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Optimization of Paddy Continuous Flow Dryer Using Response Surface Methodology

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Abstract: *A continuous flow dryer was developed to address the problems associated with the drying of parboiled paddy. The continuous flow dryer was designed and fabricated using locally available materials to provide easier, faster and more efficient parboiled rice drying method. The performance evaluation was carried out using SIPI (FARO 44) paddy variety. The paddy was steamed, dried, and de-husked. Conveyor speed (5, 10, and 15 mm/s), drying temperature (90, 110, and 130 °C), and drying airspeed (1.5, 2.0, and 2.5 m/s) each at three levels were used as input variables. A Box-Behnken design (BBD) of Response Surface Methodology (RSM) was used to determine the optimum drying condition of the paddy. Drying output capacity (kg/h), total milling yield (%), head rice yield (%), and drying time (minute) were used as response variables. Regression models were developed for each response and validation of the optimum drying condition was performed. The result for the performance evaluation of the dryer showed a maximum drying capacity of 68.70 kg in 6 hours, total milling yield ranged between 52.02 to 80.79 %, head rice yield ranged between 56.13 to 77.94 %, and drying time ranged between 26.370 to 41.118 minutes. Results of the study also indicated that the developed regression models for all the response variables were significant at a 1 % level of probability (p-values < 0.0001), while the lack of fit of the models were not significant even at 5 % level of probability indicating that most of the variation in the response variables can be explained by the regression models developed. The optimum drying condition of parboiled paddy in the continuous flow dryer was: 5.000 mm/s conveyor speed, 110.529 °C drying temperature, and 2.484 m/s drying airspeed. The predicted optimum values of the response variables obtained at this drying condition were: 10.058 kg/h of drying output capacity, 76.667 % head rice yield, and 29.914 minutes total drying time. Lastly, the validation result showed that the experimental (test) values of the responses obtained at the optimized drying conditions were: 9.860 kg/h for drying output capacity; 75.217 % head rice yield; 31.8968 min. These test values are relatively close to the predicted values of responses with percentage error values of less than 10%, meaning that the difference between the experimental (test) data and the predicted data are within the acceptable limit thus confirming the suitability of the optimal drying conditions produced from the RSM. This showed that local materials can be used to developed a continuous dryer, and that RSM can be used to determine the optimum drying condition.*

Key words: *Conveyor Speed, Drying, Paddy and Validation.*

INTRODUCTION

The increase in the demand of food due to the increasing population of the world has led to the development of different crop processing machineries. Among the most cultivated crops in the world is paddy rice. Paddy processing machineries such as dryers have been developed and modified in order to maintain the quality of the paddy. The demand for parboiled and white rice as at 2020 reached a volume of 488.3 Million Tonnes (IMARC, 2021). However, the drying of parboiled paddy is still practiced using the traditional sun-drying method. This method is tedious; time and space consuming; exposes paddy to rodents and dirt; causes internal stress in paddy which result in paddy breakage during milling (Bello *et al*., 2015).

Although there are existing designs of different types of dryers, they are mostly imported and have higher costs, which made them beyond the reach of small and medium scale paddy processors. Because of this problem, there are efforts made by some researchers to develop different dryers using locally available materials. (Owolarafe *et al*., 2021) fabricated a cabinet dryer using locally available materials and carried out the performance evaluation of the dryer. Mondal *et al*., (2019) developed and tested a small-scale mixed flow dryer for paddy drying. Gbabo *et al*., (2017) developed a steam-heated platform dryer with a capacity of 4 tons per day to dry a parboiled paddy. (Kamin and Janaun, 2017) designed, fabricated, and tested a commercial scale Laterally Aerated Moving Bed (LAMB) in a local rice mill. A laboratory-scale flat-bed dryer was designed and fabricated by Ghiasi *et al*., (2016). (Manikantan *et al*., 2014) fabricated an integrated dryer. A commercial conveyor dryer for granulated cassava was developed by (Gragasin and Martinez, 2015).

MATERIALS AND METHODS

Sample preparation

A local variety of Paddy rice called *SIPI (FARO 44)* was used for the experiments, which was obtained from Kura local government area, Kano State, Nigeria. The total quantity of paddy used for the experiment was 300 kg and the experiment was conducted at the Agricultural Engineering workshop, Bayero University, Kano. This variety (*FARO 44*) is one of the most commonly cultivated paddy varieties in Kano, it has high yield, taste, and is commonly used by consumers. The moisture content of the paddy rice variety, after purchase, was an average of 13 % (w.b). The paddy was washed thoroughly (3 times) with tap water to avoid discolouration, odour, and contamination. The immature, unfilled grains and straw were floated off to reduce breakage during de-husking and then subjected to soaking and steaming process at constant variables of steaming time (6 hours) and steaming temperature (60 ^{o}C). After the steaming process, the wet paddy at 30 % (w.b) was loaded into the continuous dryer constructed for this purpose of the drying process.

Experimental procedure

The soaking process was done according to the method of (Ejebe *et al.*, 2015). Weight of water that is 1.3 times the weight of paddy used was heated until its temperature gets to 60 ± 2 ºC. The water was then poured into a warmer and the washed paddy was then poured into the warmer and covered rapidly and tightly for 6 hours. After the soaking process, the paddy was allowed to drip-dry for steaming process.

