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Original Research Article

Optimisation of loading capacity of smoking kiln on drying characteristics of Catfish (*Clarias gariepinus*)

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Abstract

Fish smoking is widely used in the fish processing industry, especially in the post-harvest catfish product due to its simple operating technique. The objective of this study was to optimise the tray loading capacity of a smoking kiln for catfish. A mixture design was employed to investigate the effects of varied fish size (0.25, 0.30 and 0.35 kg) component tray loading on the loading capacity, drying rate and moisture ratio during smoking process. The results showed that the loading capacity of the kiln was between 190 and 198 pieces of fish at minimum and maximum 50 and 52 kg. High moisture ratio was observed at equal size combination at low drying rate. The catfish weight mixtures of 0.25, 0.30 and 0.35 kg used to evaluate the kiln load capacity optimization were significant ($P < 0.05$). The smoking kiln worked optimally at catfish size (50, 50 and 0%) with maximum desirability of 0.63 resulted in weight of fish loaded of 51.30 kg, moisture ratio of 0.21 and drying rate of 0.5 kg^{-1} h. This study brings new knowledge about the loading capacity and confirms that the smoking kiln is an acceptable technology for processing fish.

Keywords: drying rate; mixture; moisture ratio; optimum; processing; size combination; tray.

INTRODUCTION

Fresh fish meat contains up to 80% of water and is considered a perishable material, resulting in an extremely short shelf life when not properly processed (Bala and Mondol 2001). However, fish is perishable as it is a favourable medium for *post-mortem* bacterial growth (Ojutiku et al., 2009; Aliya et al., 2012; Oparaku and Mgbenka, 2012). In order to avoid deterioration, drying removes moisture, so that the water activity of the dried product is low enough ($a_w < 0.6$) to stop spoilage and the growth of pathogenic microorganisms and to reduce other deterioration processes (Ajav and Fakayode, 2011). As preservation facilitates storage and transport, thereby opening up the possibility of trade, appropriate preservation techniques are not only important for securing local food supplies but can also boost economic development in another region. In rural communities, fish are processed using only the simplest method of conservation, namely open drying chambers and single-layer ovens. Although it is the most widely available preservative method, drying in the open space and ovens has serious disadvantages (Eyo, 2001). This processing method results in poor quality, low capacity, much damage, a much darker colour as particles such as tar and soot tend to adhere to the surface (Kituu et al., 2010).

With advances in technological development, a large proportion of fish farmers in developing countries suffer from a lack of processing methods. Nigeria is an example of a country where very few farmers have access to modern conservation methods. Although agriculture remains the largest sector of the Nigerian economy and employs two-thirds of the total workforce, one of the main sources of food production is freshwater aquaculture. In addition, this sub-sector employs more than 8 million fishermen, with an additional 18 million people engaged in fish processing, distribution and marketing and accounts for well over 80% of total annual domestic fish production (Abdullahi et al,. 2001; FDF, 2008).

Many preservation techniques such as fermenting, smoking, frying, salting, and conversion into fish sauce or paste have been developed. Fish smoking is widely used in the fish processing industry, especially in the post-harvest catfish product due to its simple operating technique. This cooking process can be carried out in the oven at varied temperatures. Clucas and Ward (1996) reported that hot smoking of fish combines three effects: Preservative effect of the smoke, drying and cooking. The optimization of a fish smoking kiln on an industrial scale involves the analysis of several process variables, such as processing temperature, drying time and sample size (Correal et al., 2006). The fish loading rate is also a process variable that needs to be analyzed as the placement of the trays can affect the properties of the dried product. Andrés et al. (2007) have observed that the time needed for drying is heavily dependent on the size of the fish. However, the influence of fish size has not been studied in detail so far. In addition, most world drying studies were conducted at high temperatures, such as at 150 °C in locally constructed furnaces without power blowers. Hubackova et al. (2014) found that high temperatures increase the drying rate, but because the product is highly susceptible to spoilage, temperatures of 60 to 70 °C are preferred. However, in current industrial practice, temperatures above 85 °C are used. For small, medium or large scale processing, tray loading density is very important based on several factors, most especially the timeliness of drying operation to reduce deterioration, the number of working hours available and whether drying is achieved in batch or continuous system (Ajav and Fakayode, 2011). Based on a literature search it has been found that further research is needed to optimize the operation of the fish scale oven on an industrial scale (Barat et al., 2007; Andrés et al., 2007). Information on the use of smoking kiln regarding the impact of production loading rate and the size of the fish is sparse.

