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RESEARCH ARTICLE

OPTIMIZATION OF A CLAY-SLATE FLUIDIZED BED DRYER FOR PRODUCTION OF FISH FEED

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ABSTRACT

For feed producers who suffer from high intolerance to production costs, the only way to cope with the condition is to avoid devices that drive up costs. Extruded feed processed from a clay-slate dryer through a fluidized bed could be used to make fish feed. The aim of the study was optimise the process conditions on the clay-slate fluidized bed dryer operating at a commercial production of fish feed using the response surface methodology. The fish feed composition were processed at bed height (50-200 mm), drying air temperature (60–120°C), airflow velocity (0.66-0.70 m/s), drying time (10–90 min) and extrudates size (4–8 mm). Product quality parameters such as moisture ratio and dryer efficiency were determined and analyzed. Second-order polynomial equations, containing all the process variables, were used to measured process. Moisture ratio was influenced mostly by linear relationship temperature and drying time. The temperature and the quadratic temperature conditions significantly affected the efficiency of the dryer. For the fluidized bed drying of extruded fish feed, optimal conditions were set for the bed height of 185.76 mm, a temperature of 97.2°C, an air flow rate of 0.67, a drying time of 65.36 min and an extrudate size of 7.40 mm recommended. At these conditions the moisture ratio and efficiency were 0.86 and 74.39, respectively. The influence of the various components of the fluidized bed dryer on the drying rate must be better understood so that control systems can be developed to take full advantage of this technology.

KEYWORDS

Fluidized bed drying, Fish feed, Extruder, Process optimization, Response surface, polynomial equations.

1. INTRODUCTION

Fish feed refers to protein based feed products with proper amount of amino acids, fatty acids, vitamins, minerals and/or other ingredients, which are only processed for fish energy-yielding macronutrients (protein, lipid and carbohydrate) by physical production method (Banrie, 2013). In order to facilitate storage and delivery, fish feed is often stored in pellet form. Since fish fed in aquaculture are often completely reliant on the nutrients in the feed to provide all the nutrients required for healthy growth and development. Manufacturing of pelletized or extruded fish feed is one of the most difficult, regulated and high risk branches of feed manufacturing requiring great care and attention to detail at all stages, among which drying is one of the most important ones.

Various moisture removal devices have been used to dry agricultural products, including pelletized fish feed since ancient times. This equipment includes the use of heat to evaporate the water present in the feed, as well as the removal of steam from the feed surface. The use of hot air flowing through food is the most common way of transferring heat to a drying material, because it is mainly a convective process (Cruz et al., 2015). The effectiveness of a drying process depends on different factors: method of heat transfer, continuity or discontinuity of the process, direction of the heating fluids with respect to the product (pressure atmospheric, low, deep vacuum). Drying process can be performed by using different kinds of equipment such as: air cabinet, belt drier, tunnel drier, spray dryer, drum dryer, foam dryer, freeze-dryer, oven (Severini et al., 2005).

However, the major disadvantage of some drying process of foods is the long drying time required during the falling rate period which increase production cost. Fluidized bed drying is a drying process in which there is an intense heat and mass transfer between particles present in the liquid state and the air flowing through the bed. The drying method is widely used in various industries (Mujumdar, 1995). Since, this technology in drying application is characterized with large contact surface area between solids and gas, high thermal inertia of solids, good degree of solids mixing, and rapid transfer of heat and moisture between solids and gas that shortens drying time considerably without damaging heat sensitive materials (Freitas and Freire, 2001; Malafronte et al., 2015).

However, a significant challenge of fluidized bed drying is flow of material, which greatly reduces productivity and product quality. The major factors influencing drying rate of feed material are heat and mass transfer between air and solids because it affects the efficiency and reduces the

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drying time of the process making the process exceptional (Maheswari et al., 2015). With increasing particles size and high density, the mass flow of the material became even slower and non-uniform. Therefore, some researcher suggested that materials with density between 1.4 and 4 g/cm^3, incline a lot at the commencement of fluidization; nevertheless, it is good for high flow rates (Hrdlicka et al., 2016). Increase in air velocity, results in increase in the pressure-drop across the particle layer until it corresponds to the weight of the particles per area of the bed.

