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# Modeling the Drying of Soybean Curd Residue Based Fish Feed

**T. T. Ayanlade[1*], J. A. Adegboyega[1] and A. P. Olalusi[1]**

*[1]Department of Agricultural Engineering, Federal University of Technology, P.M.B. 704, Akure, Ondo State, Nigeria.*

***Authors' contributions***

*All authors collaborated in the achievement of this work. Author TTA designed the study, statistical analysis, analyzed and interpreted the data. Author JAA observe the experiment, proofread and reviewed thoroughly the manuscript. Author APO drafted the protocol and contributed materials. All authors read and approved the final manuscript.*

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## ABSTRACT

The drying characteristics of Soybean curd residue (SCR) based fish feed were investigated using an oven at temperatures of 40, 50, 60, 70 and 80°C, and at a constant air velocity of 1.5 m/s. The ingredients composition for the fish feed were mixed and extruded using a single screw extruder. Then, the extruded fish feeds were dried in an oven at the various temperatures. The coefficient of determination ($R^2$), Root Mean Square Error (RSME) and reduced chi-square ($\chi^2$) between the observed and predicted moisture ratio for all conditions of drying were used to study and evaluate the performance of the nine models fitted to the data gotten from the experimentation. Page model was the best for SCR based fish feed samples dried at 60°C which is the best temperature for drying by the coefficient of determination r2, which was concluded based on the mathematical modelling of the drying characteristics. Drying at all temperatures produced the proximate composition within the desirable limit. Although, protein and fat content decreased and were highest after drying at $40^0$C, while carbohydrate and fibre increased and were highest after drying at 80°C temperature content of the fish feed. At 60°C, proximate composition was at the medium within desirable limits which can be fed directly to *Clarias Gariepinus*.

**Corresponding author: Email: Timilehinayanlade26@gmail.com;*

*Keywords: Soybean curd residue (SCR); thin layer drying models; temperature; proximate composition.*

## 1. INTRODUCTION

Sustainable growth of aquaculture largely depends on factors such as feed and production techniques etc. [1]. Ana et al. [2] reported that one of the major hindrances to the successful practice of fish production is fish feed. Feed formulation involves the combination of feed ingredients to meet the requirements of the intended fishes [3].

The primary objective of feed formulation is to provide fish species under culture with an acceptable diet that meets its nutritional requirement at different stages of life, with the aim to obtain maximum production at minimum cost [4]. Sussel [5] reported that the large increase in the fish breeding was due to the development of pelletized feed and later of extruded feed. However, in producing extruded feed, the right temperature and pressure are important, to promote the suitable physical and chemical modifications in the ingredients, and improve the feeding efficiency of fishes [6,7]. Also, the production of fish feeds is also a costly endeavour, with studies undergone in the past, to ensure its safety, and its sustainability [8]. Such studies has led to the use of SCR to provide the protein requirement for the feed and it is very important to reduce wastage, especially in a country like Nigeria with high soybean producing capacity [9].

However, extruded fish feed with high protein content such as SCR suffer a problem of stability after the extrusion process [2], because agricultural materials are moisture and time dependent. The extruded fish feed has a short time span for its usability after production, causing problems in its handling and transportation. This leads to quicker spoilage due to proliferation by microorganisms [2]. In order to prevent spoilage, the moisture content can be reduced to the equilibrium moisture content (convenient for storage) by drying process. Drying might also increase the shelf life, and alter the nature of the fish feed, thus a need to investigate the drying process is important. This is essential in determining the best conditions in which drying of the feed should be carried out.

This paper is aimed at conducting a drying experiment on fish feed produced from SCR at different levels of air temperature and their effect on the proximate composition of the feed.

## 2. MATERIALS AND METHODS

This chapter covers the materials used for the production of the fish feed, the experimental set up, the methods and techniques employed in producing the extruded fish feed(pellet) prior to drying. The extruded fish feed (pellet) was dried to determine it moisture content at different temperatures. The experimental drying data were fitted into nine (9) thin layer drying model to determine the best model for the extruded fish feed.