The steaming process was also done according to the method of (Ejebe *et al.*, 2015). The soaked paddy was washed, allowed to drip-dry, and poured into a steaming basket. The steaming basket is an aluminium vat having false bottom and perforations around ¼ its height from the base. The steaming basket was then placed on an aluminium pot with water level below the base of the steaming basket and steamed to a period when paddy begins to crack open their husks and there is steam vapour arising all over the pot. After that, the steamed paddy was ventilated by ambient air until the grain temperature reached 30-33 ºC before conveying it to the drying machine.

After the steaming process, the steamed paddy was then conveyed to the place where the developed continuous dryer was located. The drying experiment was carried out based on the method given by Pruengam *et al.* (2014). For each drying experiment, 5 kg sample of parboiled paddy was measured and drying was conducted by applying the required drying conditions of drying temperature (90, 110, and 130 ^{o}C); drying airspeed (1.5, 2.0, and 2.5 m/s), and conveyor speed (5, 10, 15 mm/s). The moisture content of each paddy sample after drying was measured using a moisture meter. The temperature of each paddy sample before and after drying was also measured using a probe thermometer. Likewise, the drying time for each paddy sample was taken After drying, the paddy was labelled for its combination of drying variables (drying temperature, drying airspeed, and conveyor speed) and stored for 2 days in bags to calm internal stresses developed during the drying processing (i.e., tempering) before the de-husking operation.

Three kilograms (3 kg) of dried paddy were taken from each of the dried samples and then de-husked using a diesel de-husking machine (N110). The de-husking machine was found in the faculty of Agriculture Bayero University, Kano, Nigeria. The weight of grains left in the huller machine for each treatment was forced out by putting rice husk into the hopper of the machine, after which the de-husked weight was measured for quality evaluation (IRRI, 1996).

The performance of the prototype continuous flow dryer was evaluated based on the drying output capacity (%), total milling yield (%), head rice yield (%) and time taken for complete drying (minutes).

Experimental design and statistical analysis

The rice variety *SIPI (FARO 44)* was used to test the performance of the continuous dryer. Response Surface Methodology (RSM) with three coded levels (−1, 0, and 1) was employed to examine the effects of three levels of conveyor speed (5, 10, and 15 mm/s); three levels of temperature (90, 110, and 130 ^{0}C); and three levels of drying airspeed (1.5, 2.0 and 2.5 m/s) on the performance of the prototype continuous flow dryer. Response surface methodology (RSM) is selected to determine the optimal conditions for drying paddy, because of its ability to find the effect of various factors on each response and its ability to determine the optimum conditions of the process. Actual levels and coded factor levels of three independent variables for optimizing the paddy drying condition using RSM are shown in Table 1.

Table 1 Actual levels at coded factor levels of independent variables used in the RSM

Symbol	Independent variable	Actual levels at coded factor levels		
		-1	0	1
X_1	Conveyor speed (m/s)	5	10	15
X_2	Drying temperature (^{0}C)	90	110	130
X_3	Drying air speed (m/s)	1.5	2	2.5

The Response Surface Methodology (RSM) with Box-Behnken Design (BBD) of 3 coded levels, 3 independent variables, and 20 experimental runs including eight centre points (Table 2) was used to optimize the paddy drying condition including conveyor speed (X_1), drying temperature (X_2), and drying airspeed (X_3) using Design-Expert software (Version 11.1.2.0, Stat Ease Inc., USA).

A second-order polynomial model was fitted to the mean values of the experimental results to get the regression equations as given in equation (1) (Cui *et al.*, 2019). Analysis of variance was carried out to find out the statistical significance of the model terms at a 5% level of probability. The accuracy of the model to describe the response variables was diagnosed against the coefficients of determination (R^2) values, the normal probability plots of the residuals, and the predicted versus actual plots. 3D surface plots were generated for various responses against two independent variables while holding the other independent variable constant.

$$y = \beta_0 + \sum_{i=1}^{k} \beta_i x_i + \sum_{i=1}^{k} \beta_{ii} {x_i}^2 + \sum \sum_{i<j=1}^{k} \beta_{ij} x_i x_j + \epsilon \qquad (1)$$

Where; y = the dependent variable; β_0 = constant regression coefficient of intercept; β_i = constant regression coefficient of linear term; β_{ii} = constant regression coefficient of quadratic term; β_{ij} = constant regression coefficient of interaction term; X_i and X_j = independent variables; K = number of independent variables in the model; ϵ = the random error term.

Numerical optimization of the drying process was performed using a multiple response method called the overall or combined desirability index. The desirability index was determined using equation (2) as given by (Eren and Kaymak-Ertekin, 2007; Giri and Prasad, 2007; Myers and Montgomery, 2002).

$$DI = (Y_1 \times Y_2 \times \ldots\ldots Y_n)^{(1/n)} = \left(\prod_{i-1}^{n} d_i \right)^{(1/n)} \qquad (2)$$

Where; DI = overall or combined desirability index; Y_1 (i=1, 2......n) = the responses; n = number of the responses; d_i = desirability index for each response variable

Optimum drying conditions of parboiled paddy in the continuous dryer were provided by Response Surface Methodology (RSM) based on the maximum value of head rice yield, the minimum value of percent broken grains, minimum drying time, and maximum milling yield. Predicted values of all the responses were also derived from the optimum model. Under these conditions, a validation experiment was carried out to verify the adequacy of the model equation. Experimental values obtained were compared with predicted values by calculating their percentage error (PE) and this percentage error (PE) should be less than 10% to indicate a good fit as given in equation (3) (Nordin *et al.*, 2019).

$$PE(\%) = \frac{m_{ev} - m_{pv}}{m_{ev}} \times 100 \qquad (3)$$

Where; PE (%) = percentage error; m_{ev} = experimental value; m_{pv} = predicted value

RESULTS AND DISCUSSION

Statistical significance and verification of models

The results of the effect of conveyor speed, drying temperature, and drying airspeed on performance evaluation of the continuous flow dryer using Box-Behnken design (BBD) of Response Surface Methodology (RSM) were presented in Table 2.