Drying conditions including inlet air temperature, outlet air temperature, drying air flow rate and pressure, as well as structures of drying and heating chambers have also been studied to improve product functional properties (Erbay et al., 2015; Anjali and Satya, 2015; Francia et al., 2014; Wawrzyniak et al., 2012). A group researchers also explored the particles must have a relatively small range of particle sizes to minimize entrainment and to maximize the uniformity of moisture content (Hrdlicka et al., 2016). A group researchers optimized drying conditions of maca tuber in a pilot spray drier using response methodology and found that under optimum operating conditions (air inlet temperature was 65°C, air flow was 150 m^3/h and material particle size was 3 mm), desirability functions with maximum glucosinolates content retained at a value 3.192mg/g, as well as the better appearance such as saturation value, rehydration ratio and good sensory quality were achieved (Tu et al., 2014).

Amira and Ahlem investigated the effect of operating parameters of sucrose fluid bed drying on powder quality and on drying time and found that gas flow and sugar particle size had significant effects (in absolute values) on the quality of the sugar dried (Amira and Ahlem, 2017). The optimal drying parameters obtained in this experiment were lower values temperature of 40°C, compressed air flow rate of 3.5 N/m^3, pressure of 2.5 bar and at higher level of particle size of 500 granulom. A studied the effect of different drying conditions (inlet air temperature, feed flow rate and total solids) on potato dehydrated in microwave assisted fluidized bed drying system and the optimum conditions obtained by the response surface methodology for browning index were inlet air velocity 20 m/s and drying temperature 50°C with desirability 1.00 (Akhtar et al., 2015). According to previous researches, drying conditions had significant influences on the drying rate and quality of final products. For commercial animal feed manufacturers who suffer from high intolerance to production costs, the only way to cope with the condition is to avoid devices that drive up costs. Extruded feed processed from a clay-slate dryer through a fluidized bed could be used to make fish feed.The objectives of this study were to investigate the effect of drying conditions on the efficiency of the clay slated fluidizied dryer using experimental data of response surface experiment.

2. MATERIALS AND METHODS

2.1 Design of the clay slate screen

The clay slate consists of clay soil (90%) and cement powder (10%), which is reinforced with acid-resistant stainless steel and is used to absorb heat from the heating elements and to dissipate the heat (Figure 1). The simple design consists of a work screen inclined at 30°, built under the one-third length of the screen. The slate ensures efficient hot air flow and further improves the air direction by reducing the backflow on the blower impeller.

2.2 Sample preparation

Powdered formulated samples, with protein, fat fibre and ash content of 36.8%, 8.8%, 4.7% and 12.6%, respectively, were purchased from a local market in Ibadan, Nigeria. The blend samples was extruded at different die size (4, 6 and 8 mm), at screw speed (401 rpm) and barrel temperature (80°C).

2.3 Sample drying

A commercial, fluidized bed dryer (FEDOX-645FD), which had a holding capacity of 200 kg, was used in this study. The dryer consists of four sub-units comprising of the heating, clay-slate block, drying and collecting unit of the fluidized bed dryer (Figure 1). The blower speed was alternated from between 1200, 1300, 1400 rpm by using the variable voltammeter across drying runs. Airflow velocity on the shelf measured by an anemometer (model 24-6111, Kanomax, Inc., Japan) were 0.67, 0.68, 0.7 m/s respect to blower speed variations. The temperature of the drying air was varied by the thermocouple placed inside the heating chamber to meet the predetermined temperatures (60, 80, 100, 120°C).

Relative humidity (RH) inside the drier was maintained at 40%. The extruded feed was loaded into the fluidized bed dryer at varied thin layer (0.05, 0.10, 0.15, 0.20 m). Five samples each were collected between time intervals of 10–90 min were used to determine the initial moisture content in an air oven at 103°C for 25 h. To complete drying and attain equilibrium, the test was terminated when the change of sample mass was less than 0.01 g. After drying, moisture content of the sample was determined by the same procedure used for measurement of initial moisture content.

2.4 Moisture content analysis

For moisture content analysis, about 10 g of feed was weighed by an electronic balance of ±0.001 g accuracy (PS-20, frtcraft, Germany). The samples were put into plastic bags and sealed for transport to the laboratory. Gravimetric method was conducted according to AOAC methods using a ventilated oven (ESP-400 Series, BLUE M, USA) at 130°C for 16 h (Chen, 2003). Moisture content (MC, wet basis) was computed as:

$$MC = \frac{M_i - M_{DM}}{M_I} . 100\% \qquad (1)$$

where, M_i is the initial mass of the sample before oven-drying, g; M_{DM} is the mass of dry matter, g.