### 2.1 Experimental Site

The experiment was performed at Crop Processing and Storage Laboratory in the Department of Agricultural and Environmental Engineering, School of Engineering and Engineering Technology, Federal University of Technology, Akure (FUTA), Ondo State, Nigeria.

### 2.2 Materials

Ingredients required for the formulation of the SCR based fish feed were gotten as follows: the SCR was gotten from a local soybean milk seller at Federal University of Technology, Akure, while the other ingredients such as maize, wheat bran, soya bean, fish meal, vitamin C, methionine and antioxidant were gotten at Farm Support Group, along Road Block Akure – Ilesha Expressway, Opp. Scab Filing Station, Akure, Ondo State, Nigeria. The samples were well selected and timed so as to ensure freshness of the produce and for proper handling prior to preparation, drying and other analysis.

The equipment and machines used for the project include a Kerro BL30001 weighing balance, mesh, moisture seal bags, mixing bowl/container an oven and an extruder. A Dhg-9053A oven was used, this is a convective dryer with an air velocity of 1.5 m/s. With a combined movement of heat transfer that uses an inactive gas as the drying medium. It operates on an intermittent flow. The extruder used was a single screw extruder, powered by a 25hp 3-phase electric motor designed and fabricated in the Agricultural Engineering department Workshop, FUTA [10]. Transmission is achieved through chains and sprockets. The extruder consists of a steel barrel that contains a hopper at one end, an extrusion worm and a die plate, through which the material is forced at the other end of the barrel. The machine also includes two vents, located at the compression and discharge zones of the extrusion barrel.

## 2.3 Methods

The materials to be used for the experiment were according to measurement, which are suitable for the *Clarias gariepinus* which the feed is to be fed to. The measurements provided data of the ingredients needed for the formulation of fish feed (in percentage) and the corresponding mass for each component was used, as shown in Table 1.

On purchase of the SCR, a very high amount of water/moisture was present in it. It was then dewatered using the traditional method of placing a stone on SCR stuffed in a mesh to extract the moisture. Afterwards, the ingredients were mixed thoroughly in the dry state in a mixing bowl until there was consistency.

**Table 1. Ingredient composition in percentage; this is the proportion of constituents for every kilogram (kg) of fish feed formed**

| Ingredient | Percentage (%) |
|---|---|
| Maize | 24 |
| SCR | 35 |
| Wheat bran | 20 |
| Soybean meal | 10 |
| Fish meal | 5 |
| Vitamin C | 0.3 |
| Methionine | 0.4 |
| Antioxidant | 0.3 |
| Total | 100 |

*Source: Farm Support Group Akure*

Extrusion of the fish feed was done using an 8 mm die. Being a locally fabricated single screw self-heat generated extruder, it was run for 15 minutes before the feed was poured, this was to allow proper heating of the trough. The process was repeated three (3) times, which involved the already extruded pellets being recycled back into the extruder. This was done to ensure proper gelatinization of the extruded fish feed [11]. The moisture content after extrusion was determined. Extruded pellets were placed into moisture proof bags. This was done in order to conserve the moisture prior to carrying out the drying process and storage. The proximate analysis of samples were then taken, which was done to determine the nutrient composition of the extruded pellets prior to drying. Pellets were placed in a mesh of predetermined weight and put in an oven, which had been set to a temperature of 40°C. Weight of pellets (including container) was taken at an interval of 10 minutes till the pellets were dry and there was little to no difference in the weights of pellets weighed (this was about 240 min) and the material was bone dry as shown in Plate 1. This was used to determine the moisture content at each interval. The process was repeated with different sets of extruded pellets at temperatures of 50°C, 60°C, 70°C, and 80°C. The proximate analysis of samples after drying were then conducted on the SCR based fish feed, these data were used for analysis. Biochemical analysis carried out on the sample is the proximate composition of the SCR based fish feed done prior to drying and after drying. From an industry standard, proximate includes six constituents which are: carbohydrate, moisture, ash, fat, protein and fiber.

### 2.3.1 Statistical Analysis of drying data

The experimental drying data obtained were fitted to the nine (9) thin layer drying models shown in Table 2. The following parameters were used: moisture content, drying rate and moisture ratio.