In the present study, catfish were applied to smoking kiln by arranging different sizes of the fish on the individual trays to improve the drying property of fish. The aim of this work is to optimise the effect of tray loading density on drying characteristics of catfish.

MATERIALS AND METHODS

Based on local surveys carried out on the largest fish markets in Ibadan Oyo State, the most common fish species from Nigeria, namely catfish were selected for this study as locally most typical and most commonly sold. Samples from the above-mentioned fish class were purchased at the fish farm, University of Ibadan, Ibadan, Nigeria. The fish were cleaned and folded into a round shape. The fish were seasoned according to international regulations. The samples were then placed in experimental smoking kiln at varied operating conditions.

Description of the smoking kiln

The smoking kiln has a rectangular shape measuring 1.30×0.60 m, constructed and designed based on the availability of materials and durability. The kiln has six trays with a diameter of 0.55×0.46 m with a wire. It has two doors that can be opened and closed easily. The main door serves for loading trays, whereas the lower door for loading coal during processing. The device is also equipped with a blower that improved the air and heat circulation, ensuring dryness and moisture management. To increase efficiency, the furnace is powered by charcoal as a drying fuel.

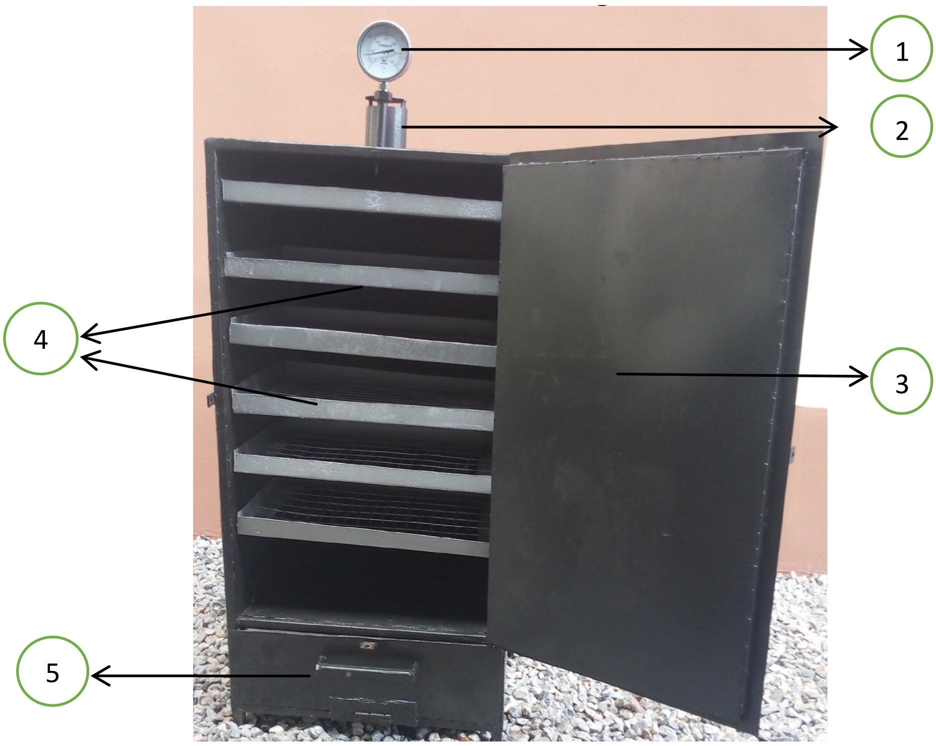

Figure 1. The smoking kiln; 1 – thermometer, 2 – chimney, 3 – kiln door, 4 – trays, 5 – charcoal area

The heat chamber is constructed in such a way that it can drive heat from the charcoal supported by the blower. The chamber is separated by a perforated stainless steel tray that allows heat exchange and is designed to allow the extraction of molten fat from smoked fish. The heat is generated by placing charcoal directly under the blower, which burns faster and increases the rate at which the fish are smoked. The thermometer was installed in the upper part of the smoking chamber to monitor the indoor temperature. The kiln consists of a single chimney, which is located in the upper part of the smoking chamber to allow efficient extraction of smoke and excess heat from the kiln (Figure 1).

