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Research Article

Modelling Kinetics of Extruded Fish Feeds in a Continuous Belt Dryer

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ABSTRACT

Feed is the major inputs in aquaculture production which affects the development growth of aquaculture in the African continent. Extruded fish feeds are dried to desire moisture content to increase the shelf life. Conventional method of drying fish feeds had gained attention recently in Nigeria in order to reduce high cost of producing fish feeds. However, this method is still grossly underutilized. Extrude floating fish feed was dried using continuous belt dryer at drying air temperature from 60°C to 100°C at an interval of 10°C, velocity of air using for drying from 0.8 m s^{-1} to 1.0 m s^{-1} at an interval of 0.1 m s^{-1} using a constant linear belt speed of 50 m s^{-1}. Various moisture contents gotten at different conditions were changed to ratio of the dried extrudates moisture so as to obtain curves of drying by plotting the ratio of moisture against time. The dried extrudates behaviour was determined by fixing the drying curves with five well known models. Model with high determination coefficient and low reduced chi-square, low standard error, low value of least square and low standard deviation error (SEE) was used as best model. Midilli et al model was found suitable in describing the behaviour of extruded fish feed during drying. The temperature of air used for drying was discovered to have a major influence on the drying kinetics of the extruded fish feeds based on the conditions of this experiment.

RESEARCH ARTICLE

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- Kinetic of drying,
- Extruded fish feed,
- Drying curves,
- Belt dryer,
- Drying model

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INTRODUCTION

Extruded feed is the most typical form of animal feed produced in the western world. Fish feed which contributes a global demand of 50 - 75 million tons per year; has shown an annual growth rate of more than 6% in the last few decades. According to FAO (2020) the global fish production in 2018 is estimated as 179 million tones and this is expected to increase to 204 million by 2030 as a result of increase in production of extruded fish feeds. Although, either floating or sinking feed can produce satisfactory growth, but most fish species prefer floating than sinking. This is due to the fact that extruded feed have superior water stability, better floating properties, ease in digestion, zero water pollution, optimized labour usage, zero wastage of raw materials (Amalraaj, 2010) and a higher energy than sinking pelleted feed (Hilton *et al.*, 1981; Johnson and Wanderwick, 1991; Momo *et al.*, 2016). Drying according to Kallia and Patankar (2001) can be defined has the universal method of conditioning the material by removing moisture to such a level that it is in equilibrium with the normal atmospheric air in order to preserve the quality and nutritive value of the food product. According to Misha *et al.* (2013), to obtain the best conditions of drying and for energy saving during procedure for drying, it is imperative to know the solid temperature and effects of the drying variables (temperature of air use for drying, velocity of air use for drying etc) in moisture removal. Drying of temperature sensitive materials such as food and agricultural products, particularly at temperatures sensitive enough to cells, lead to probable cell damage and gelatinization (Fernando *et al.*, 2008). Pacheco *et al.* (2011) stated that low temperature between 30°C to 70°C is the sorption isotherms required for an extruded fish feed and that the energy equilibrium of thermal system is delineated by heat and mass transfer in a continuous convective dryer. In estimating the coefficient of heat and mass transfer, the heat transfer coefficient is often used because of its reliability than the mass transfer coefficient (Sander *et al.*, 2001). Haubjerg *et al.* (2014) opined that this is true since surface temperature can more easily be measured over the course of drying. Barati and Esfahani (2011) also reported that the center and surface temperature are almost same especially when drying with for Biot numbers less than one especially for small fish feed pellets convectively exposed hot air use for drying (Haubjerg *et al.*, 2014). For the best management of operation parameters and prediction of process involved in drying, mathematical models are used. According to Brooker *et al.* (1992), semi–empirical and empirical models are used to estimate how moisture varies in feed materials. The condition of drying, dryer type and the characterization of the feeds (Ozdemir and Devres, 1999) to be dried are factors that affect drying kinetics of the feeds. Most aquatic and pet feeds are dry mostly in belt dryer, this is due to the fact that it has high efficiency and simple design (FAO, 2020). Although, there had been studies on kinetic modeling of fish feeds, but few literatures on kinetic modeling of extruded fish feeds in a continuous belt dryer. Investigating the influence of drying variables on the drying kinetics of fish feed extrudates using continuous flow belt dryer and using seven known models with the objectives of selecting the most well adopted model were objectives of the research.