*2.3.1.1 Determination of Moisture Content*

Moisture content of a sample was calculated on a wet basis by gravimetric method as shown below:

$$MC_{wb} = \frac{\mathrm{Wi-Wf}}{\mathrm{Wi}} * 100\% \quad (1)$$

Where

$MC_{wb}$ is Moisture content wet basis (%)
$W_i$ is initial weight
$W_f$ is final weight

*2.3.1.2 Determination of Drying rate (DR)*

Drying rate of a sample was calculated using the following formulae:

$$DR = \frac{Mt+dt-Mt}{t+dt-t} \quad (2)$$

$M_{t+dt}$ is the moisture content at t+dt (Kg water/Kg dm), and t is drying time (hrs)

*2.3.1.3 Determination of Moisture ratio*

The moisture ratio (MR) is calculated using the following equation:

$$MR = \frac{M-Me}{Mo-Me} \quad (3)$$

**Plate 1. Dried extruded pellet**

Where,

M is the moisture content at each timing
$M_o$ is initial moisture content
$M_e$ is Equilibrium moisture content, assumed to be zero [2,12,13].

The regression analysis was performed on the data using Microsoft Excel Solva version 2012 as shown in Table 3. Basically, the coefficient of determination ($R^2$) was criterion used to select the best model in describing the drying curves. The deviations between experimental and predicted values for the models and root mean square error analysis (RMSE) were also used to determine the goodness of the fit. The higher the values of coefficient of determination ($R^2$) signifies a better goodness of fit. In addition to this, the lower the values of $\chi 2$ and RMSE, the better the goodness of the fit [14]. These values were calculated using the following formulae:

$$R^2 = \frac{\sum_{i=1}^{N}(MRi - MRprei) * (MRi - MRexpi)}{\sqrt{\sum_{i=1}^{N}[MRi - MRprei]^2 * [\sum_{i=1}^{N}(MRi - MRexpi))^2]}} \quad (4)$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}(MRexpi - MRcal.i)^2}{N}} \quad (5)$$

$$\chi 2 = \frac{\sum_{i=1}^{N}(MRexp.i - MRcal.i)^2}{N-n} \quad (6)$$

Where

$R^2$ is called the coefficient of determination
$MR_{exp,i}$ stands for the experimental moisture ratio
$MR_{pre,i}$ is the predicted moisture ratio for this measurement
N is the total number of observations [15,16,17].

**Table 2. Thin-layer drying models most frequently used by various authors**

| S/N | Model Name | Model | References |
|---|---|---|---|
| 1. | Newton | MR = $\exp^{(-kt)}$ | [18,19,20] |
| 2. | Page | MR = $\exp^{(-ktn)}$ | [21,22,23] |
| 3 | Henderson and Pabis | MR = a.exp(-kt) | [22,24,25] |
| 4 | Logarithmic | MR = $a.\exp^{(-c(t/L2))}$ | [17,26,27] |
| 5 | Two-term | MR = $a.\exp^{(-kt)} + b.\exp^{(k1t)}$ | [17,28,29] |
| 6 | Two-term Exponential | MR = $a.\exp^{(-kt)}+(1-a)\exp^{(-kat)}$ | [14,30,31] |
| 7 | Wang and Singh | MR = $1 + at + bt^2$ | [32] |
| 8 | Thomson | t = $a.\ln(MR) + b[\ln(MR)]^2$ | [33] |
| 9 | Midilli and Kucuk | MR = $a\exp^{(ktn)} + bt$ | [14] |

*Moisture ratio (MR) = dependent variable, Drying constant (k) = independent variable*

## 3. RESULTS AND DISCUSSION

### 3.1 Moisture Content of SCR Based Fish Feed

The initial moisture of the SCR based fish feed was found out by gravimetric method to be 22% on a wet basis. Ana et al. [2] also had a similar result.