Table 2: Box-Behnken design showing the experimental results responses and variables

S/No.	A:Conveyor Speed	B:Drying Temp.	C:Drying Air Speed	Drying output capacity	Total milling yield	Head rice yield	Time taken for complete drying
	(mm/s)	(^{0}C)	(m/s)	(kg/h)	(%)	(%)	(minute)
1	15	130	2	9.84	68.17	62.7	30.672
2	10	110	2	8.99	72.99	77.94	33.624
3	10	90	1.5	7.32	62.03	64.27	41.118
4	10	110	2	8.5	77.69	74	35.304
5	5	110	2.5	10.12	56.41	77.06	29.748
6	5	90	2	8.14	79.21	72.26	36.978
7	10	110	2	8.9	78.24	73.42	33.822
8	10	110	2	8.37	76.69	72.57	35.904
9	10	110	2	8.9	78.02	70.51	33.84
10	5	110	1.5	7.77	58.81	71.94	38.706
11	10	110	2	8.59	80.02	72.9	34.962
12	15	110	1.5	7.78	55.56	74.97	38.688
13	10	130	1.5	8.47	54.8	60.77	35.55
14	15	90	2	8.13	80.79	74.07	36.996
15	10	130	2.5	11.45	52.02	56.13	26.37
16	10	110	2	8.93	77.58	77.58	33.78
17	15	110	2.5	10.12	54.35	73.42	29.778
18	5	130	2	9.77	71.46	67.59	30.87
19	10	110	2	9.03	77.02	75.48	33.336
20	10	90	2.5	9.08	61	66.37	33.192

The independent and dependent variables were fitted by the second-order polynomial equation to develop regression models that predict over a wide range the effect of the drying conditions on the response variables as shown in equation 4 to 7.

$$(y_{doc})^{-1.55} = 0.0345 - 0.0000A - 0.0048B - 0.0068C - 0.0001AB + 6.715 \times 10^{-6}AC - 0.0002BC - 0.0002A^2 - 0.0004B^2 + 0.0003C^2 \quad (4)$$

$$y_{tmy} = 77.28 - 0.8765A - 4.57B - 0.9275C - 1.22AB + 0.2975AC - 0.4369BC - 1.78A^2 - 0.5952B^2 - 19.22C^2 \quad (5)$$

$$y_{hry} = 74.30 - 0.4617A - 3.72B + 0.1268C - 1.67AB - 1.67AC - 1.68BC + 3.66A^2 - 8.80B^2 - 3.61C^2 \quad (6)$$

$$T = 34.32 - 0.0210A - 3.10B - 4.37C - 0.0540AB + 0.0120AC - 0.3135BC - 0.1350A^2 - 0.3075B^2 + 0.0435C^2 \quad (7)$$

Where: y_{doc} = drying output capacity (kg/h); y_{tmy} = Total milling yield (%); y_{hry} = Head rice yield (%); T = time taken for complete drying (min).

The results for the fitness of the regression models developed were presented in ANOVA table (Table 3). From the ANOVA table it is observed that the quadratic models developed for all the responses were significant at ($p<0.0001$) which showed that the models best describe the variation between the input and the response variables. From Table 3, it is also observed that the effect of lack of fit on the responses is not significant, indicating that the models best fit the experimental data. The significance of the model equations and the goodness of fit were also evaluated by considering the R^2 values. The results of the ANOVA table showed that the coefficient of determination R^2 values of all the responses (Drying output capacity, 0.9702; Total milling yield, 0.9847; Head rice yield, 0.9235; Time taken for drying, 0.9739) were above 0.8, indicating that the developed quadratic models appropriately predict the response variables. According to Zaibunnisa *et al.* (2009), the R^2 value should be at least 0.80 to have a good fit of a regression model.

Table 3 ANOVA for response surface quadratic model of the performance evaluation of the paddy continuous flow dryer