MATERIALS AND METHODS

Feed ingredients were procured from a retail outlet at Akure, Ondo State. The feedwas formulated using ingredients used for catfish feed production in Nigeria according to Fagbenro and Adebayo (2005). The materials were extruded byusing a single screw extruder, developed at The Federal University of Technology, Akure. The extruded fish feed preliminary moisture content was evaluated by drying the sample in an oven at 102°C until the weights remain steady. A continuous flow belt dryer (Figure 1) was used in drying the extruded feeds.

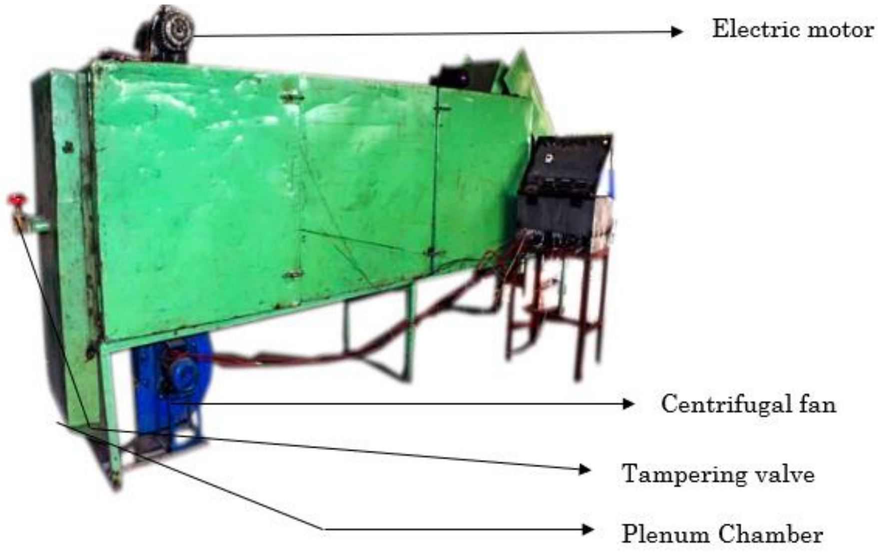

Figure 1. Side view of continuous flow belt dryer.

A digital balance was used to weigh the samples every 30 minutes. Five temperatures (60 to 100°C) of air used for drying and three velocitie of air for drying (0.7 to 0.9 m s^{-1}) were chosen to investigate the influence of temperature of air use for drying and velocity of air use for drying on the feeds. A constant value of 50 m s^{-1} was used as the linear belt speed. 2000 g of wet extruded fish feeds as thin layer were loaded inside the dryer. The procedure for drying continues until the weight of the feed was steady for ten successive readings.

Table 1 shows the drying models. The ratio of the moisture by using the models is given has

$$M_i = \frac{M_t - M_s}{M_o - M_s} \quad (1)$$

Where; M_i is amount of moisture in the extruded fish feed (dry basis) at any time; M_0 is initial amount of moisture in the extruded fish feed; M_s is amount of stable moisture in the extruded fish feed. In contrast to M_t and M_0, the amount of extrudate stable in water is small, thus Equation 1 is simplified to

$$M_i = \frac{M_t}{M_o} \quad (2)$$

The thin layer models which describe the drying dynamic of the extruded fish feeds were fitted to Table 1 in order to ascertain the most acceptable model that can represent the extruded fish feeds drying curves. In validating the model that best describes the drying dynamic of the feed, *R* squared *(R^2)*, reduced chi – square *(x^2)*, standard deviation error *(SEE)*, least square error *(SSE)* standard error *(RMSE)* statistical methods were used. The goodness of fitness of the selected model to the experimental data was determined using these statistical methods. These methods were calculated has follows

$$X^2 = \sum_{i=1}^{N} \left(MR_{prei} - MR_{exp,i}\right)^2 \quad (3)$$

$$\text{RMSE} = r\left[\frac{1}{N}\sum_{i=1}^{N}\left(MR_{pre,i} - nMR_{expi}\right)^2\right]^{1r^2} \quad (4)$$

$$R^2 = 1 - \frac{\sum_{s=1}^{W}\left(AR_{exps} - AR_{pre\,s}\right)^2}{\sum_{s=1}^{W}\left(\overline{AR_{\exp s}} - AR_{pre\,s}\right)^2} \quad (5)$$

where $AR_{pre,i}$ is ratio of the moisture in nth predictions, AR_{expi} is ratio of observed experment in nth predictions, $AR_{exp\,s}$ is mean value of experimental dimensionless ratio of the moisture, N is amount of observations and n is the amount of constant in a model. A plot of curve drying model was used to determine the value of each model coefficient. MATLAB 2014R software was used to find the best model fit and the mathematical model coefficients.