### 3.2 Effects of Drying Air Temperature on the Drying Characteristics of SCR Based Fish Feed

SCR based fish feeds were dried at an interval of 10°C over a temperature range of 40°C to 80°C, to study and investigate the influence of temperature on their drying characteristics. From Fig. 1; a graph of moisture ratio was plotted against time. Moisture ratio which was gotten by the determination of moisture content from the drying data (mass) and using formulae 3, the drying time was then calculated in hours before plotting the graph. Due to the increase in heat transfer between air and the fish feeds and acceleration of water migration inside them, higher temperature caused a higher drying rate and consequently the drying time is reduced. The results were similar to the observations made earlier by Olalusi et al. [34] on Taro slices and by Ana et al. [2] on fish feed.

All of the drying occurred in the falling rate period, which means that the mass transfer was governed by internal resistance; this indicates that diffusion is the main physical mechanism governing moisture migration in the samples. The drying rate decreased continuously with a decreasing moisture ratio and increasing drying time. At constant temperature, a decrease in the moisture ratio was observed with increasing drying time was observed. Similar trend were observed by Doymaz [35] for broccoli, Wankhade et al. [36] for okra. Drying rate of SCR based fish feed decreased as the temperature decreased, this agrees with notable researchers with similar reports in earlier researches on products such as chili [37], pepino fruit [38]. Fig. 2 is a graph which shows the relationship between the moisture ratio and time for drying at 60°C.

### 3.3 Effect of Drying Air Temperature on the Proximate Composition of SCR Based Fish Feed

In this study, the SCR based fish feed was dried at temperatures of 40°C, 50°C, 60°C, 70°C, 80°C, and this were capable of removing the moisture in the fish feed to a safe stage. Removal of moisture extends the shelf life of the fish feed and reduces perish ability. The protein and fat content of the fish feed were reduced by all temperatures used during the study as shown in Fig. 1. None of the temperature produced a

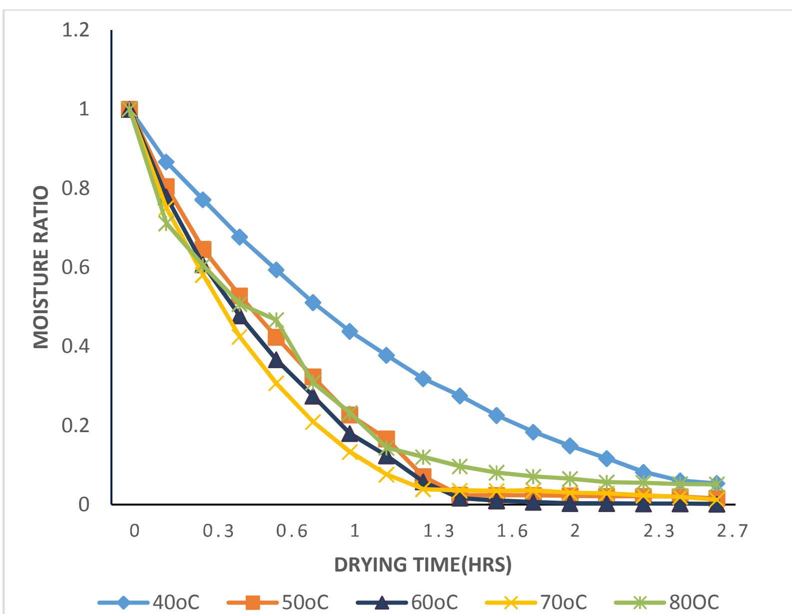


**Fig. 1. Influence of temperature on the soybean Curd residue based fish feed at 40, 50, 60, 70 and 80°C**

major loss in the macronutrient composition, but the percentage loss was highest in fat, with protein having the lowest loss. This occurred as a result of the application of heat. This is similar to the report made by Hassan et al. [39]. There can be a beneficial and detrimental effect of the application of heat, this occurs by inducing biochemical and nutritional variation in food composition. Changes in protein, fat, occurred as a result of the effect of tannin, lipid oxidation respectively [40]. Carbohydrate increase occurred as a result of Mallard reaction. The increase in ash and fibre content could have been as a result of the removal of moisture which tends to increase the concentration of nutrients [40]. These changes can be seen in Fig. 5.