Source	df	Drying output capacity (kg/h)		Total milling yield (%)		Head rice yield (%)		Time taken for drying (min)	
		Sum of Squares	p-value	Sum of Squares	p-value	Sum of Squares	p-value	Sum of Squares	p-value
Model	9	0.0006	< 0.0001	2052.26	< 0.0001	623.14	0.0002	230.91	< 0.0001
A-Conveyor Speed	1	1.12E-08	0.9372	6.15	0.195	1.71	0.5782	0.0035	0.9413
B-Drying Temp.	1	0.0002	< 0.0001	167.27	< 0.0001	110.8	0.0009	77.02	< 0.0001
C-Drying Airspeed	1	0.0004	< 0.0001	6.88	0.1724	0.1285	0.8778	152.9	< 0.0001
AB	1	3.13E-08	0.8953	5.95	0.2018	11.22	0.1713	0.0117	0.8935
AC	1	1.80E-10	0.992	0.354	0.7458	11.12	0.173	0.0006	0.9763
BC	1	1.04E-07	0.8107	0.7637	0.635	11.33	0.1693	0.3931	0.444
A^2	1	1.81E-07	0.752	14.42	0.0593	61.22	0.0063	0.0833	0.7213
B^2	1	7.82E-07	0.5152	1.62	0.4922	354.15	< 0.0001	0.4323	0.4229
C^2	1	4.10E-07	0.6358	1689	< 0.0001	59.56	0.0068	0.0087	0.9082
Residual	10	0		31.86		51.64		6.19	
Lack of Fit	3	2.51E-07	0.9906	3.79	0.8146	6.08	0.817	0.0774	0.9925
Pure Error	7	0		28.08		45.57		6.11	
Cor Total	19	0.0006		2084.13		674.78		237.1	
R^2		0.9702		0.9847		0.9235		0.9739	
Adjusted R^2		0.9434		0.971		0.8546		0.9504	
Predicted R^2		0.9547		0.9533		0.7677		0.9611	
Adeq Precision		25.1317		22.4199		12.4432		26.8719	

The adjusted R^2 values of drying output capacity, total milling yield, head rice yield, time taken for drying were 0.9434, 0.971, 0.8546 and 0.9504 respectively as shown in Table 3. Also from the ANOVA table it can be seen that the Predicted R^2 values of drying output capacity, total milling yield, head rice yield, time taken for drying were 0.9547, 0.9533, 0.7677 and 0.9611 respectively. This showed that the difference between the adjusted R^2 and predicted R^2 value of all the response variables is less than 0.2, meaning that there is reasonable agreement between the adjusted R^2 and predicted R^2 values. This is also an indication of goodness of fit of the predicted models. From Table 3, it is observed that the adequate precision values of drying output capacity, total milling yield, head rice yield, time taken for drying were 25.1317, 22.4199, 12.4432 and 26.8719. According to Islam Shishir *et al.* (2016), the value of adequate precision should be greater than 4 for a regression model to be consistent in describing the experimental process. Therefore, from Table 3, it is observed that the value of the adequate precision for all the developed quadratic models is greater than 4, indicating the consistency of the developed models in describing the experimental data. Figure 1 shows a correlation plot between the predicted and actual value of the response variables. From Figure 1, it can be observed that the points on the graphs were reasonably distributed near the straight line, meaning that the underlying assumptions of all the quadratic models developed were appropriate. The correlation plots also suggest that the developed quadratic models were adequate in predicting the response variables for the experimental results. Figure 2 is a plot of studentized residuals versus predicted values of the response variables. From Figure 2, it can be seen that the points on the plots are randomly scattered around 0.00, pointing out that the assumption of the random errors having a mean of zero in all the developed quadratic models have not been violated. It can also be seen from Figure 2 that these points are spread randomly from left to right, indicating that the quadratic models best fit the experimental results.