Table 1. Mathematical model to predict the procedure of drying.

Model	Type	Reference
Newton	$MR = exp\ (-kt)$	Mujumdar (1987)
Page	$MR = exp\ (-kt)^n$	Diamante and Munro (1993)
Modified Page 1	$MR = exp\ [-\ (kt)^n]$	Whith et al. (1978)
Midilli, Kucuk and Yapar	$MR = a\ exp\ (-ktn) + bt$	Midilli et al. (2002)
Tow term	$MR = a\ exp\ (k_0t) + b\ exp(-k_1t)$	Henderson (1974)
Tow- term exponential	$MR = a\ exp\ (-kt) + (1 – a)\ exp\ (-k_at)$	Sharaf-eldeen *et al.* (1980)
Wang and Singh	$MR = a\ exp\ (-kt) + (1 – a)\ exp\ (kbt)$	Yaldız *et al.* (2001)

RESULTS AND DISCUSSION

Figures 2 to 4 show the drying curve of extruded fish feeds dried in continuous flow belt dryer. It was observed that as the drying time increase, there is progressive reduction in the moisture ratio of the extrudate. The increase in the drying temperature of 60°C to 100°C leads to an increase in the amount moisture loss by the extrudate over the drying time considered in this study. This explains the fact that moisture at the surface of the extrudates evaporated at a faster rate when the temperature is high. This shows that the moisture on the outer surface layer of the sample evaporated very fast at higher temperatures. A similar trend has been reported by many researchers such as Arumuganathan *et al.* (2009) when drying mushroom; Meziane (2011) in drying pomace made from olive, Gorjian *et al.* (2011) when drying barberry. Also, similar result was reported by Haujerg *et al.* (2014) when drying extruded fish feed in a hot air convective dryer using temperature between 50°C and 80°C, Aghbashlo *et al.* (2012) in carrot drying, Ruiz-Celma *et al.* (2012) when drying tomatoes and corn drying (Odjo *et al.*, 2012).

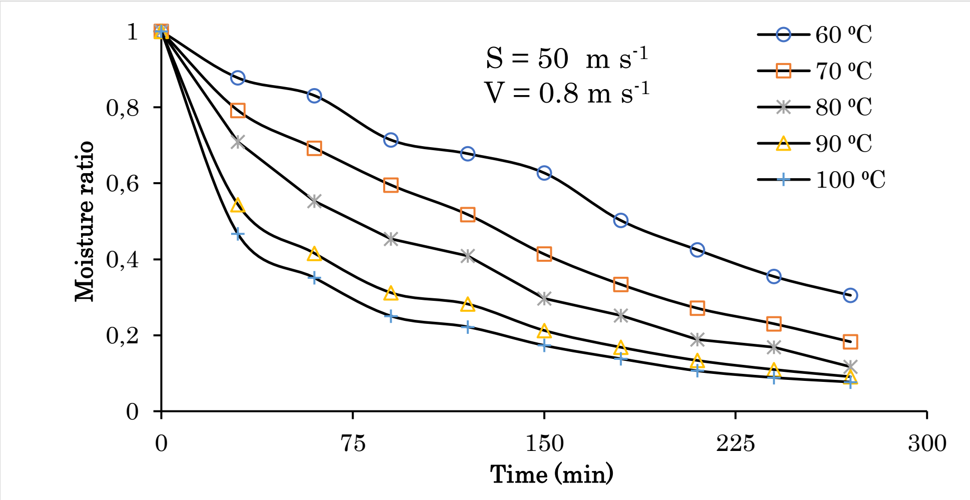

Figure 2. Influence of temperature on the moisture ratio vs time for drying for velocity of air for drying at 0.8 m s^{-1}.

