 2 presents the plots of ln(MR) versus drying time at various temperatures, used to estimate the effective moisture diffusivity (D_e). The corresponding D_e values are presented in Table 4. These values, calculated based on a uniform fillet thickness of 5 mm, ranged from 5.59×10^{-10} to 5.29×10^{-9} m^2/s. This range agrees with earlier findings by Zogzas *et al.* (1996), who reported effective diffusivities for food materials between 10^{-12} and 10^{-8} m^2/s.

As expected, D_e increased with temperature, consistent with moisture diffusion being a thermally activated process. To describe the temperature dependence of diffusivity, the Arrhenius equation was applied in its linearized form:

$$\ln D_e = \ln D_o - \left(\frac{E_a}{R}\right)\frac{1}{T} \quad (14)$$

where D_o 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). The plot of ln D_e against 1/T (Figure 3) yielded a straight line, indicating that the drying process followed Arrhenius-type behaviour.

From the linear regression, the relationship between D_e and temperature for *M. poutassou* was obtained as:

$$\ln D_e = -14.685 - \frac{2157.9}{T} \quad (15)$$

The slope of this line corresponds to a drying activation energy of 17.94 kJ/mol. This value is within the typical range for biological materials and supports the temperature dependency of the drying process.

2. Influence of Drying Temperature on Model Parameters

Drying temperature was found to exert a pronounced effect on the model parameters, particularly on the drying rate constants (k, k_1) and empirical exponents (n), showing its important role in moisture removal dynamics. For instance, in the Lewis model, the drying constant k increased steadily from 0.0203 min^{-1} at 60 °C to 0.0504 min^{-1} at 100 °C, indicating enhanced drying rates with increasing thermal energy. The Page and Midilli-Kucuk models also showed similar temperature-dependent behaviour in their k values, further substantiating the direct correlation between temperature and moisture diffusivity.

Interestingly, the n values in both the Page and Midilli-Kucuk models showed a declining trend with increasing temperature. In the Page model, n decreased from 0.7571 at 60 °C to 0.6552 at 100 °C, suggesting a transition from a more uniform drying pattern at lower temperatures to a biphasic process at higher temperatures (initial rapid drying followed by internal moisture diffusion limitations), possibly due to crust formation (Krokida and Maroulis, 1999).

In the Two-term Exponential model, both drying rate constants k_1 and k_2 rose with temperature, with k_1 (associated with the initial fast drying phase) showing a more significant increase from 0.1355 to 0.3187 min^{-1}, as compared to k_2 (linked to slower moisture movement at the latter drying stages), which increased from 0.0153 to 0.0263 min^{-1}. This divergence suggests that higher temperatures predominantly accelerate the evaporation of free moisture, while bound water diffusion remains relatively less affected.