Experimental procedure

The loading of the kiln was distributed by grouping the six trays into three different mixed loading combinations of different weight classes of 0.25, 0.30 and 0.35 kg. Two of the trays were assigned to each of the predetermined weights. A factor with three (3) weight combinations was used against time to determine drying rate (response). A flexible design structure of the blend was developed to optimize the kiln performance with a total of sixteen (16) experimental trials. All fish used were smoked hot at a temperature between 100 and 120 °C. Charcoal was used as a fuel source and as an electrically driven blower. After loading the oven, the temperature was recorded and the weight of the fish was measured at a one-hour interval to check the drying time to the point where there was no significant weight change of the fish.

Determination of moisture content

During drying, water at the surface of the substance evaporates and water in the inner part migrates to the surface to get evaporated. The ease of migration depends on the porosity of the substance and the surface area available. The weight loss during smoking was obtained from this relationship

$$W_L = W_i - W_f \quad (1)$$

Where;
W_L = Weight loss
W_i = Initial weight
W_f = Final weight

Percentage weight loss was determined using Equation (2) (Buchinger and Weiss, 2001)

$$\text{Percentage (\%) weight loss} = 100(W_i - W_f)/W_i \quad (2)$$

Mathematical modelling of drying curves

The Fick's equation for solid materials with thick geometry was applied to the experimental data during fish drying (Equation 3). The assumption for the thick form of dried fish 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):

$$MR = (W_t - W_e)/(W_i - W_e) \quad (3)$$

where MR is the dimensionless moisture ratio, W_t, the average moisture content at time t, W_i, the initial moisture content, and W_e, the equilibrium moisture content respectively, on dry weight basis. Thus, the moisture ratio in Equation (3) was simplified according to Evin (2012) to equation 4.

$$MR = W_t/W_i \quad (4)$$

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

Optimisation for concentration

Since the size of the product is considered important in the drying of agricultural products, its maximum point was used as a criterion for optimizing process variables. It was assumed that the process parameters retain the maximum (size). Numerical optimization was performed for three independent variables (0.25, 0.30 and 0.35 kg) and two dependent variables (drying rate and loading capacity) using Stat-Ease Design-Expert 11 software. The set of restrictions for the numerical solution of the optimal concentration conditions are shown in Table (1) below.

Statistical analysis

Mixture design experiments were carried out with the statistical software Design-Expert 11 and a regression analysis of the experimental data to estimate the response of the independent variables.

Table 1. Design constraints for the fish size loading conditions

Mixture Coding:	**Actual**	
Low (%)	**Constraint (kg)**	**High (%)**
0.00	A:0.25	100.00
0.00	B:0.30	100.00
0.00	C:0.35	100.00
	A+B+C	100.00

Table 2. Full factorial experimental design

Run	Factor Mixture of catfish sizes		
	Component 1 **A: 0.25 kg**	**Component 2** **B: 0.30 kg**	**Component 3** **C: 0.35 g**
1	0.00	1.00	0.00
2	0.00	0.50	0.50
3	0.00	0.00	1.00
4	0.33	0.34	0.34
5	0.18	0.15	0.67
6	0.50	0.00	0.50
7	0.67	0.16	0.16
8	0.25	0.75	0.00
9	0.50	0.00	0.50
10	0.50	0.00	0.50
11	0.50	0.50	0.00
12	0.00	0.75	0.25
13	0.50	0.50	0.00
14	0.00	0.00	1.00
15	1.00	0.00	0.00
16	0.00	0.50	0.50

The quality of fit of the second order equations was expressed by the coefficient of determination (R^2) and $P < 0.05$ was considered statistically significant for all analyses. This is a statistical software package from Stat-Ease Inc. specifically designed to determine the significance of these factors using analysis of variance (ANOVA). Projects with an optimal mix were used if the response varied depending on the relative components of the combination (fish weight). Table 2 shows the 16 experimental trials and the different size combination.