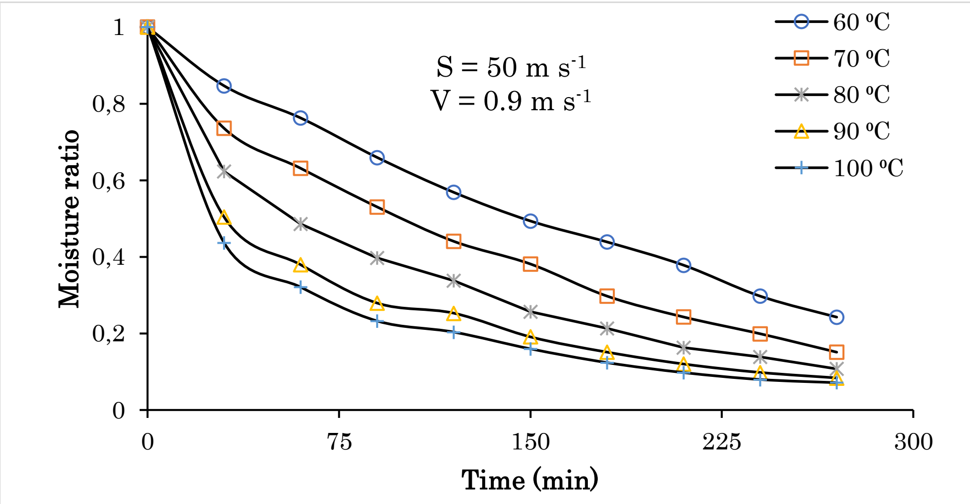

Figure 3. Influence of temperature on the moisture ratio vs time for drying for velocity of air for drying at 0.9 m s^{-1}.

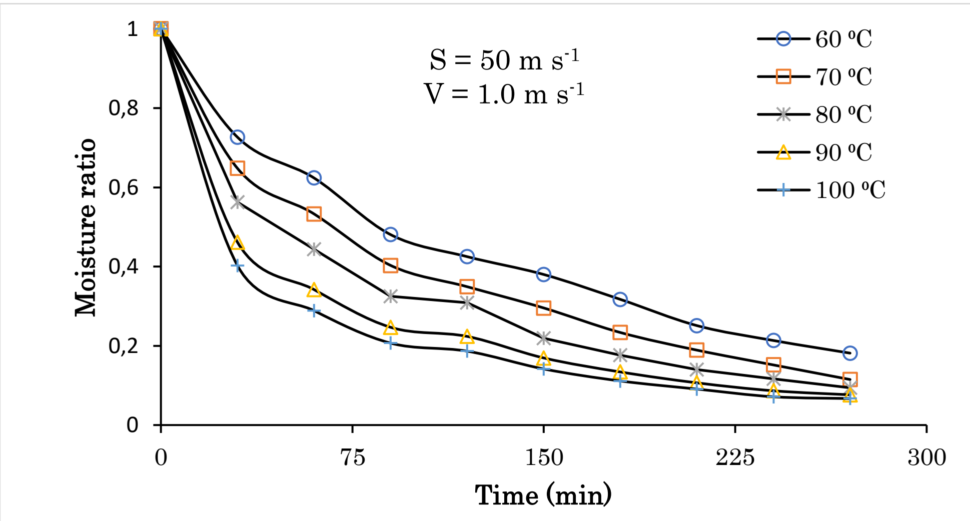

Figure 4. Influence of temperature on the moisture ratio vs time for drying for velocity of air for drying at 1.0 m s^{-1}.

Using non-linear regression approach on Microsoft Excel solver add, moisture ratio of the extruded fish feeds during the drying experiment was fitted with seven thin layer existing mathematic models as depicted in Table 1. The outcome of the goodness of fit variables for the best fitted mathematical model for different air temperatures and conveyor belt speed at 50 m s^{-1} is as shown in Table 2. The overall goodness of fit parameter showed that the *R* square *(R^2)*, standard error *(RMSE)*, standard deviation error *(SEE)*, reduced chi-square *(χ^2)*, least square error *(SSE)* values were obtained as $0.9923 \leq R^2 \leq 0.9995, 0.0071 \leq RMSE \leq 0.0193, 0.0091 \leq SEE \leq 0.2860, 0.0000 \leq \chi^2 \leq 0.0954, 0.0001 \leq SEE \leq 0.7632$ respectively. The highest values of coefficient of determination ($R^2 \geq 0.9995$) was given by Midilli et al model. Thus, this model may display the drying behaviuor of fish feed extrudates. The validation performance of the most suitable model selected shows that the predicted ratio of the moisture values and experiential moisture ratio (Figure 5a, 5b, 5c) data scattered adjacent to the 45° straight line. This implies that the Midilli et al model is used to forecast the drying characteristic of the extruded fish feeds.