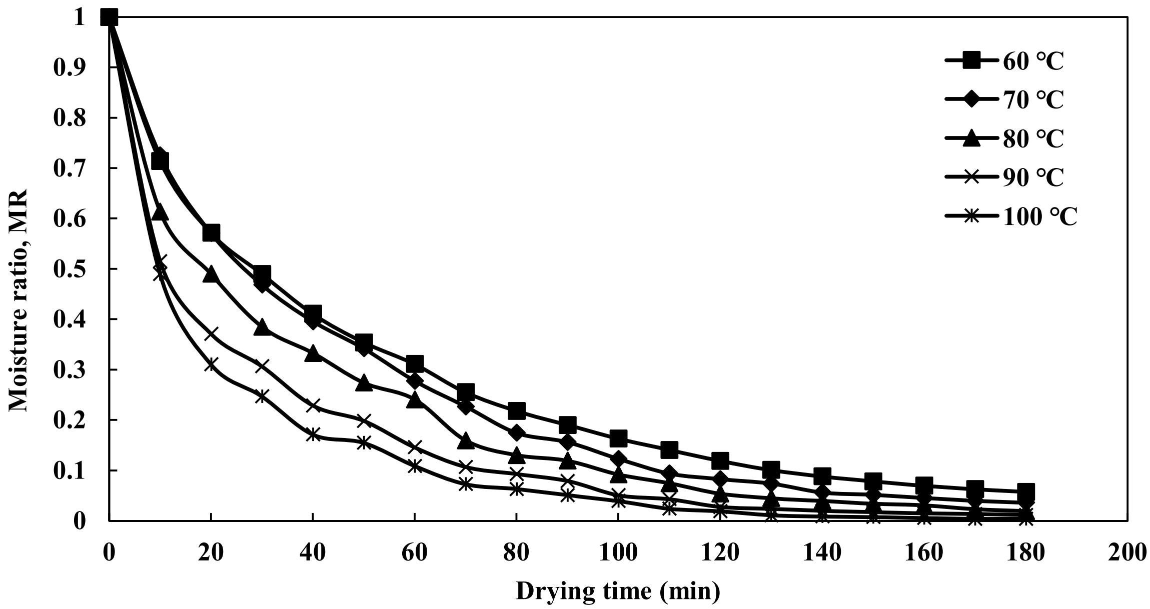

Figure 1 Variation of moisture ratios with drying time for the unsalted *Micromesistius poutassou* fillets

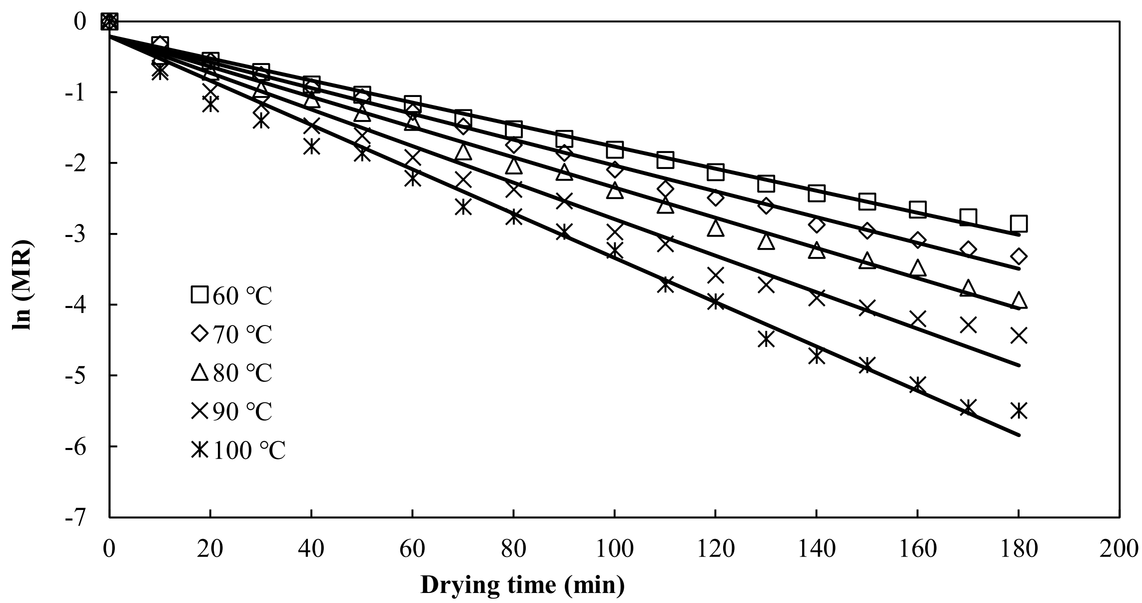

Figure 2 Plots of ln(MR) against drying time at different temperatures for the unsalted *Micromesistius poutassou* fillets

Table 3 Model parameters for the drying of unsalted *Micromesistius poutassou* fillets at different temperatures