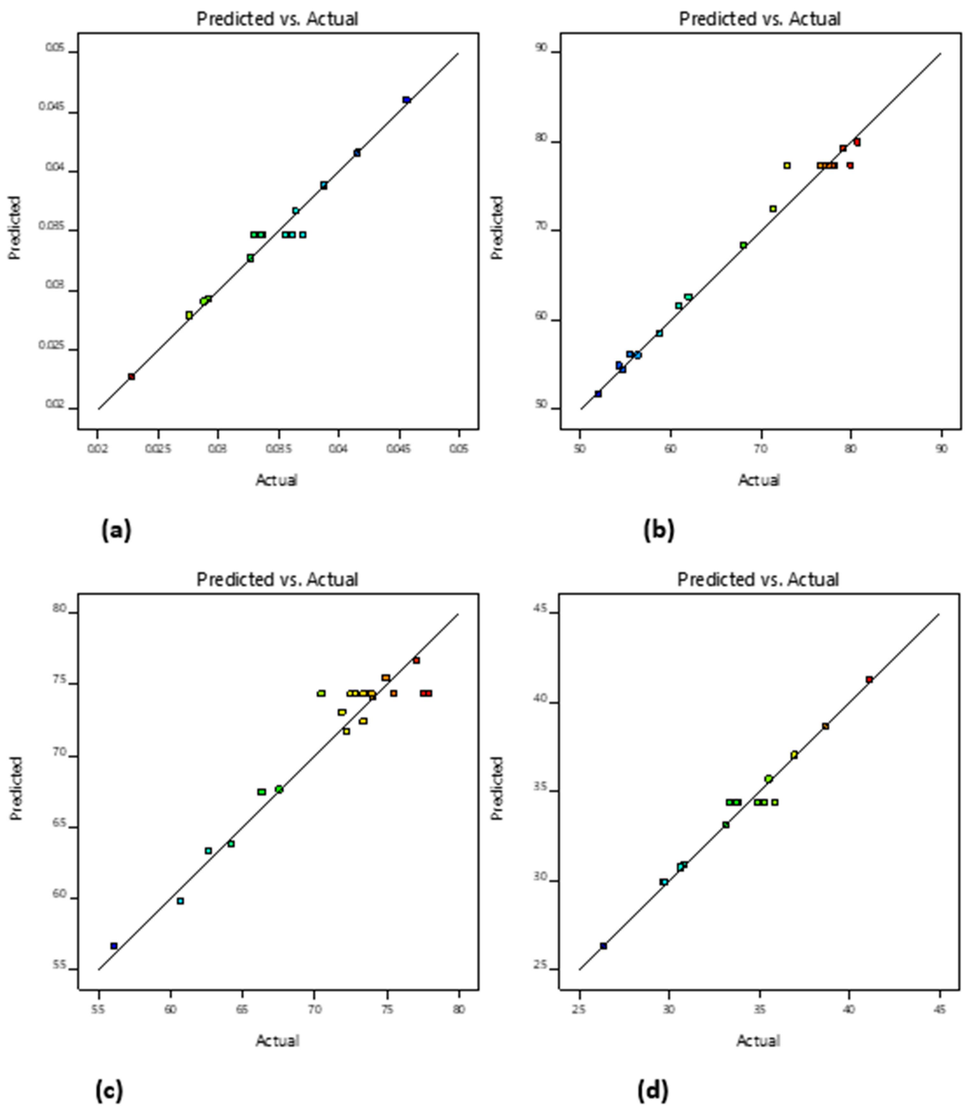

Figure 1: Correlation plot showing the distribution of predicted versus experimental values of (a) drying output capacity (b) total milling yield (c) head rice yield and (d) time taken for drying

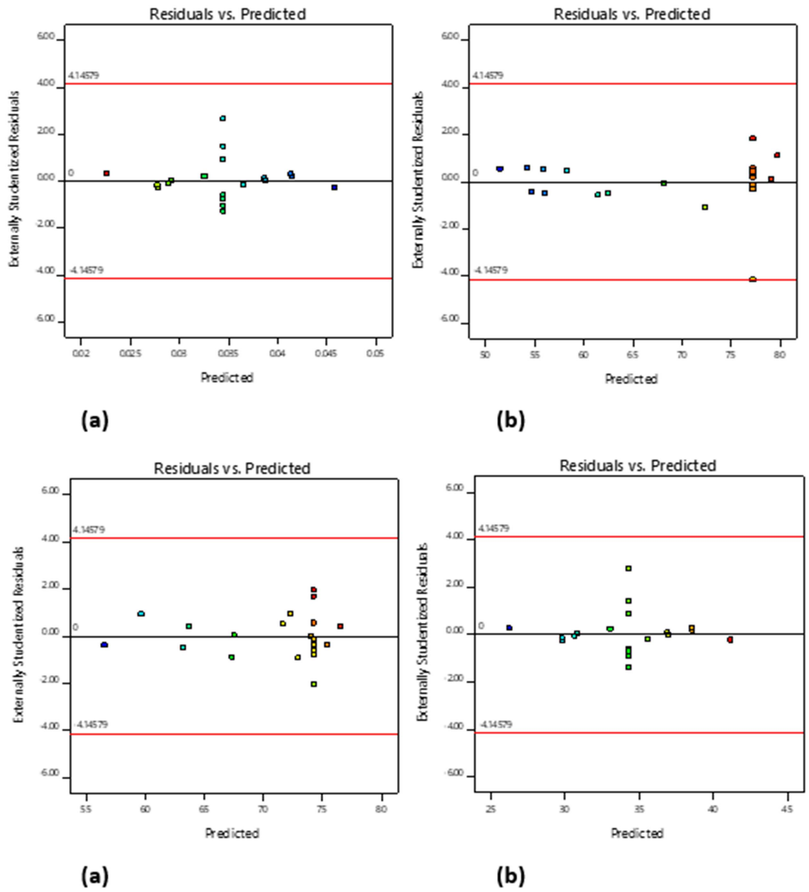

Figure 2: Plot of studentized residual versus predicted values of (a) drying output capacity (b) total milling yield (c) head rice yield and (d) time taken for drying

Effects of the input variables on the performance of the paddy continuous flow dryer

DRYING OUTPUT CAPACITY

Table 2 showed that the drying output capacity of the continuous dryer ranges from 7.32 kg/h to 11.45 kg/h with a maximum design capacity of 22.57 kg/ batch. The average drying capacity of the developed continuous flow dryer was 112.68 kg in 12 hours. This capacity is higher than the capacity of other researchers (such as Abubakar & Isiyaku, 2014 who reported a drying output capacity of 30 kg in 12 hours; Wincy et al., 2021 who also reported a drying output capacity of 60 kg in 13 hours).

Figure 3 is the surface plot of drying output capacity versus conveyor speed and drying temperature, holding drying airspeed constant. This surface plot shows the effect of each of the three independent variables and their interaction on the drying output capacity. The plot showed that the effect of conveyor speed does not affect the drying output capacity. However, Figure 3 showed that the drying temperature has a positive effect on the drying output capacity of the continuous dryer. The surface plot also showed that holding the drying airspeed constant and increasing the drying temperature from 90 °C to 130 °C causes an increase in the drying output capacity. This could be due to the decrease in the drying time when a higher drying temperature is applied to the dryer. Similar results have been reported for drying of rough rice in a flat-bed dryer by (Ghiasi *et al.*, 2016) where it stated increase in drying temperature increases the output capacity of the flat-bed dryer. A similar report was also given by (Ibrahim *et al.*, 2014).