2.5 Moisture removed

The moisture content removed from the fish feed extrudates is then calculated after the initial and final weight of the extrudates sample has been gotten or determined. The ease of migration depends on the porosity of the substance and the surface area available. This is calculated by using Eq. (2) (Buchinger and Weiss, 2001)

$$MC_{rm} = W_i - W_f \qquad (2)$$

Where MC_{rm} is Moisture content removed, W_i is initial weight, and W_f is final weight

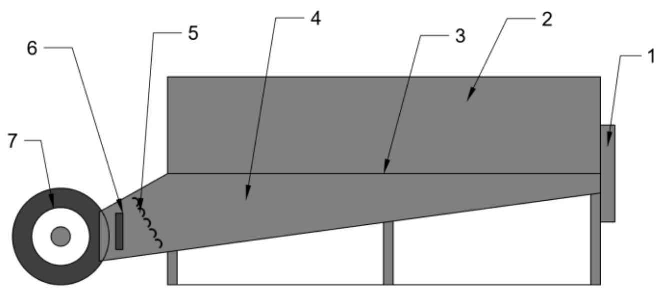


Figure 1: Description of the fluidized bed dryer system.

1-Exit opening, 2-Chamber cover, 3-Drying bed, 4-Heating chamber, 5-Clay slate, 6-Heater, 7-Blower.

2.6 Mathematical modeling of drying curves

The Fick's equation for solid materials with thick geometry was applied to the experimental data during the extrudates drying (Eq. 3). The assumption for the thick form of extrudates samples was that the moisture was initially evenly distributed, with negligible external resistance, temperature gradients and shrinkage during drying throughout the bulk of a sample. The surface moisture content of the sample immediately equilibrates with the state of the surrounding air. The resistance to mass transfer at the surface is negligible compared to the internal resistance of the sample. The equation is as follows (Tunde-Akintunde, 2011):

$$MR = \left[\frac{M_t - M_e}{M_i - M_e}\right] = Aexp(-Kt) \quad (3)$$

Where MR is the dimensionless moisture ratio, W_t, the average moisture content at time t, W_i, the initial moisture content, W_e, the equilibrium moisture content respectively, on dry weight basis, K is the drying constant (s^{-1}), and A is a constant. It is believed that the rate of moisture removal is proportional to the difference between the products to be dried and their equilibrium moisture content, and the total resistance to moisture transfer is on the outer surface of the products. It is expressed mathematically as:

$$\frac{dM}{dt} = -k_0(M_t - M_e) \quad (4)$$

where k_o is the drying constant (s^{-1}). The solution of this equation is:

From Saravacos and Charm, the drying constant (K_o) in Eq. 4 is related to the diffusion coefficient by (Saravacos and Charm, 1962):

$$K_o = \left[\frac{\pi^2 D}{4L^2}\right] \quad (5)$$

where D is the diffusivity (m^2/s), and L is the half-thickness of the sample (m).

This semi-empirical model is generally used to express the relationships between the drying constant and the characteristic dimension of the drying sample or the drying temperature, while at the same time satisfactorily describing the drying behavior of the thin film (Madamba et al., 1996; Sarsavadia et al., 1999). Thus, the moisture ratio in Eq. (3) according to Evin to Eq. (6) has been simplified (Evin, 2012).

$$MR = W_t / W_i \quad (6)$$

The drying data were graphically analyzed in terms of reduction in moisture content and moisture ratio.

2.7 Efficiency of drying

The psychometric chart was used to calculate the efficiency of the fluidized bed dryer based on the resulted parameters determined. The drying efficiency was used for evaluation of dryer designs or comparison between dryers, since it is a measurement of the degree of utilization of the sensible heat in the drying air (Foster, 1973).

The Eq. (7) is used to calculate the efficiency of the dryer as stated by ASAE (Rev. Aug. 2005)

$$\eta = \frac{m \times M_{fg}}{h_{fg}} \times 100\% \quad (7)$$

where η is drying efficiency (%), ṁ is mass of air flow (m^3/s) = Specific volume of input air × air flow, M_{fg} is mass of water to be evaporated, g, h_{fg} is latent heat of evaporation of water kJ/Kg of H_2O, Specific volume of input air (v) is 1.01 m^3/kg and air flow = 0.7 kg/s.

2.8 Experimental design and Statistical optimization of factors

The design required 38 independent experiments. Machine efficiency was measured in triplicate. The results which were obtained during tests were analyzed with the use of the response surface experiment designed using I-optimal design module in Design Expert software (Version 11.0, Stat-Ease, Inc., Minneapolis, USA) to investigate the effect of machine drying conditions. In I-optimal design module, the numeric factor, block and running times were set as 5, 1 and 38, respectively. The range of five factors were based on the results of single factor experiment. This was used to reveal the effect of operating conditions on the dryer performance. The experimental run for the fluidized bed drying operation is displayed in Table 1.