Drying model	**parameters**	**Drying temperature**				
		60°C	**70°C**	**80°C**	**90°C**	**100°C**
Lewis	k	0.0203	0.0225	0.0282	0.0403	0.0504
	Chi square	0.0017	0.0008	0.0020	0.0025	0.0018
	RSME	0.0403	0.0275	0.0432	0.0484	0.0409
	R^2	0.9891	0.9943	0.9819	0.9727	0.9785
Page	k	0.0554	0.0444	0.0794	0.1383	0.1569
	n	0.7571	0.8320	0.7320	0.6503	0.6552
	Chi square	0.0001	0.0001	0.0003	0.0002	0.0001
	RSME	0.0078	0.0100	0.0162	0.0124	0.0090
	R^2	0.9989	0.9984	0.9955	0.9972	0.9985
Henderson and Pabis	k	0.0183	0.0211	0.0253	0.0359	0.0467
	a	0.9086	0.9398	0.9053	0.9063	0.9369
	Chi square	0.0010	0.0005	0.0013	0.0020	0.0015
	RSME	0.0231	0.0172	0.0288	0.0380	0.0358
	R^2	0.9850	0.9930	0.9792	0.9687	0.9761
Logarithmic	k	0.0227	0.0234	0.0291	0.0428	0.0537
	a	0.8837	0.9268	0.8942	0.8980	0.9273
	c	0.0585	0.0294	0.0333	0.0365	0.0297
	Chi square	0.0005	0.0004	0.0011	0.0014	0.0011
	RSME	0.0182	0.0150	0.0264	0.0327	0.0298
	R^2	0.9907	0.9945	0.9820	0.9732	0.9791
2 – terms exponential	a	0.2418	0.1692	0.2589	0.3955	0.4833
	b	0.7582	0.8311	0.7411	0.6046	0.5170
	k_1	0.1355	0.1641	0.3187	0.2380	0.1692
	k_2	0.0153	0.0187	0.0206	0.0236	0.0263
	Chi square	1.66×10^{-5}	4.41×10^{-5}	7.81×10^{-5}	3.17×10^{-5}	3.81×10^{-5}
	RSME	0.0037	0.0061	0.0081	0.0051	0.0056
	R^2	0.9997	0.9993	0.9987	0.9994	0.9993
Midilli - Kucuk	a	0.9935	0.9926	0.9897	0.9954	0.9935
	b	0	0	0	0	0
	k	0.0538	0.0428	0.0765	0.1366	0.0538
	N	0.7626	0.8388	0.7394	0.6527	0.7626
	Chi square	6.23×10^{-5}	0.0001	0.0003	0.0002	8.51×10^{-5}
	RSME	0.0076	0.0097	0.0159	0.0123	0.0090
	R^2	0.9990	0.9985	0.9956	0.9972	0.9985

Table 4 Effective diffusivities for drying of the fillets at different temperatures

Drying temperature (°C)	**D_{eff} (m^2/s)**	**R^2**
60	5.59×10^{-10}	0.9919
70	7.68×10^{-10}	0.9926
80	8.99×10^{-9}	0.9927
90	1.09×10^{-9}	0.9762
100	5.29×10^{-9}	0.9875