RESULTS

Effect of fish size on performance of each tray

The physical properties (size and weight) of the fish are important especially to determine the ability to load the kiln. The influence of the load size on the performance of a single tray is given in Table 3. The number of fish on each tray increases as the size of the fish decreases. The capacity of the tray was 28 pieces (0.25 kg), 23 pieces (0.30 kg) and 20 pieces (0.35 kg).

Interaction of catfish size mixture design on the weight of the fish loaded

The mixture design for the three components A (0.25 kg), B (0.30 kg) and C (0.35 kg) was significant ($P < 0.05$). The model F value of 4.78 meant that the model was significant. This is an indication that the mixture used was suitable. Taking into account the catfish size mixture design, a negative "exact predicted R squared value" was obtained at 7.6423, indicating that the overall average is a better predictor of the response. The R-squared value of 0.8071 indicated a high variability of the model. A reasonable accuracy was 4.78, which is more than 4, indicating that the connection was desirable and good for future development. The standard deviation for the experiment was 0.34. The special quadratic equation for the loading rate as size attributes was determined as coded variables as follows:

$$Y_{CLoad} = 52.08x_1 + 51.03x_2 + 52.02x_3 - 0.96x_1x_2 - 0.20x_1x_3 + 0.26x_2x_3 - 0.08x^2x_2x_3 + 158x_1x_2^2x_3 - 174.45x_1x_2x_3^2 \quad (5),$$

From equation 5, it was observed that an increase in charge of 0.25 kg (x_1) increased the load capacity to

Table 3. Loading capacity on each tray

S/N	Fish weight (kg)	Capacity of a tray
1	0.25	28(0.82)*
2	0.30	23(1.34)
3	0.35	20(0.73)

* Values represent pooled means and SD of triplicate determinations.

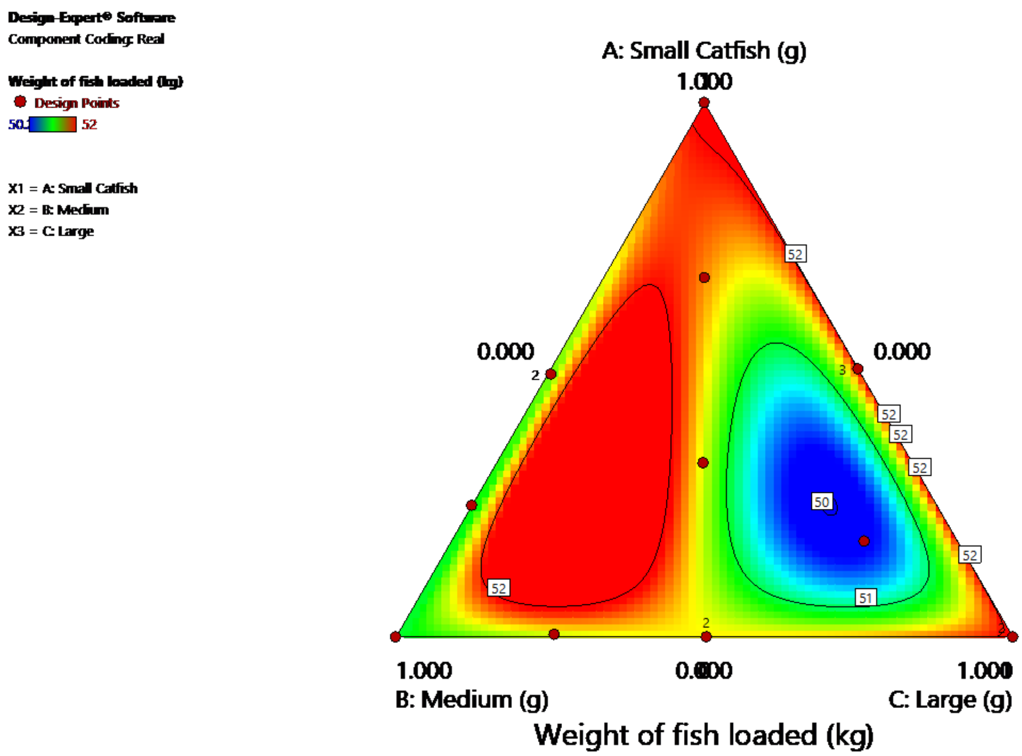

Figure 2. Contour diagram for the load capacity as a function of fish size before smoking