Table 1: Experimental Run

Run	Bed Height (mm)	Temp. (°C)	Airflow velocity (m/s)	Drying Time (min)	Extrudates size (mm)
1	200	60	0.66	90	8
2	50	60	0.68	70	4
3	50	100	0.70	90	4
4	50	60	0.68	90	8
5	50	60	0.70	10	8
6	150	60	0.68	90	6
7	150	80	0.66	90	4
8	150	60	0.68	90	6
9	150	60	0.68	50	8
10	150	80	0.70	70	6
11	50	120	0.68	10	4
12	50	120	0.68	50	6
13	150	100	0.68	90	8
14	200	120	0.66	50	6
15	150	80	0.70	70	6
16	200	60	0.70	90	8
17	100	60	0.70	30	4
18	200	60	0.66	10	4
19	50	60	0.70	70	6
20	50	120	0.66	90	8
21	200	80	0.68	10	6
22	150	120	0.70	30	8
23	100	120	0.66	10	8
24	200	80	0.68	70	4
25	100	120	0.68	10	4
26	50	80	0.66	30	6
27	50	80	0.66	30	6
28	150	60	0.68	50	8
29	150	100	0.68	90	8
30	200	60	0.70	10	4
31	100	120	0.70	70	6
32	200	120	0.70	10	4
33	100	60	0.68	30	6
34	200	100	0.66	10	8
35	200	120	0.70	90	4
36	50	100	0.70	30	6
37	200	60	0.66	10	4
38	100	120	0.66	90	4

Based on the experiments design, the optimized drying condition was obtained on which the highest efficiency could be achieved. Under this optimized drying condition, samples with different sizes were dried and the influences of each on machine efficiency were analyzed. The response (efficiency) for various experimental conditions was related to coded variables (x_{i}, I = 1, 2, 3 and 4) by a second-degree polynomial (Eq. 8) as given below:

$$y = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 + b_5x_5 + b_{12}x_1x_2 + b_{13}x_1x_3 + b_{14}x_1x_4 + b_{23}x_2x_3 + b_{24}x_2x_4 + b_{34}x_3x_4 + b_{11}x_{12} + b_{22}x_{22} + b_{33}x_{32} + b_{44}x_{42} + \quad (8)$$

Where, x_1, x_2, x_3, x_4 and x_5 are the coded values of bed height (mm), temperature (°C), airflow velocity (ms^{-1}), drying time (min) and extrudates size (mm) respectively. The coefficients of the polynomial were represented by b_0 (constant); b_1,b_2,b_3,b_4,b_5 (linear effects); $b_{12},b_{13},b_{14},b_{23},b_{24},b_{34}$ (interaction effects); $b_{11},b_{22},b_{33},b_{44},b_{55}$ (quadratic effects); and _ (random errors). The quality of the polynomial model is expressed using the determination coefficient, namely R^2 and Adj-R^2.

Statistical significance was verified using the appropriate precision factor and F test (Rauf et al., 2008).

3. Result and Discussion

3.1 Optimization of Fluidized bed dryer using the RSM approach

The experimental result of testing a fluid bed dryer in Table 2, which shows the effect of extruded fish feed on the moisture ratio. The lowest result was obtained with a bed height of 100 mm when temperature, airflow velocity, time and extrudates size were 120°C, 0.66 ms^{-1}, 90 minutes and 4 mm, respectively, with a moisture content of 0.646 g. The highest moisture ratio of 0.986 was established at 50 mm bed height, temperature (60°C), airflow velocity (0.7 ms^{-1}), time (10 min) and size of extruded fish (8 mm). It can be seen that the high selected values for all operational factors led to a high moisture ratio value. Table 2 shows that low productivity was observed at 38%, while high machine performance was observed at 75%. It was observed that the operating temperature increased with increasing machine performance.

Table 2: Experimental result

Run	Moisture Ratio	Efficiency (%)
1	0.78	38
2	0.89	38
3	0.75	75
4	0.80	38
5	0.99	38
6	0.85	38
7	0.73	66
8	0.85	38
9	0.89	38
10	0.89	66
11	0.98	57.8
12	0.75	57.8
13	0.77	75
14	0.81	57.8
15	0.89	66
16	0.77	38
17	0.89	38
18	0.88	38
19	0.65	38
20	0.82	57.8
21	0.98	66
22	0.95	57.8
23	0.98	57.8
24	0.89	66
25	0.92	57.8
26	0.94	66
27	0.95	66
28	0.90	38
29	0.77	75
30	0.97	38
31	0.72	57.8
32	0.86	57.8
33	0.94	38
34	0.98	75
35	0.74	57.8
36	0.89	75
37	0.88	38
38	0.65	57.8

Table 3 summarizes the results of each dependent variable with their coefficients of determination (R^2). The statistical analysis indicates that the proposed model was adequate, possessing significant lack of fit and with very satisfactory values of the R^2 for all the responses.