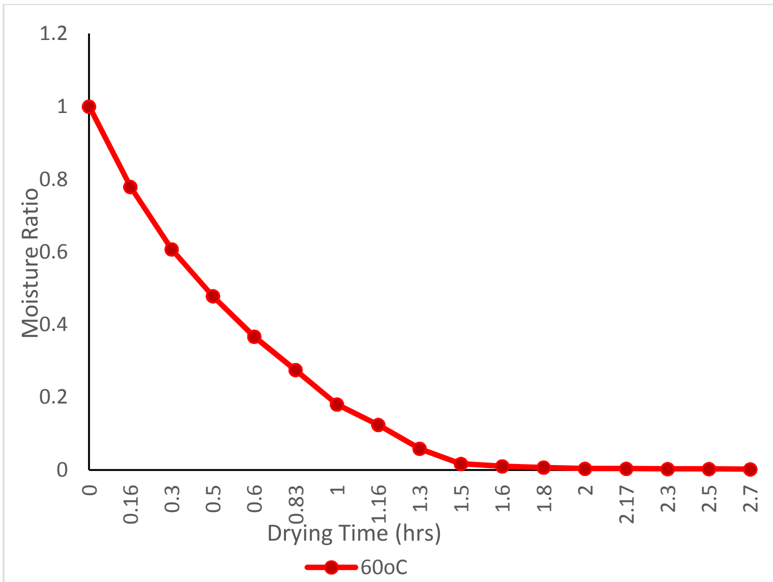


**Fig. 2. Influence of temperature on the soybean Curd residue based fish feed at 60°C**

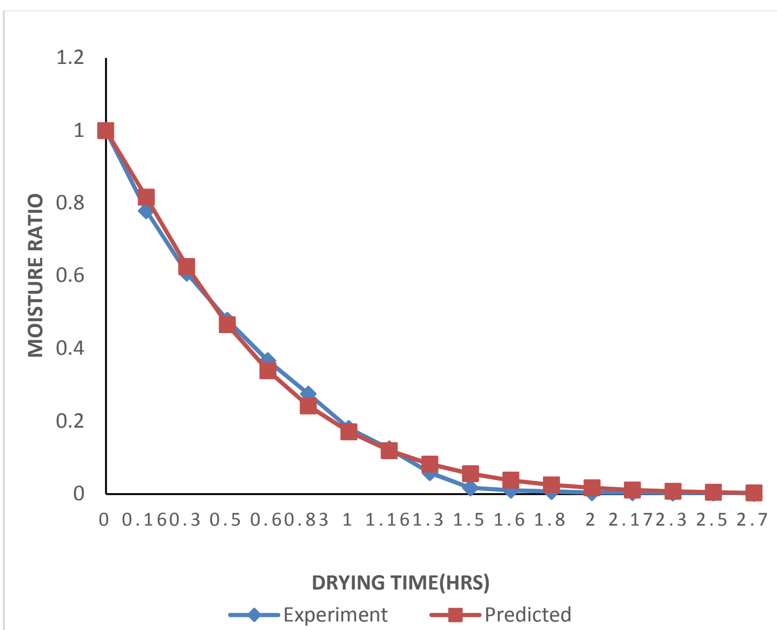


**Fig. 3. Relationship between experimental result and predicted result of the soybean Curd residue based fish feed**

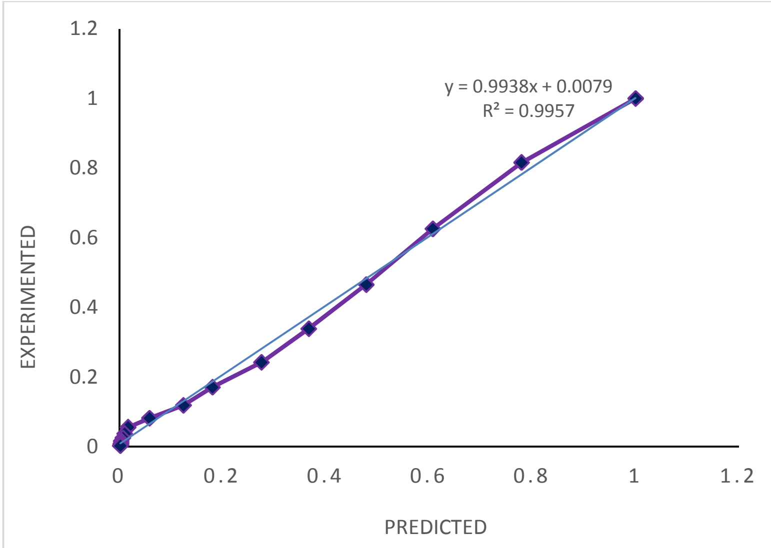


**Fig. 4. Linearity between the experimental and predicted model**

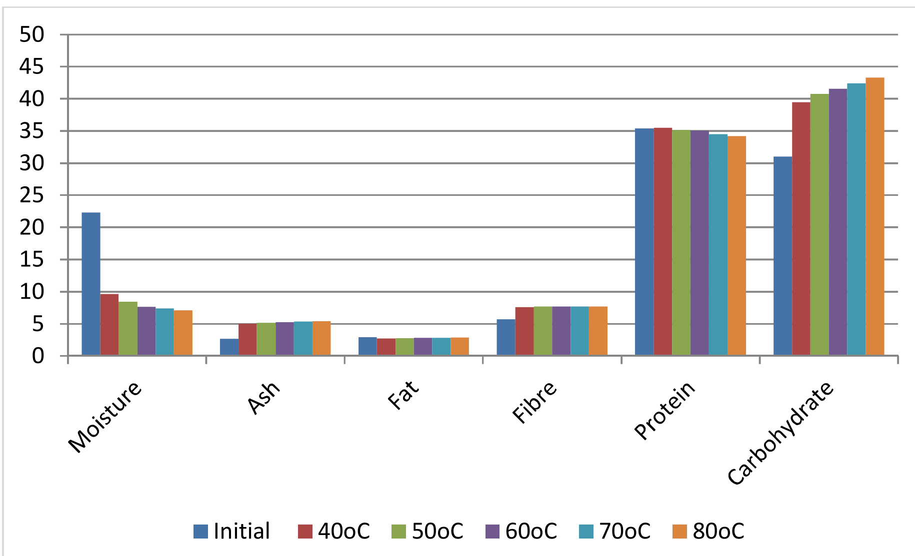


**Fig. 5. Chart showing variation in percentage of the proximate composition of the fish feed**

### 3.4 Evaluation of the Model

The best model describing the drying of SCR based fish feed was chosen from Table 3, which had the coefficient of determination ($R^2$) greater than 0.9. Table 3, shows the results of a non-linear regression analysis of the nine models. The coefficient of determination ($R^2$) values was consistently high in the range of 0.90126 to 0.9978 in the entire model. It shows the summary of statistical results obtained from mathematical models. The criteria for choosing the best model in describing the drying characteristics of SCR based fish feed using an oven and the best temperature was to choose the model with the highest coefficient of determination ($R^2$) values, the lowest chi square $\chi 2$ and lowest RMSE values. Temperatures at 40°C, 50°C, 60°C, 70°C, and 80°C were considered. Details for other constants are also available in Table 3. Of all the models tested, the Page model gave the highest value of $R^2$ and the lowest values of $\chi 2$ and RMSE at the best temperature of 60°C. Olurin et al. [41] got similar results for the drying of blanched field pumpkin slices.