52.08 kg ($P < 0.05$), followed by 0.35g (x_2) at full load capacity of 52.02 kg. The interaction between 0.30 kg (x_2) and 0.35 kg (x_3) loading gave a high positive coefficient value of 0.26, indicating an increase in unit ($P < 0.05$) in each of the sizes. The equation shows quadratic terms of 0.30 kg that interacted with other sizes of catfish loaded at a high positive coefficient value of 158.

A typical variation of the interactions between three (3) catfish size mix to perform the experiments is represented in the contour plot in Figure 2. It shows that the weight of the loaded fish increases from 51.45 to 52.08 kg when the 0.25 g catfish rises from zero in the right direction. Similarly, an increase in load from 51.45 to an optimum load of 52.78 kg was observed for catfish size (0.30 g). It was observed that the weight of catfish size (0.35 g) dropped from 51.45 kg to 50.0 kg.

Effect of loading capacity on the varied fish size drying rate

The model F value of 2.26 implies that the model is not significantly relative. There is a 14.90% chance that such a large F value can be used for experimentation in the experiment. Nevertheless, it was found that 0.25, 0.30 and 0.35 kg are significant model terms. The drying rate was in the range of 0.46 to 0.83 $kg^{-1}h$ with a maximum to minimum ratio of 1.83. The lack of matching F value of 60.17 implies that the lack of matching was significant. The R square of 0.7213 showed that 72% of the variation was due to the association between the factors and the response.

For the different catfish sizes a square model was derived. The results showed that the linear coefficients of 0.25, 0.30 and 0.35 kg significantly affected the drying rate. From Equation 6, the coefficients for all varied sizes are linear; a two-factor interaction of 0.25 and 0.35 kg had significant effects on the drying rate of the samples. The specific quadratic equation for the drying rate as size attributes was determined as coded variables as follows:

$$Y_{DR} = 0.49x_1 + 0.52x_2 + 0.45x_3 - 0.04x_1x_2 - 0.19x_1x_3 + + 0.28x_2x_3 - 30.49x^2x_2x_3 - 22x_1x_2^2x_3 - 0.82x_1x_2x_3^2 \quad (6)$$

The coefficients of x_1, x_2 and x_3 are positive, so increasing the number of individual fish sizes can increase the drying rate. Equation 6, however, suggested that the fish drying rate increased by 0.52 kg^{-1} h with increasing fish size of 0.30 kg, which was the highest among the various sizes. Load capacity contour plot as a function of drying rate shows combinations of 0.25, 0.30 and 0.35 kg catfish was loaded into the kiln at a percentage of 67.20, 16.30 and 16.5, resulting in a maximum drying rate of 0.83 $kg^{-1}h$ (Figure 3).

The effect of moisture on the load capacity of fish

The results of the experiment showed that the moisture ratio (MR) is in the range of 0.199 to 0.262 with a maximum ratio of 1.32. This suggests that MR had a small transforming effect on fish sizes. In this case, fish sizes A (0.25 kg), B (0.30 kg), C (0.35 kg) and BC (0.30/0.25 kg) are significant model terms. R^2 with