Table 3: Model analysis data for the moisture ratio response variables for the fluidized bed dryer.

Source	Sum of square	Df	Mean square	F value	P value Prob>F
Model	0.2743	20	0.0137	4.19	0.0022
x_1	0.0000	1	0.0000	0.0036	0.9529
x_2	0.0196	1	0.0196	6.00	0.0255
x_3	0.0002	1	0.0002	0.0529	0.8209
x_4	0.2154	1	0.2154	65.82	< 0.0001
x_5	0.0086	1	0.0086	2.64	0.1226
$x_1 x_2$	0.0006	1	0.0006	0.1717	0.6838
$x_1 x_3$	0.0139	1	0.0139	4.24	0.0551
$x_1 x_4$	0.0051	1	0.0051	1.57	0.2271
$x_1 x_5$	0.0000	1	0.0000	0.0132	0.9098
$x_2 x_3$	0.0004	1	0.0004	0.1313	0.7216
$x_2 x_4$	0.0022	1	0.0022	0.6744	0.4229
$x_2 x_5$	0.0073	1	0.0073	2.24	0.1530
$x_3 x_4$	0.0007	1	0.0007	0.2275	0.6395
$x_3 x_5$	0.0032	1	0.0032	0.9878	0.3342
$x_4 x_5$	0.0063	1	0.0063	1.92	0.1836
x_1^2	0.0001	1	0.0001	0.0296	0.8655
x_2^2	0.0060	1	0.0060	1.84	0.1921
x_3^2	0.0095	1	0.0095	2.89	0.1072
x_4^2	0.0008	1	0.0008	0.2361	0.6333
x_5^2	0.0005	1	0.0005	0.1499	0.7034
Lack of fit	0.0556	11	0.0051	444.82	< 0.0001
R^2	0.8313				

The Model F-value of 4.19 implies the model is significant ($p<0.05$). There is only a 0.01% chance that an F-value this large could occur due to noise. P-values less than 0.05 indicate model terms are significant ($p<0.05$). The Lack of Fit F-value of 444.82 implies the Lack of Fit is significant ($p<0.05$). There is only a 0.26% chance that a Lack of Fit F-value this large could occur due to noise. R^2 and adjusted R^2 values of the model are 0.8313 and 0.6329, respectively. A negative Predicted R^2 (-0.1523) implies that the overall mean may be a better predictor of your response than the current model. Adequate Precision measures the signal to noise ratio. A ratio greater than 4 is desirable (Montgomery, 2001). Therefore adequate precision ratio of 8.15 indicates a good signal. This model can be used to navigate the design space.

Analysis of variance for quadratic model (Table 3) showed that the moisture ratio was significantly based on the linear conditions of temperature [(T, $p<0.05$)] and drying time [(DT, $p<0.05$)]. By neglecting the non significant terms in the predictive models in Eq. 1 and with the coded values of independent variables, the following equation (Eq. 2) describes the effect of significant process variables on fluidized bed dryer for the production of fish feed.

$$Y_{MR} = 0.892 - 0.03x_2 - 0.1x_4 - 0.01x_1x_2 + 0.03x_1x_3 + 0.02x_1x_4 - 0.01x_2x_3 - 0.02 x_2x_4 - 0.02 x_2x_5 \quad (9)$$

From the regression equation presented in Eq. (9), the negative coefficient of temperature (x_2) and drying time (x_4), indicated a decrease in the fluidized bed moisture ratio as the temperature and drying time level increased. The equation indicate a high value of coefficient and significant level ($p<0.05$) from drying time considered in the study. The perturbation chart in Fig. 2 shows how the function of a given factor reacted as a level, this factor changes when other factors are set at the optimal level (Oh et al., 1995). It shows that decrease in drying time, increase the moisture ratio from 0.89 to 1.0 significantly; a slight quadratic rise in moisture ratio was established when the bed height was rised. Rise in the extrudes size increase the moisture ratio to 0.92. In addition, increase in airflow velocity decrease the moisture ratio to 0.84 and increase in temperature also indicated a quadratic decrease (0.80).