**Table 3. Results of the non-linear regression analysis**

| Model | Constant | $R^2$ | SSE | RMSE | $X^2$ | Rank |
|---|---|---|---|---|---|---|
| Page | k=0.9959, n=1.096 | 0.990349 | 0.036496 | 0.191038 | 0.001587 | 1 |
| Logarithmic | k=1.1255,n=0.9979,c=0.0304 | 0.977823 | 0.062248 | 0.249496 | 0.002706 | 3 |
| Two term | ko=9.28E-01 ,k1=-0.0672,a=5.5172,b=0.926428 | 0.98127 | 0.012033 | 0.002168 | 0.002479 | 2 |
| Newton | k=0.7095 | 0.9357 | 0.019325 | 0.029014 | 0.001208 | 4 |
| Henderson & Pabis | k=1.0244, a=1.034605 | 0.93125 | 0.017477 | 0.132199 | 0.001092 | 5 |
| Wang & Singh | a=0.4315, b=0.0519 | 0.92916 | 0.012891 | 0.002384 | 0.001291 | 6 |
| Gokhan Gurlek | a=0.1197, b=0.005133, c=-0.00007 | 0.92476 | 0.023411 | 0.012224 | 0.001047 | 7 |
| Midilli Kucuk *et al.* | k=0.0418, a=0.9906,b=0.1319,c=0.6473 | 0.90187 | 0.031887 | 0.021113 | 0.002198 | 8 |
| Two term exponential | ko=0.0561,k1=1.2865,a=0.202,b=0.4866 | 0.90126 | 0.02129 | 0.05294 | 0.021023 | 9 |
| Page | k=1.554088, n=1.240104 | 0.993479 | 0.010712 | 0.025103 | 0.00063 | 1 |
| Logarithmic | k=0.5398,n=0.9436,c=0.0707 | 0.921062 | 1.957533 | 1.399119 | 0.122346 | 3 |
| Two term | ko=0.6036,k1=0.5886,a=0.1297,b=0.89 | 0.929887 | 1.333119 | 1.154608 | 0.08332 | 2 |
| Newton | k=0.438 | 0.90145 | 2.204267 | 0.360087 | 0.129663 | 4 |
| Henderson & Pabis | k=2.38E-01, a=0.0136 | 0.856019 | 2.610373 | 0.391856 | 0.163148 | 5 |
| Wang & Singh | a=0.2601, b=0.0162 | 0.759612 | 26.58833 | 5.156387 | 1.66177 | 8 |
| Gokhan Gurlek | a=0.1197, b=0.005133, c=-0.00007 | 0.821492 | 27.77499 | 5.270198 | 1.735937 | 6 |
| Midilli Kucuk *et al.* | k=0.0418, a=0.9906,b=-0.1319,c=0.6473 | 0.813041 | 5.135456 | 0.549623 | 0.320966 | 7 |
| Two term exponential | ko=0.8761,k1=1.2865,a=0.3571,b=0.4866 | 0.475139 | 16.88183 | 4.108751 | 1.055115 | 9 |
| Page | k=1.765536, n=1.207352 | 0.99781 | 0.007394 | 0.085988 | 0.000462 | 1 |
| Logarithmic | k=1.7244,n=1.034605,c= | 0.9912 | 0.032063 | 0.001092 | 0.001092 | 2 |
| Two term | ko=-0.4758, k1=0.0672 ,a=5.5172,b=0.2002 | 0.98127 | 0.012033 | 0.002168 | 0.002479 | 3 |
| Newton | k=0.7095 | 0.9357 | 0.019325 | 0.029014 | 0.001208 | 4 |
| Henderson & Pabis | k=1.0244, a=1.034605 | 0.93125 | 0.017477 | 0.132199 | 0.001092 | 5 |
| Wang & Singh | a=0.4315, b=0.0519 | 0.92916 | 0.012891 | 0.002384 | 0.001291 | 6 |
| Gokhan Gurlek | a=0.1197, b=0.005133, c=-0.00007 | 0.92476 | 0.023411 | 0.012224 | 0.001047 | 7 |
| Midilli Kucuk *et al.* | k=0.0418, a=0.9906,b=0.1319,c=0.6473 | 0.90187 | 0.031887 | 0.021113 | 0.002198 | 8 |
| Two term exponential | ko=0.0561,k1=1.2865,a=0.202,b=0.4866 | 0.90126 | 0.02129 | 0.05294 | 0.021023 | 9 |