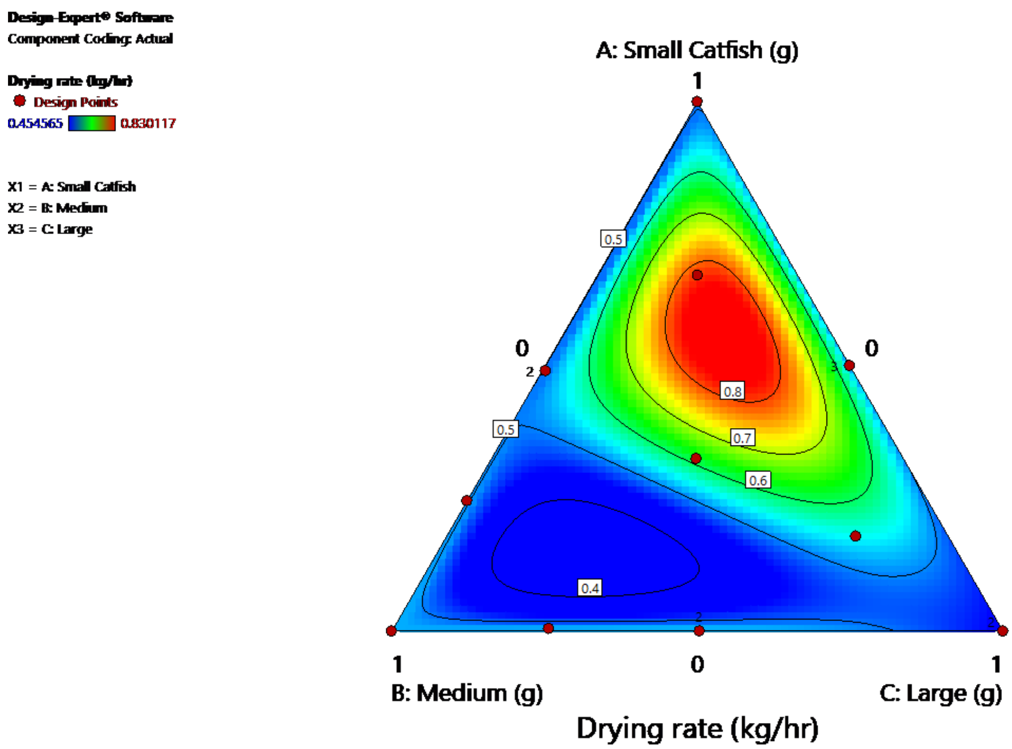

Figure 3. Contour diagram for the load capacity as a function of fish drying rate