Table 2. The goodness of fit parameters at different drying temperature and velocity of air for drying at conveyor speed of 50 m s^{-1}.

Velocity of air for drying (m s^{-1})	Drying air temperature (°C)	Model constant	R^2	RMSE	SEE	X^2	SSE
0.8	60	k = 0.0418, b = -0.1319, a = 0.9906, n = 0.6473	0.9923	0.0193	0.025	0.0001	0.0037
	70	k = 0.0844, b = 0.0377, a = 0.9843, n = 2.1488	0.9976	0.0124	0.016	0.0003	0.0015
	80	k = 0.4818, b = -0.0565, a = 1.0024, n = 0.5134	0.9961	0.0165	0.0213	0.0005	0.0027
	90	k = 0.8786, b = -0.0047, a = 0.9989, n = 0.5886	0.9983	0.0109	0.0154	0.0002	0.001
	100	k = 1.0585, b = -0.0047, a = 0.997, n = 0.5189	0.9992	0.0077	0.0099	0.0001	0.0006
0.9	60	k = 0.2323, b = -0.0448, a = 1.0014, n = 0.8232	0.9988	0.0082	0.0106	0.0001	0.0007
	70	k = 0.4207, b = -0.0321, a = 0.9966, n = 0.7006	0.9988	0.0088	0.0114	0.0001	0.0008
	80	k = 0.1266, b = 0.0016, a = 1.0457, n = 1.0047	0.9928	0.0221	0.0286	0.0008	0.0049
	90	k = 0.8309, b = -0.0424, a = 0.9831, n = 0.3685	0.998	0.014	0.0197	0.0004	0.002
	100	k = 0.1266, b = 0.0016, a = 1.0457, n = 1.0047	0.9995	0.0059	0.0076	0.0001	0.0003
1.0	60	k = 0.4719, b = -0.0219, a = 0.9999, n = 0.6659	0.9974	0.0125	0.0162	0.0001	0.0016
	70	k = 0.5775, b = -0.0461, a = 1.0024, n = 0.4736	0.9979	0.0118	0.0152	0.0002	0.0014
	80	k = 0.7961, b = -0.0182, a = 0.9997, n = 0.5329	0.9976	0.013	0.0167	0.0003	0.0017
	90	k = 1.0522, b = -0.0119, a = 1, n = 0.4685	0.9992	0.0077	0.011	0.0001	0.0005
	100	k = 1.2539, b = -0.0015, a = 0.9997, n = 0.4848	0.9993	0.0071	0.0091	0.0001	0.0005

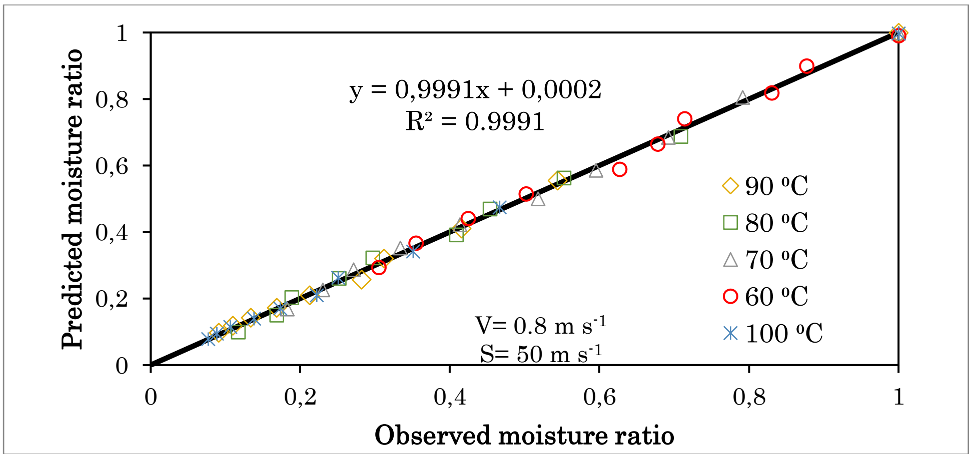

Figure 5a. The graph of predicted ratio versus observed moisture ratio at different temperature for drying, velocity of air for drying at 0.8 m s^{-1}.