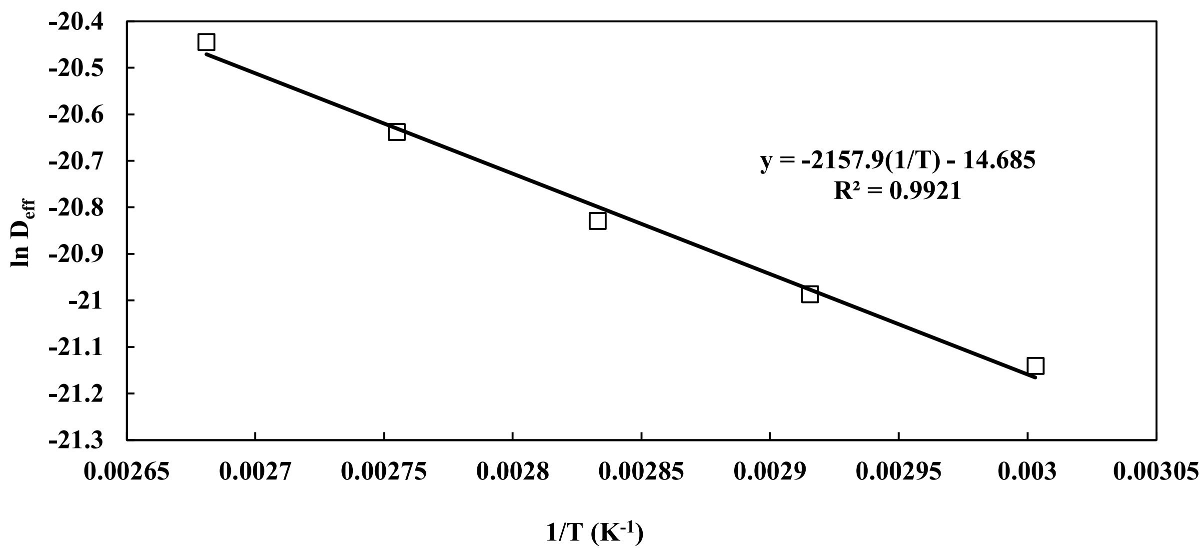

Figure 3 Arrhenius plots for the drying process activation energies

3 Effect of Salting on the drying characteristics of the fillets

The impact of salt pretreatment on the drying behaviour of *M.* poutassou fillets is illustrated in Figure 4. As the salt concentration increased, the drying rate also increased, indicating that salting enhanced moisture removal. This improvement is attributed to osmotic dehydration, where salt induces a hypertonic environment that causes water to migrate from the fish tissue to the surface, facilitating evaporation during drying (Qiu *et al.*, 2019).

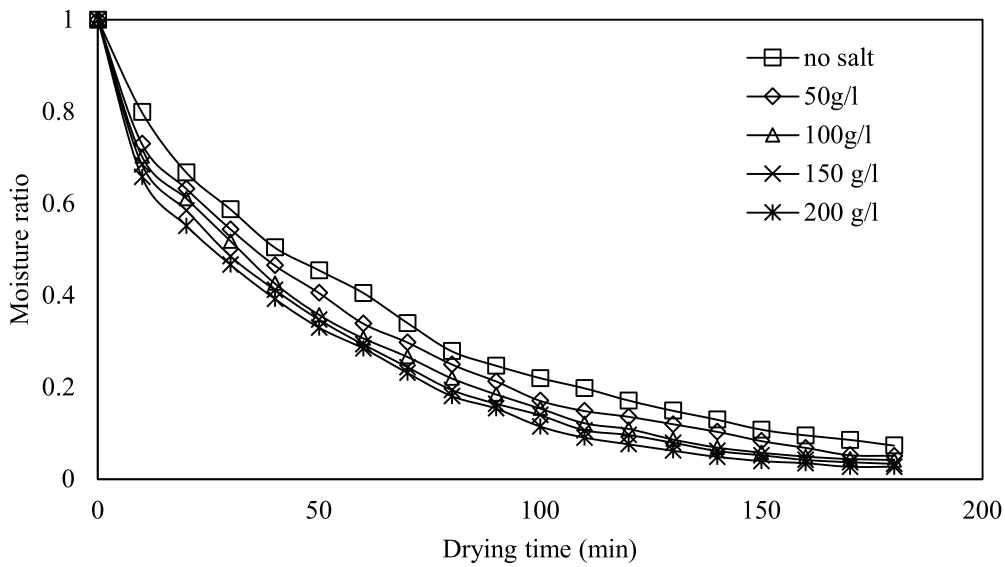

Figure 4 Variation of moisture ratios with salt concentration for the *M. poutassou* fillets (drying temperature: 100ºC)

Drying kinetics for the salted fillets at 100 °C were best represented by the two-term exponential model, as shown in Table 5. The model achieved high goodness-of-fit across all salting levels, with R^2 values ranging from 0.9987 to 0.9997, chi-square values between 1.66×10^{-5} and 7.81×10^{-5}, and RMSE values from 0.00398 to 0.00863. These results support the model's suitability in describing the drying process of salt-treated fillets.

The effective moisture diffusivity (D_e) values, calculated from ln(MR) versus drying time plots (Figure 5) and assuming an average fillet thickness of 5 mm, are summarized in Table 5. The results show a progressive increase in D_e with salt concentration, ranging from 5.31×10^{-9} m²/s for the unsalted fillets to 4.96×10^{-8} m²/s for fillets treated with 200 g/L sodium chloride solution. R^2 values for these fits remained consistently above 0.97. This increase can be attributed to the higher osmotic pressure imposed by concentrated brine, which promotes water efflux from muscle cells and partial disruption of cellular membranes. Such osmotic dehydration is known to increase tissue permeability and create microstructural pathways that facilitate internal moisture diffusion and water vapour escape during drying. Although microstructural changes were not directly examined in this study, the observed enhancement in D_e with increasing salt concentration is consistent with reported mechanisms in salt-assisted dehydration of fish and meat products (Zhao et al., 2020; Mirzaee *et al.*, 2021).