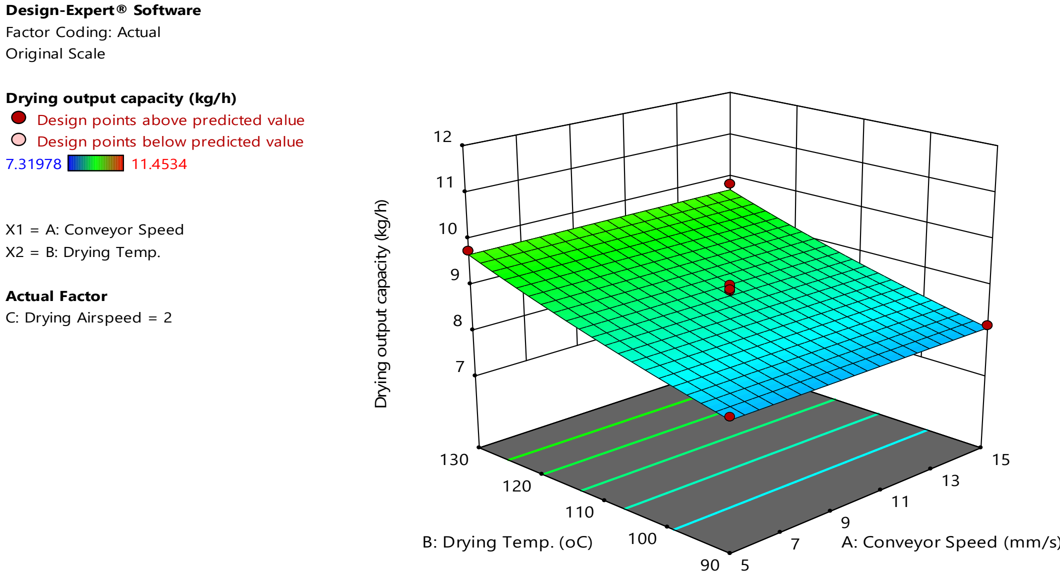

Figure 3 Response surface plot of drying output capacity versus conveyor speed and drying temperature holding drying airspeed at 2.0 m/s

TOTAL MILLING YIELD

The total milling yield of the paddy ranges from 52.02 % to 80.7944 % as shown in Table 2**.** Figure 4 is a three-dimensional (3D) surface plot showing the effect of each of the three independent variables and their interaction on the total milling yield. The plot showed that the drying temperature has a negative influence on the total milling yield of paddy. It can be observed from Figure 4 that the effect of conveyor speed also has a negative influence on the total milling yield. Therefore, figure 4 showed that increasing the conveyor speed (from 5 to 15 mm/s) and drying temperature (from 90 to 130 °C) during the drying of paddy at a constant drying airspeed decreases the total milling yield. This could be as a result of internal stress developed in the paddy at high drying conditions. Ibrahim *et al.*, (2014) while studying the performance of inclined bed paddy drying reported a decrease of about 2.47 % in total milling recovery when drying fresh paddy from 38 – 39 ^{o}C.

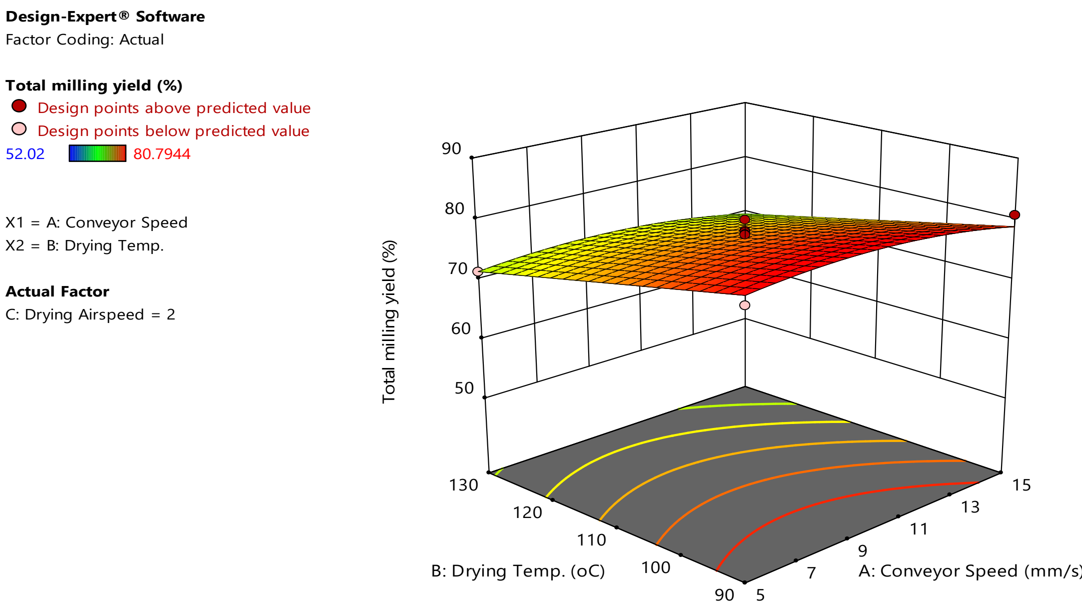

Figure 4: Response surface plot of total milling yield versus conveyor speed and drying temperature holding drying airspeed at 2.0 m/s