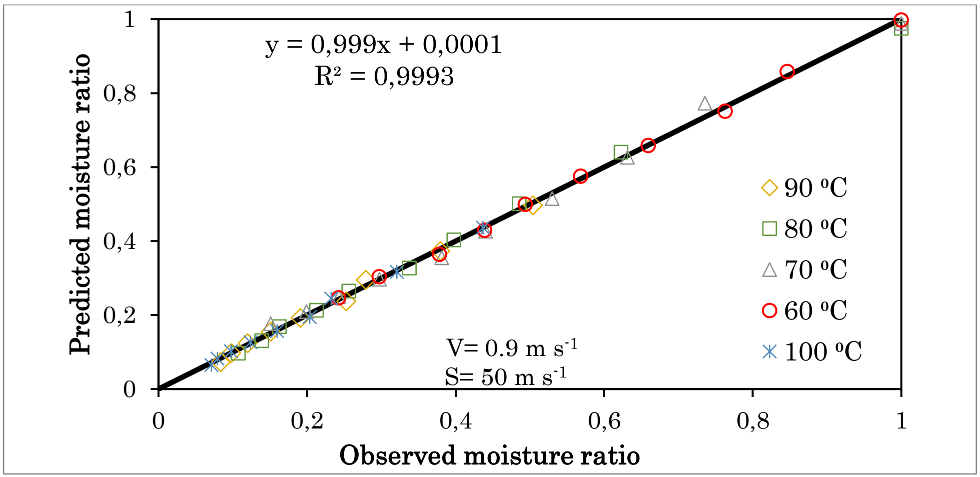

Figure 5b. The graph of predicted ratio versus observed moisture ratio at different temperature for drying, velocity of air for drying at 0.9 m s^{-1}.

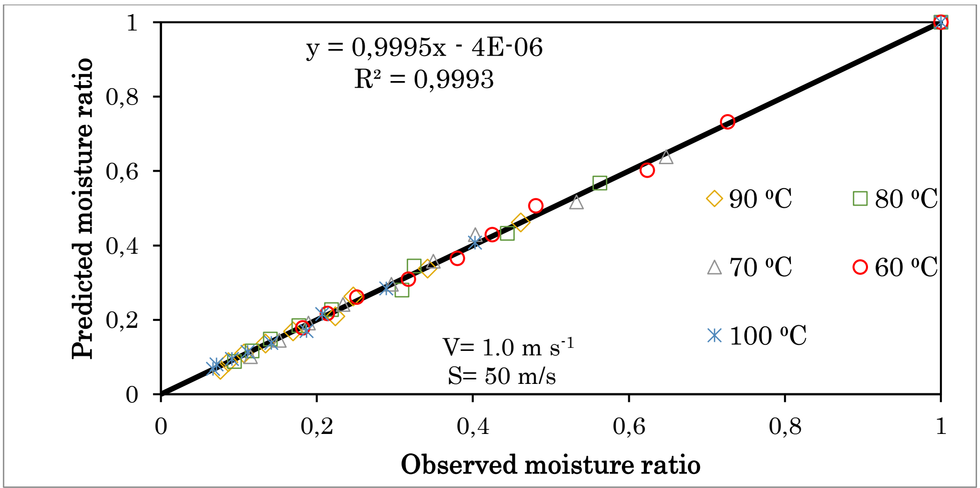

Figure 5c. The graph of predicted ratio versus observed moisture ratio at different temperature for drying, velocity of air for drying at 1.0 m s^{-1}.

CONCLUSION

The modeling kinetic of extruded floating fish feeds and influence of the temperature of air used for drying, velocity of air used for drying and a constant linear belt speed under different machine operational condition was investigated. A rise in the temperature of air for drying leads to reduction of time required to dry the fish feeds. Temperature of air for drying and velocity of air for drying were discovered to be the major influence on drying behavior of the fish feed with belt linear speed having the least effect. In predicting the drying kinetics of the extruded fish feeds, Midilli et al model was ascertained to be the most fitting model to use.

DECLARATION OF COMPETING INTEREST

The authors declare that there are no conflict of interest

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

Funmilayo Ogunnaike: Investigation of the manuscript, materials and methods used in the research, conceptualization, data analysis and validation and writing of the original draft of the manuscript.

Pius Olalusi: Investigation of the manuscript, materials and methods used in the research, conceptualization, edition of the manuscript and reviewing of the manuscript.

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