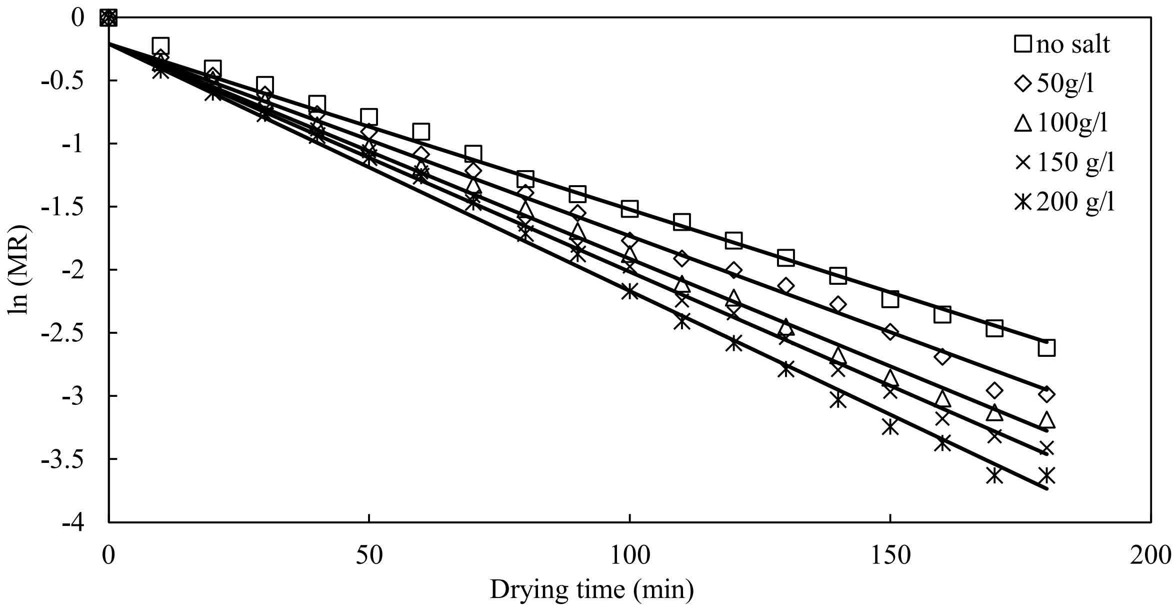

Figure 5 Plots of ln(MR) against drying time at different salt concentrations for the *M. poutassou* fillets

Table 5 Effective diffusivities for drying of the fillets at different salt concentrations (drying temperature: 100 ºC)

Salt concentration (g/L)	Effective diffusivity (D_o) (m^2/s)	R^2
0	5.31×10^{-9}	0.9915
50	3.85×10^{-8}	0.9927
100	4.31×10^{-8}	0.9943
150	4.58×10^{-8}	0.9760
200	4.96×10^{-8}	0.9942

4. Effect of Treatment Processes on the Colour of the Fillets

Brining significantly affected the colour parameters of *M. poutassou* fillets before and after drying (Table 6). Before drying, L* values increased with brine concentration, particularly at 150–200 g/L, suggesting enhanced surface lightness due to osmotic dehydration and surface moisture removal. The a* values shifted from negative to positive with increasing salt concentration, indicating increased redness, likely due to pigment concentration effects. Chroma (C*) was highest at 100 g/L, indicating more vivid colour, while the decrease in hue angle (h) reflected a shift toward reddish tones. The progressive increase in ΔE with salt concentration indicates perceptible colour changes induced by brining prior to drying.