HEAD RICE YIELD

Table 2 showed that the head rice yield of the paddy ranges from 56.1314 % to 77.935 %**.** These findings are similar to results reported by other researchers (Ebrahim *et al.*, 2019). They reported the values of head rice yield in the range of 60 % to 80 % for parboiled rice. Figure 5 is the surface plot of head rice yield versus conveyor speed and drying temperature, holding drying airspeed constant. Figure 5 showed that increasing the drying temperature gradually from 90 ^{o}C to 110 ^{o}C increases the head rice yield, but head rice yield gradually decreases when drying the paddy above 110 ^{o}C. The surface plot also showed that there is a slight decrease in the head rice yield when the conveyor speed increases from 5 mm/s to 10 mm/s, but the head rice yield increases slightly at a conveyor speed of greater than 10 mm/s. The increase in the head rice yield could be related to less moisture gradient in final products. While the decrease in the head rice yield could be attributed to the cracks and fissures developed on the rice kernel due to the high moisture gradient when drying the paddy at a temperature above 110 ^{o}C. Reports related to the effect of the drying conditions on the head rice yield have also been presented by other researchers (Tirawanichakul *et al.*, 2012; Ebrahim *et al.,* 2019). They reported that the head rice yield of parboiled rice was relatively high when drying temperature increased up to 100 ^{o}C.

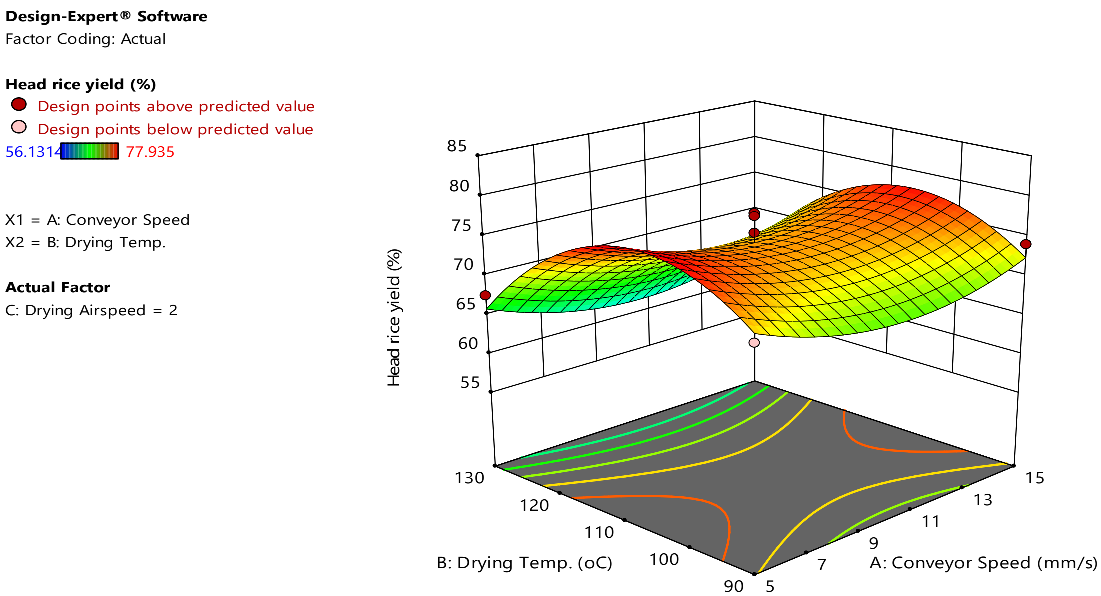

Figure 5: Response surface plot of total milling yield versus conveyor speed and drying temperature holding drying airspeed at 2.0 m/s

TIME TAKEN FOR COMPLETE DRYING

The time taken for complete drying of the paddy ranges from 26.370 min to 41.118 min as shown in Table 2. Figure 6 shows a surface plot of time taken for complete drying versus conveyor speed and drying temperature, holding drying airspeed constant. This surface plot shows the effect of each of the three independent variables on the time taken for complete drying of paddy in the continuous dryer. Figure 6 showed that the conveyor speed has a significant effect on the time taken for complete drying. Moreover, the (3D) surface plot showed that the drying temperature has a positive effect on the time taken for the complete drying of paddy in the continuous dryer. The surface plot also showed that holding the drying airspeed constant, and increasing drying temperature (from 100°C to 120°C), and increasing conveyor speed (from 10mm/s to 15mm/s), caused a decrease in the time taken for complete drying. This decrease in drying time could be attributed to an increase in the amount of water evaporation from the paddy. This result is in agreement with the results of other researches (Onwude *et al.*, 2018) where they reported that the value of drying time decreases linearly with an increase in drying temperature.