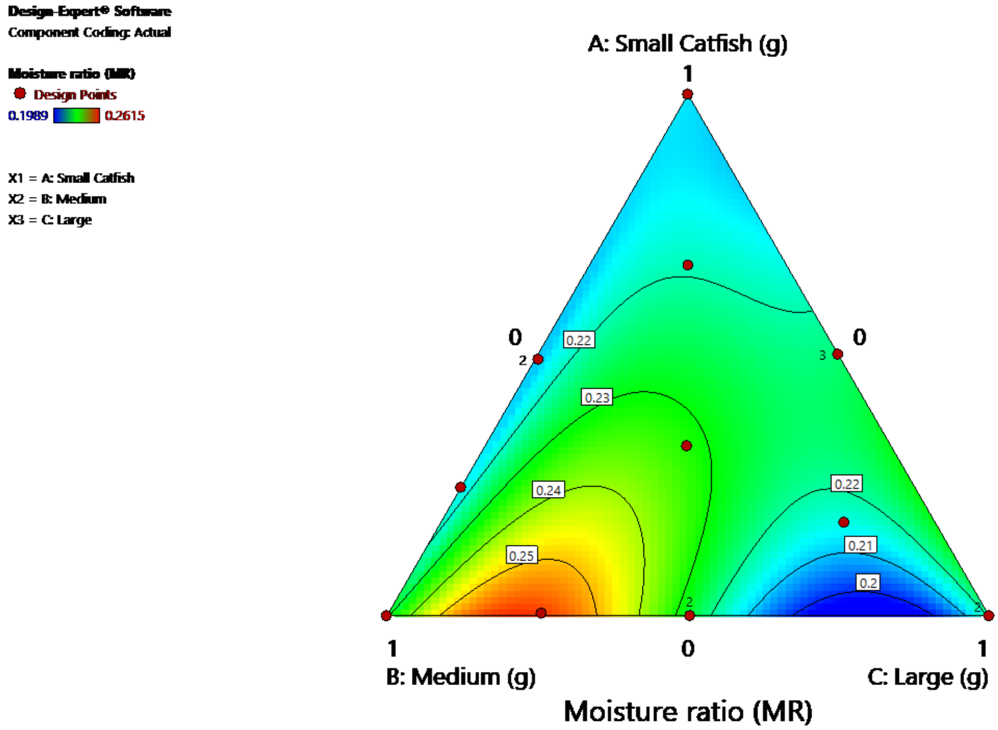

Figure 4. Contour diagram for the load capacity as a function of moisture ratio

a value of 0.8085 indicated a good fit model. The model provided a better fit to the furnace due to the uniform drying conditions between the individual sizes and the interaction between 0.30 and 0.35 kg. Cubic regression equations for MR as a function of mixed-well sizes are given below.

$$Y_{MR} = 0.21x_1 + 0.23x_2 + 0.22x_3 - 0.04x_1x_2 + 0.03x_1x_3 + 0.30x_1x_2x_3 \quad (7)$$

The equation (7) showed that there was a linear relationship between the fish sizes and the MR. The coefficients of all fish sizes were positive.

Table 4. Optimum point derived using the response optimizer

Optimal solution			Predicted response		
x_1 (kg)	x_2 (kg)	x_3 (kg)	Fish load (kg)	Drying rate (kg^{-1}h)	Moisture ratio
0.25	0.30	0.35	51.30	0.50	0.21

Therefore, an increase in fish sizes of 0.25, 0.30 and 0.35 kg, which are charged one by one, and an equal mixing ratio of sizes can increase the MR. On the other hand, the interaction between x_1 (0.25 kg) and x_2 (0.30 kg) coefficient is negative, an increase in two sizes resulted in a reduction in MR. A high coefficient of MR was found between the interactions of the three sizes. The highest MR value (0.23) between the predetermined fish size was observed when the oven was loaded with 0.30 g of fish.

Figure 4 shows the MR trace value for mixing the size of the model and the actual contour graph. The optimal MR with the fish sizes for the kiln was shown in Figure 3. During the loading of catfish sizes (0.25 and 0.35 kg) the MR was lower at the beginning of the drying process and later increased with increasing fish size. On the other hand, when loading the 0.30 kg catfish, the MR was gradually increased to an optimum value of 0.245 with a deviation value of 0.3 at the beginning of the smoking process before the MR was reduced to 0.20.

As shown in Figure 4, the combination of medium size (0.30 kg) at 75% loading rate of 25% large size (0.35 kg) describes the optimum operating point of the kiln. The maximum MR value of 0.25 was observed in a range of red color from the graph. A mixture of the three sizes with a loading percentage of 10, 67.5 and 21.5 of the fish sizes 0.25, 0.30 and 0.35 kg was considered to be the best mixture for the loading of the kiln.

Optimised conditions for smoking kiln catfish

In order to optimize loading capacity for smoking kiln of varied catfish size blend by numerical optimization, which finds a point that maximizes the desirability function, three parameters and the entire three responses (Table 4). The overall desirability, which ranges from zero outside of the limits to one at the goal, was 0.6299 (Figure 5).

DISCUSSION

In situ determination of the effect of fish size loading on each tray showed that the smaller the size of the fish, the greater the number of pieces contained in each tray and the greater its capacity. For larger size, the number of fish in the tray is smaller. This phenomenon resulted in an increase in density with weight loss, as expected from the literature (Karathanos et al., 1996; Zogzas et al., 1994).