After drying, L* values decreased at moderate salt concentrations (50–100 g/L), indicating pronounced darkening, whereas fillets treated with higher salt levels (150–200 g/L) retained higher lightness values. The darkening observed at 50–100 g/L is likely associated with enhanced non-enzymatic browning, particularly Maillard reactions, which are accelerated at elevated drying temperatures (100 °C) in the presence of concentrated amino acids and reducing sugars. Moderate salting may increase reactant concentration at the fillet surface, thereby intensifying browning reactions, while higher salt concentrations may partially suppress Maillard activity through reduced water availability and ionic effects.

Table 6 Colour analysis parameters for salted *M. poutassou* fillets before and after drying

Treatment	Colour parameters	Brine treatment (g/L NaCl)				
		Unsalted	50	100	150	200
Before drying	L*	68.56	67.61	67.9	72.05	77.65
	a*	-0.50	1.87	4.70	5.30	3.18
	b*	6.30	4.47	7.70	4.10	5.81
	ΔE	0.00	3.14	5.43	7.12	9.82
	Chroma C*	6.32	4.85	9.02	6.70	6.61
	Hue angle h	94.54	67.3	58.6	37.72	61.27
After drying	L*	69.00	65.50	62.53	70.30	76.10
	a*	5.61	1.52	0.70	-0.15	-0.11
	b*	6.70	18.00	9.10	10.40	0.80
	ΔE	6.14	13.70	6.84	8.51	6.18
	Chroma C*	8.74	18.06	9.13	10.40	0.81
	Hue angle h	50.06	85.17	85.60	90.83	97.83

The a* values decreased or shifted slightly toward green at higher salt concentrations, while b* values peaked at 50 g/L and declined sharply at 200 g/L, suggesting salt-dependent changes in pigment stability and thermal degradation. Chroma increased significantly at 50 g/L but declined with increasing salinity, consistent with intensified browning at moderate salt levels and colour dulling at higher concentrations. Hue angle increased across all treatments after drying, indicating a general shift toward yellowish hues. The highest ΔE after drying occurred at 50 g/L, confirming that moderate salting produced the most visually perceptible colour changes. The observed colour variations can be attributed to the combined effects of Maillard browning, pigment oxidation, and salt-induced modifications of surface reflectance during high-temperature drying. Although these chemical reactions were not directly quantified, the interpretations are supported by the measured CIE colour parameters and are consistent with reported behaviour of salt-treated fish dried at elevated temperatures (von Gersdorff *et al.*, 2021).

IV. CONCLUSION

This study showed that brine pretreatment significantly affects the thin-layer drying behaviour, moisture transport, and colour characteristics of blue whiting fillets during hot-air drying. Higher drying temperature and brine concentration increased the drying rate. Effective moisture diffusivity rose from 5.59×10^{-10} –5.29×10^{-9} m²/s in unbrined fillets, to 4.96×10^{-8} m²/s in samples pretreated with 200 g/L NaCl, indicating improved internal moisture transport. Of the models tested, the Two-term Exponential model best fit the experimental data and is suitable for predicting the drying kinetics of brine-treated fish fillets. Brining also affected colour attributes before and after drying. Moderate salt concentrations (50–100 g/L) caused the most pronounced changes in lightness, chroma, and hue, while higher salinity reduced browning during drying. These findings show that brine pretreatment is an effective process variable for controlling drying kinetics and quality attributes of dried fish products, and provide useful data for process optimization in fish drying.

AUTHOR CONTRIBUTIONS

O. Sanda: conceived and managed the project, designed the research, supervised the study, performed data analysis, edited and approved the final manuscript; **D. A. Sanda**: conducted proximate analysis, processed data, and prepared tables; **B. J. Fowowe**: carried out experimental work and data collection; **B. D. Thompson-Ajayi**: assisted with laboratory experiments and data processing; E. A. Taiwo: provided co-supervision, methodological guidance, and critically reviewed the manuscript.

REFERENCES

Abd El-Hay, M. M. (2022). Processing and preparation of fish. In *Postharvest and Postmortem Processing of Raw* Food *Materials* (pp. 315-342). Woodhead Publishing.

Abraha, B., Admassu, H., Mahmud, A., Tsighe, N., Shui, X. W., & Fang, Y. (2018). Effect of processing methods on nutritional and physico-chemical composition of fish: a review. *MOJ Food Processing and Technology*, *6*(4), 376-382.