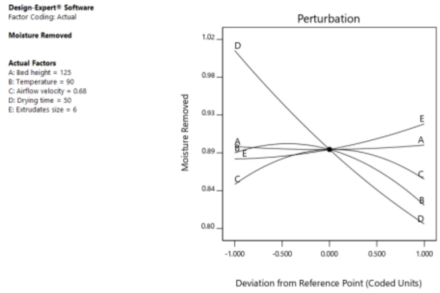
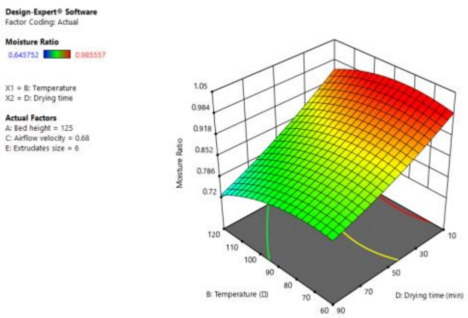
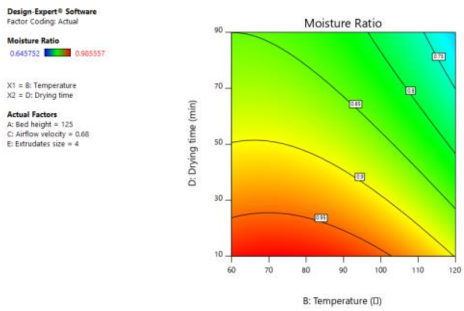


Figure 2: A perturbation plan for moisture ratio

The 3D surface plot in Figure 3 shows the effect of temperature and drying time under constant bed height (125mm), airflow velocity (0.68 m/s) and extrudates size (4mm) on moisture ratio. An optimal temperature of 60^{o}C and drying time of 10min was observed at which the extrudates start drying upon getting to the temperature (90^{o}C), and thus the maximum moisture ratio was obtained. Increase in trend may be due to the high moisture content in the extrudate capillary structure with low in the exhaust air temperature which was an indication of extremely low airflow velocity and poor fluidization in the fluid bed. Similar findings were observed in pharmaceutical industry for drying granulating powders and bambara groundnut (Badday et al., 2014; Gao et al., 2000). With the increase of temperature above 119^{o}C at 68 min drying time, less efficient moisture ratio was established from drying chamber, so that the final product was dried enough before entering the collection bag, leading to high values of moisture removal. In addition, as the increased from 103.9 to 120^{o}C at all levels of drying time, more extrudates were moved toward the entrance to the collection chamber and the end products were sufficiently dried as they entered the collection bag. The contour diagram shows that the moisture ratio is greatest when the bed height is in the range of 122 to 200 mm, the air flow rate increases slightly and the moisture ratio increases with increasing air flow rate.



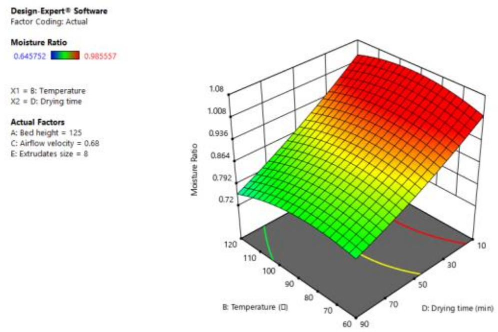
a. Plot of response surface



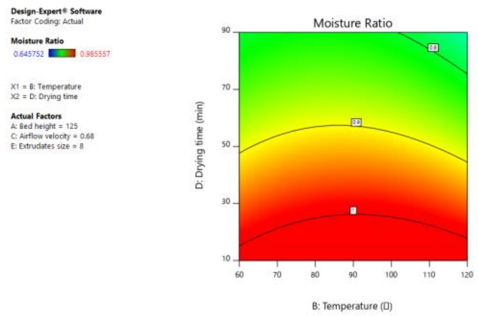
b. Plot of contour

Figure 3: 3-D representation of the interaction between temperatue and drying time at 4mm extrudates size on moisture ratio.