| MODEL | CONSTANT | $R^2$ | SSE | RMSE | $X^2$ | Rank |
|---|---|---|---|---|---|---|
| Page | k=2.107089, n=1.247533 | 0.988684 | 0.034218 | 0.184981 | 0.002139 | 1 |
| Logarithmic | k=2.004126,n=1.040521,c=0 | 0.98514 | 0.049296 | 0.222027 | 0.003081 | 3 |
| Two term | ko=-0.0781,k1=1.1066 ,a=0.0205,b=1.066 | 0.987301 | 0.639065 | 0.193887 | 0.039942 | 2 |
| Newton | k=1.0063 | 0.980133 | 0.571976 | 0.756291 | 0.035749 | 5 |
| Henderson & Pabis | k=2.004195, a=1.040528 | 0.985137 | 0.049296 | 0.222027 | 0.003081 | 4 |
| Wang & Singh | a=0.4803, b=0.0519 | 0.738537 | 53.30053 | 7.300721 | 3.331283 | 7 |
| Gokhan Gurlek | a=0.1197, b=0.005133, c=--0.00007 | 0.766908 | 19.48379 | 1.070563 | 1.217737 | 6 |
| Midilli Kucuk *et al.* | k=0.0844, a=0.9843, b=0.0377,c=2.1488 | 0.537723 | 8.515666 | 0.707758 | 0.532229 | 8 |
| Two term exponential | ko=1.2206, k1=1.2865,a=0.6172,b=0.4866 | 0.392119 | 39.26151 | 6.2659 | 2.453844 | 9 |
| | | | | | | |
| Page | k=0.9959, n=1.096 | 0.47874 | 7.749046 | 0.675149 | 0.484315 | 3 |
| Logarithmic | k=1.1255,n=0.9979,c=0.0304 | 0.435811 | 7.59175 | 0.668262 | 0.474484 | 7 |
| Two term | ko=-0.0781,k1=1.1066, a=0.0205, b=1.066 | 0.438835 | 7.539814 | 0.665972 | 0.471238 | 6 |
| Newton | k=1.0063 | 0.451659 | 7.574901 | 0.66752 | 0.473431 | 4 |
| Henderson & Pabis | k=1.0248, a=1.0195 | 0.449299 | 7.605008 | 0.668845 | 0.475313 | 5 |
| Wang & Singh | a=0.4803, b=0.0519 | 0.490662 | 10.48719 | 0.785426 | 0.655449 | 1 |
| Gokhan Gurlek | a=0.1197, b=0.005133, c=-0.00007 | 0.485719 | 1.107204 | 0.255205 | 0.0692 | 2 |
| Midilli Kucuk et al. | k=0.0844, a=0.9843, b=0.0377, c=2.1488 | 0.490662 | 0.283104 | 0.129047 | 0.017694 | 1 |
| Two term exponential | ko=0.512033, k1=1.2865, a=0.592312, b=0.4866 | 0.001259 | 0.161157 | 0.097364 | 0.010072 | 8 |

*Moisture ratio (MR) = dependent variable, Drying constant (k) = independent variable*

### 3.5 Validation of the Model

Validation of the existing model was done through the comparison made between the observed moisture ratios to the moisture ratio predicted by the established model, which was the Page model. This can be seen in Fig. 3 where a good fit can be observed from the graph. Ertekin and Yaldiz, Kingsley et al., Goyal et al. [42,43,44] obtained similar results, in the drying organically eggplant, produced tomato and plum. From Fig. 4, it can be seen that a high linearity exists between the predicted model and the experimented model with a coefficient of determination $R^2$ which is equal to 0.9957.

## 4. CONCLUSION

In this study, the drying behaviour of SCR based fish feed was investigated in an oven with convection mode of drying at temperatures of 40°C, 50°C, 60°C, 70°C, 80°C. Based on the result of the study carried out, the following submissions are made:

1. The drying air temperature is an important factor in drying of SCR based fish feed, there was shorter drying time at higher drying temperatures and there was no constant rate period in most of the dried SCR based fish feed, the drying took place in the falling rate period;
2. Page model was best in accurately predicting the drying of SCR based fish feed samples dried at 60°C in a convective oven, this is because the highest coefficient of determination ($R^2$) was gotten at 60°C and the page model had the highest coefficient of determination when drying at 60°C temperature with a value of 0.99781 and;
3. The proximate composition of the SCR based fish feed was within acceptable limits after drying at all the air temperatures. However, drying at 60°C gave the best fish feed based on the proximate composition.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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