Agustini, T. W., Fahmi, A. S., & Riyadi, P. H. (2021). Dried salted anchovy different processing methods: drying kinetics and modelling. *Food Research*, *5*(3), 70-75.

Akpinar, E. K. (2006). Determination of suitable thin layer drying curve model for some vegetables and fruits. *Journal of food engineering*, *73*(1), 75-84.

Ali, A., Wei, S., Ali, A., Khan, I., Sun, Q., Xia, Q., ... & Liu, S. (2022). Research progress on nutritional value, preservation and processing of fish—A review. *Foods*, *11*(22), 3669.

Amusan, E. E., Sanni, A. I., & Banwo, K. (2019). Prevalence of Listeria Species in Blue Whiting (*Micromesistus poutasou*) in Lagos State, Nigeria. *FUDMA Journal of Sciences*, *3*(3), 270-274.

Boruczkowska, H., Boruczkowski, T., Bronkowska, M., Prajzner, M., & Rytel, E. (2025). Comparison of Colour Measurement Methods in the Food Industry. *Processes*, *13*(5), 1268.

Desta, D. T., Zello, G. A., Alemayehu, F., Estfanos, T., Zatti, K., & Drew, M. (2019). Proximate analysis of Nile Tilapia, (*Oreochromis niloticus*), Fish fillet harvested from farmers pond and Lake Hawassa, Southern Ethiopia. *International Journal for research and development in technology*, *11*(1), 94-99.

Dinrifo, R. R. (2024). The effects of brine concentrations on the drying characteristics and microbial quality of dried fillets of African catfish (*Clarias gariepinus*). *International Journal of Environment, Agriculture and Biotechnology, 9*(2), 224 – 229.

Doymaz, I. (2004). Drying kinetics of white mulberry. *Journal of food engineering*, *61*(3), 341-346.

Egerton, S., Mannion, D., Culloty, S., Whooley, J., Stanton, C. A. T. H. E. R. I. N. E., & Ross, R. P. (2020). The proximate composition of three marine pelagic fish. *Irish Journal of Agricultural and Food Research*, *59*(1), 185-200.

Elshehawy, S. M., & Mosad, G. A. (2022). Mathematical modeling of tilapia fish fillets dried in thin layer. *Journal of Soil Sciences and Agricultural Engineering*, *13*(11), 359-364.

Ertekin, C., & Yaldiz, O. S. M. A. N. (2004). Drying of eggplant and selection of a suitable thin layer drying model. *Journal of food engineering*, *63*(3), 349-359.

Gang, M., Thorarinsdottir, K. A., Bergsson, A. B., & Jonsson, A. (2013). Changes in the quality and yield of fish fillets due to temperature fluctuations during processing. *Dalian Ocean University, China. Pp*, 1-45.

Hossain, M. N., Jamil, M. G. M., Mia, M. M., Uddin, M. N., & Mansur, M. A. (2017). Studies on the proximate composition, quality and heavy metal concentration of two sun-dried marine fish (sun-dried Silver Pomfret and sun-dried Perch) of Cox's Bazar District of Bangladesh. *Journal of Environmental Science and Natural Resources*, *10*(1), 25-32.

Inyang, U., Oboh, I., & Etuk, B. (2017). Drying and the different techniques. *International Journal of Food Nutrition and Safety*, *8*(1), 45-72.

İsmail, O., & Kocabay, Ö. G. (2020). Effect of different pre-treatments on drying of rainbow trout. *Niğde Ömer Halisdemir Üniversitesi Mühendislik Bilimleri Dergisi*, *9*(1), 688-695.

Jain, D., & Pathare, P. B. (2007). Study the drying kinetics of open sun drying of fish. *Journal of food Engineering*, *78*(4), 1315-1319.

Krokida, M. K., & Maroulis, Z. B. (1999). Effect of microwave drying on some quality properties of dehydrated products. *Drying technology*, *17*(3), 449-466.

Mebratu, A. T., Asfaw, Y. T., Merckx, W., Hendriks, W. H., & Janssens, G. P. (2024). Impact of brining and drying processes on the nutritive value of tambaqui fish (*Colossoma macropomum*). *Plos one*, *19*(4), e0299926.