With the increase of extrudates size (8mm), higher drying time could be applied for decreased optimal moisture ratio rate meanwhile obtaining higher production efficiency (Figure 4). Increase in drying time resulted in decrease in moisture ratio. The fish feed extrudates could be dried in in a longer time. From thi study, 0.68 m/sec was still adopted in response surface experiment even though the moisture ratio was pretty high at given drying conditions. The result of the experiment as shown that a high value of moisture ratio was established in a wider coverage at below drying time less than 30min with all levels of temperature. Similar findings were observed in rice paddy and bambara groundnut seed (Caicedo et al., 2002; Badday et al., 2014). The contour chart shows that the moisture ratio is the optimum value of 1.0 when the drying time is in the region of 10-30 min. the contour are ellipses, and decrease with increase drying time. This implies that a small change in drying time could make a significant change in the drying pattern of the extrudates.



a. Plot of response surface



b. Plot of contour

Figure 4: 3-D representation of the interaction between temperatue and drying time at 6mm extrudates size on moisture ratio.

3.2 Interaction between temperatue and drying time in determining the efficiency

The experimental conditions and the corresponding machine efficiency were shown in Table 2 and the analysis of variance was shown in Table 4. The quadratic model F value of 1165.69 implies the model is significant. It was observed from Table 4 and Eq. 10 that F values for x_1, x_3, x_4 and x_5 are less than 3.66 and p values greater than 0.0726, indicating no direct significance on machine efficiency. F-values for temperature (x_2) ; interaction of bed height and airflow velocity, square terms of temperature (x_2^2) were 7074.80, 9.02 and 10398.73 and p values less than 0.0001, 0.008 and less than 0.0001 respectively ($P < 0.05$), indicating that both terms are significant. Considering these criteria, following response model was selected for representing the variation of lateral expansion for further analysis. These insignificant terms were then deleted from the quadratic model to gain a modified quadratic model, which can describe the relationship between efficiency and influencing factors more simply. The obtained modified quadratic model was shown in Eq. (10) where Y_{eff} represented efficiency in response surface experiment.

$$Y_{eff} = 72.71 - 0.069x_1 + 0.15x_2 + 0.23x_3 + 0.06x_4 + 0.23x_5 - 0.13x_1x_2 - 0.46x_1x_3 - 0.05x_1x_4 + +0.33x_1x_5 - 25.14\, x_2{}^2 \quad (10)$$

It is evident from Eq. 10 that coefficients of x_2, x_3, x_4 and x_5 are positive, but that of x_1 is negative. Therefore, increase in temperature, airflow velocity, drying time and extrudate size may increase the machine drying efficiency, whereas increase in bed height may reduce the machine performance. Since coefficient of x_2^2 is negative, a maximum efficiency will occur in the range of temperature selected for the study.

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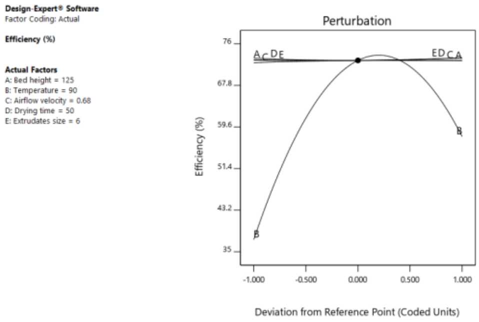

Figure 5: A perturbation plan for fluidizied bed efficiency

The pertubation chart shows how the function of a given factor reacted as a level, this factor changes when other factors are set at the optimal level (Oh et al., 1995). The steep slope or curve in the graphs indicates the responsiveness of the response rate (Anderson and Whitcomb, 2005). A graph presenting the result of individual factor on machine's efficiency is shown in Figure 5 The combination of are the main factors influencing machine efficiency. Figure 5 shows that efficiency decreases from 72.98 to 57.78% because the factor (temperature) increases from the zero point to the right. On the other hand, the machine's efficiency was almost constant as the other factors increases. It was observed that temperature is highly significant for all runs. This may be due to the design of clay slate arrangement towards the drying of extrudates during the experimental test.

The effect of varying the temperature and drying time on dryer efficiency while bed heighr, airflow veocity and extrudates size are fixed at 125mm, 0.68 m/s and 4 mm, respectively. From Figure 6, it is evident that the efficiency increased with the increase in temperature until at a temperature above 108°C when the efficiency begin to fall, which may be due to increase airflow with the decrease in moisture content. A high optimum efficiency (70%) was experienced at different operative condition of the fluidized bed dryer. However, no significant change was observed with the change in drying time in the drying processess. This was due to the limiting factor caused by bulk density of extrudates, which was significant at the high bed height and hence reduced the efficiency percentage of the fluidized bed dryer.

Table 4: Model analysis data for the efficiency response variables for the fluidized bed dryer.