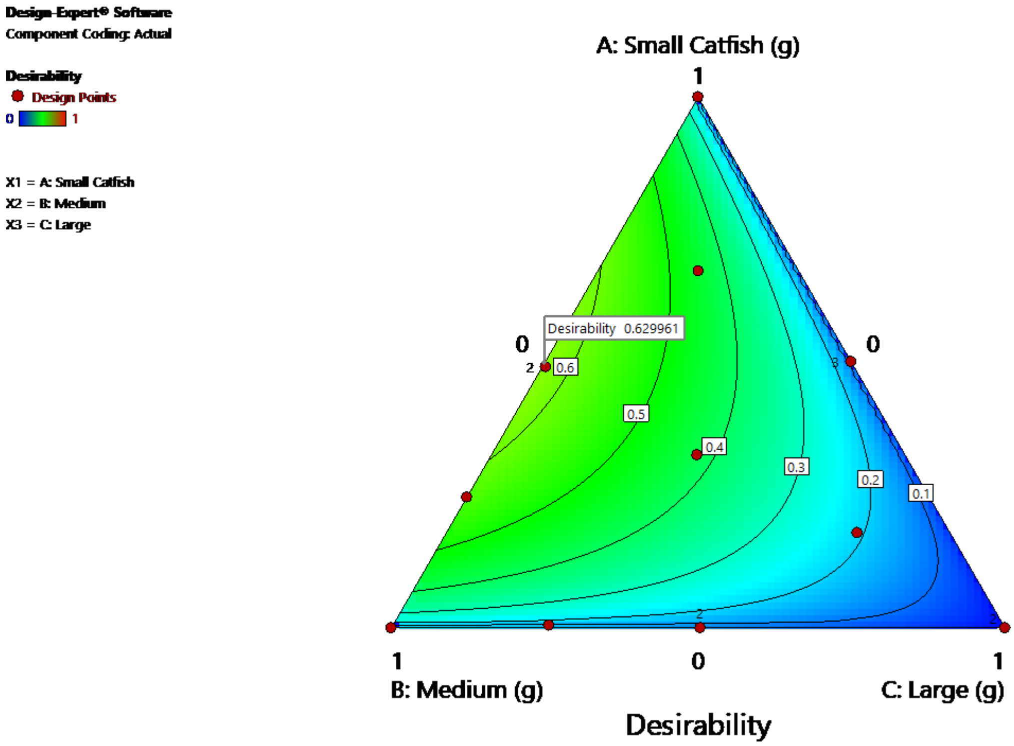

Figure 5. Desirability function response surface

In observing the interaction of the catfish size mixture design with the loaded fish, it was observed that with low water content, a significant weight loss relative to the volume of the tray was noted. Several authors (Zogzas et al., 1994; Wang and Brennan, 1995; Krokida and Maroulis, 1997) observed an increased density, because agricultural products lose water during drying. Wang and Brennan (1995) also explained this as a consequence of shrinkage reduction in the final stages of drying.

During the drying process, variations in drying rates were observed due to different shape, size and position of the fish on the tray. This observation is in accordance with other bibliographic references (Jain and Pathare 2007; Hubackova et al., 2014).

According to the result provided in the capacity of fish loading in the drying speed of the size of the fish, it can be observed that when the load increases, the drying time increases and the speed of drying decreases. This is consistent with the results of Ajav and Fakayode (2011) that the loading density of products has an impact on the rate of drying of agricultural products.

High moisture ratio was observed with the best size combination at low drying rate. This phenomenon is attributed to the internal resistance of the mass transfer of moisture, and increment of MR (Tunde-Akintunde, 2011; Hubackova et al., 2014).

The predicted values of the loading capacity/drying characteristics at these optimum conditions were used in predicting the optimum performance of the kiln. The optimal percentage loading combination for catfish size 0.25, 0.30 and 0.35 kg was 50%, 50% and 0% resulted in weight of fish loaded of 51.30 kg, moisture ratio of 0.21 and drying rate of 0.5 $kg^{-1}h$ (Table 4) which corresponds to total experimental trials carried out.

CONCLUSIONS

The 0.25, 0.30 and 0.35 kg mixtures used to assess kiln load optimization were significant ($P < 0.05$). A negative "R-squared precision" was obtained, which indicates a better rate of response. The individual tray capacity was 7 kg, and the optimal load capacity of the kiln was 52 kg. The obtained results showed that the kiln is effective in drying fish at a higher rate when using 0.25 g. The blower used also increased the drying rate of fish, and also ensured uniformity in the final product due to the appropriate heat transfer in the kiln. The smoking kiln produces dried fish products in hygienic conditions.

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