Mohanty, B. P., Mahanty, A., Ganguly, S., Mitra, T., Karunakaran, D., & Anandan, R. (2019). Nutritional composition of food fishes and their importance in providing food and nutritional security. *Food chemistry*, *293*, 561-570.

Natarajan, S. K., Elangovan, E., Elavarasan, R. M., Balaraman, A., & Sundaram, S. (2022). Review on solar dryers for drying fish, fruits, and vegetables. *Environmental Science and Pollution Research*, *29*(27), 40478-40506.

Niakan, S., Safi, M., Younespour, S., & Khoshtarkib, S. (2025). Comparative analysis of smartphone colorimeter apps and spectrophotometry for measuring forehead skin colour in maxillofacial prosthesis fabrication. *Journal of Prosthodontics*, *34*(6), 602-608.

Ogunyebi, O., & Osibona, A. (2022). Proximate Composition of Fresh, Cold and Hot Smoked Blue Whiting (*Micromesistius poutassou*, Risso 1827). *Nigerian Journal of Scientific Research*, *21*(2), 409-414.

Okeleye, A. F., Akanbi, C. T., & Morakinyo, T. A. (2021). Modelling of thin layer drying characteristics of blanch-assisted water yam (*Dioscorea alata*) slices. *Croatian journal of food science and technology*, *13*(1), 43-50.

Oku, I., & Amamakoromo, E. R. (2023). Influence of Brine Salting on the Quality Attributes of Smoke-dried Catfish (*Clarias anguillaris*) Stored at Ambient Temperature. *Journal of Applied Sciences and Environmental Management*, *27*(7), 1471-1475.

Rasul, M. G., Yuan, C., Yu, K., Takaki, K., & Shah, A. K. M. A. (2022). Factors influencing the nutritional composition, quality and safety of dried fishery products. *Food Research*, *6*(5), 444-466.

Sanda, O., Sanda, D. A., Taiwo, E. A., Aremu, C. O., Ojediran, J. O., & Fakinle, B. S. (2023). Mathematical Modelling of the Drying Kinetics and Optimization of Process Conditions for Tilapia zillii Fillets Dried in a Convection Oven. *Tropical Journal of Natural Product Research*, *7*(6).

Shrestha, L., Kulig, B., Moscetti, R., Massantini, R., Pawelzik, E., Hensel, O., & Sturm, B. (2020). Optimisation of physical and chemical treatments to control browning development and enzymatic activity on fresh-cut apple slices. *Foods*, *9*(1), 76.

Sobukola, O. P., & Olatunde, S. O. (2011). Effect of salting techniques on salt uptake and drying kinetics of African catfish (*Clarias gariepinus*). *Food and Bioproducts Processing*, *89*(3), 170-177.

Toğrul, İ. T., & Pehlivan, D. (2003). Modelling of drying kinetics of single apricot. *Journal of food Engineering*, *58*(1), 23-32.

Valous, N. A., Mendoza, F., Sun, D. W., & Allen, P. (2009). Colour calibration of a laboratory computer vision system for quality evaluation of pre-sliced hams. *Meat science*, *81*(1), 132-141.

von Gersdorff, G. J., Kirchner, S. M., Hensel, O., & Sturm, B. (2021). Impact of drying temperature and salt pre-treatments on drying behavior and instrumental colour and investigations on spectral product monitoring during drying of beef slices. *Meat science*, *178*, 108525.

Witjaksono, G., Hussin, N. H. F. B. M., Rabih, A. A. S., & Alfa, S. (2017). Real time chromametry measurement for food quality detection using mobile device. In *IOP Conference Series: Materials Science and Engineering*. 237(1), 012024.

Zibokere, D. S., & Egbe, E. W. (2021). Thin layer drying kinetics of Freshwater Clawed Lobsters (*Astacus astacus*). *Nigerian Journal of Technology*, *40*(2), 340-347.

Zogzas, N. P., & Maroulis, Z. B. (1996). Effective moisture diffusivity estimation from drying data. A comparison between various methods of analysis. *Drying Technology*, *14*(7-8), 1543-1573.