Source	Sum of square	df	Mean square	F value	P value Prob>F
Model	7204.36	20	360.22	1165.69	< 0.0001
x_1	0.0884	1	0.0884	0.2859	0.5998
x_2	2186.24	1	2186.24	7074.80	< 0.0001
x_3	1.01	1	1.01	3.27	0.0884
x_4	0.0709	1	0.0709	0.2294	0.6381
x_5	1.13	1	1.13	3.66	0.0726
$x_1 x_2$	0.1861	1	0.1861	0.6023	0.4484
$x_1 x_3$	2.79	1	2.79	9.02	0.0080
$x_1 x_4$	0.0239	1	0.0239	0.0774	0.7842
$x_1 x_5$	1.05	1	1.05	3.40	0.0828
$x_2 x_3$	0.0273	1	0.0273	0.0883	0.7700
$x_2 x_4$	0.8553	1	0.8553	2.77	0.1145
$x_2 x_5$	0.2199	1	0.2199	0.7117	0.4106
$x_3 x_4$	0.0858	1	0.0858	0.2776	0.6051
$x_3 x_5$	0.4515	1	0.4515	1.46	0.2433
$x_4 x_5$	0.3346	1	0.3346	1.08	0.3126
x_1^2	0.0043	1	0.0043	0.0138	0.9080
x_2^2	3213.39	1	3213.39	10398.73	< 0.0001
x_3^2	0.3488	1	0.3488	1.13	0.3029
x_4^2	0.9235	1	0.9235	2.99	0.1020
x_5^2	0.3607	1	0.3607	1.17	0.2951
Lack of fit	6.29	14	0.4492		
R^2	0.9899				

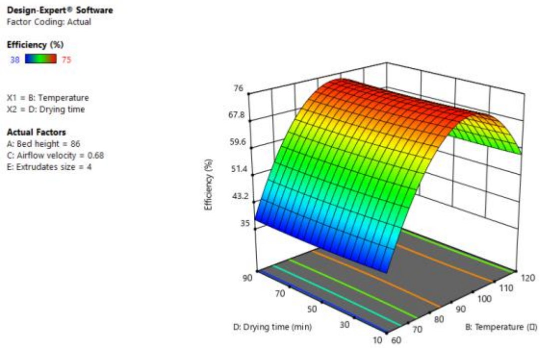

Figure 6. 3-D representation of the interaction between temperature and drying time at 4mm extrudates size on dryer efficiency

3.3 Optimization by Response Surface Methodology and Model Validation

The next step in the present study was to determine the effects of five independent variables (bed height, temperature, airflow velocity, drying time and extrudates size) shown in Table 6, alongwith the mean predicted values for bed dryer. For this purpose, the response surface methodology, using I-optimal design, was adopted for finding optimal conditions. Experiment was then carried out under the recommended conditions and resulting response was compared to the predicted values. On the optimized drying condition for our experimental facilities bed height of 185.76 mm, temperature of 97.2°C, airflow velocity of 0.67 m/s, drying time of 65.36 min and extrudates size of 7.40 mm. Comparison between RSM and validation methods was then assessed in optimum conditions point for drying machine at 1:1 scale. The reaction of experiment gave the reasonable percentage of moisture ratio and efficiency of 0.86% and 74.39%, respectively. This result confirmed the validity of the model, and the experimental value was determined to be quite close to the predicted value, implying that empirical model derived from RSM experimental design can be used to adequately describe the relationship between the factors and responses.

Table 6: Optimum conditions derived by drying system

Method	Bed height, mm	Temp., °C	Airflow velocity, m/s	Drying time, min.	Extrudates size, mm	Moisture ratio	Efficiency,%
Predicted	185.76	97.2	0.67	65.36	7.40	0.86	74.39
Experimental	187.40	93.3	0.67	64.85	7.03	0.88	73.42

4. Conclusion

The drying rate phenomenon during fluid bed drying process can be reduced by optimizing drying condition. Moisture removal of the fish feed could be improved by reducing temperature, interaction term of temperature-airflow velocity and drying time-exdrudates size. Optimum conditions of facilities bed height of 185.76 mm, temperature of 97.2°C, airflow velocity of 0.67, drying time of 65.36 and extrudates size of 7.4 mm were recommended for the fluidized bed drying of extruded fish feed. For the efficiency, temperature and airflow rate are significant model terms with quadratic terms. The method to improve the machine effeciency by optimizing drying condition can also be applied in larger scale fish feed drying.

Authors' Contributions

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Oduntan, O. B and Oluwayemi, B. J. The first draft of the manuscript was written by

Oduntan, O. B and all authors commented on previous version of the manuscript. All authors read and approved the final.

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