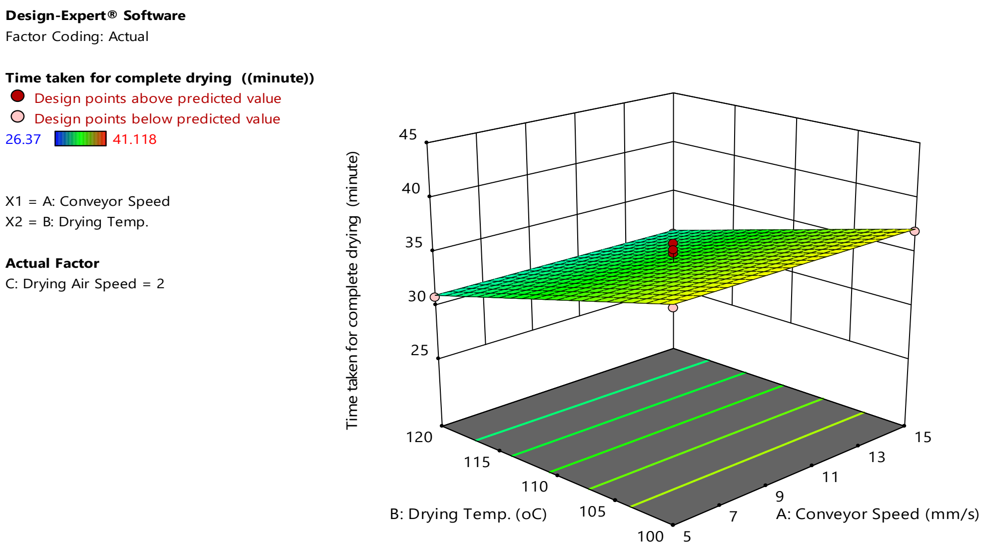

Figure 6: Response surface plot of drying time versus conveyor speed and drying temperature holding drying airspeed at 2.0 m/s

NUMERICAL OPTIMIZATION OF PROCESS CONDITIONS

The main objective of the current research was to find the optimum process variables for minimizing the drying time of parboiled paddy and maximizing head rice recovery of parboiled rice. To find the optimum drying condition, the following targets were set: drying output capacity should be maximum, Percentage head rice should also be maximum, and drying time should be minimum. The details of the set targets were presented in Table 4.

Table 4: Constraints Made for the Optimization of the Drying Condition

Name	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Importance
A: Conveyor Speed	is in range	5	15	1	1	3
B: Drying Temp.	is in range	100	120	1	1	3
C: Drying Air Speed	is in range	1.5	2.5	1	1	3
Drying output capacity	Maximize	8	12	1	1	3
Head rice yield	Maximize	60	78	1	1	5
Time taken for complete drying	Minimize	30	42	1	1	4

Fig. 7 displays individual desirability values of input variables, response variables, and combined optimization with combined desirability (D = 0.8663). The value of desirability (D) ranges from (0 to 1). The desirability function (D) is a composite function describing how desirable (well-matched) the responses are at a particular level of independent factors (variables). The program of the statistical software seeks to find the values of variables, which can result in the maximum value of desirability function (Yadav *et al.*, 2010). The desirability function for input variables (conveyor speed, drying temperature, and drying airspeed) and response variable (time taken for complete drying) is equal to 1 because their targets are set to be in range in the optimization. Other response variables (drying output capacity and head rice yield) were optimized to be at a maximum level within the desired range. The desirability function for drying output capacity and head rice yield were obtained to be 0.6402 and 0.9260 respectively. The optimum values of input variables were: 5.000 mm/s conveyor speed, 110.529 ^{o}C drying temperature, and 2.484 m/s drying airspeed. The predicted optimum values of the response variables obtained at this drying condition were: 10.058 kg/h of drying output capacity, 76.667 % head rice yield, and 29.914 minutes total drying time.

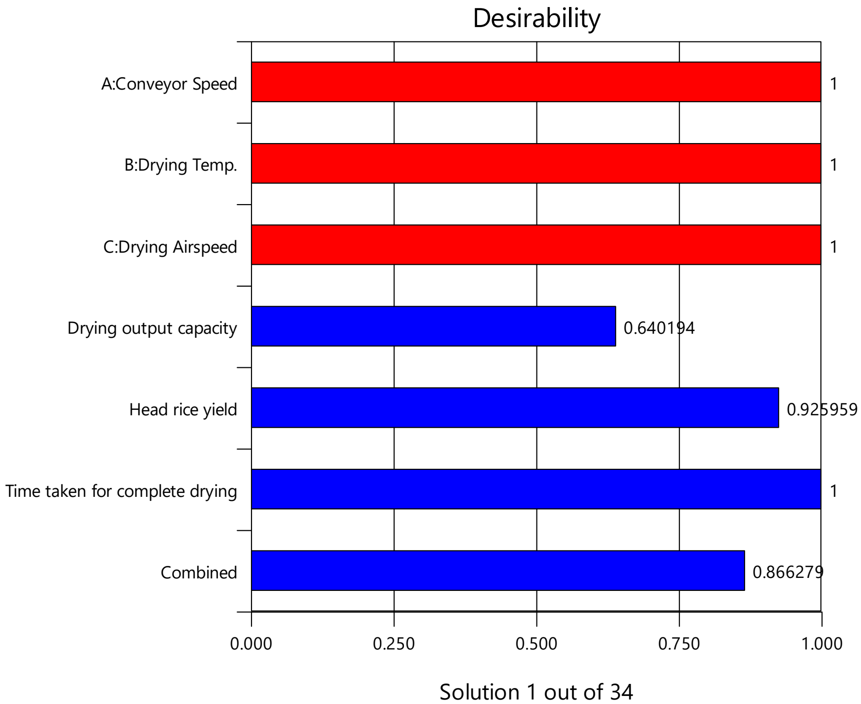

Figure 7: Individual desirability values of input variables, responses, and combined optimization

VALIDATION OF THE OPTIMAL CONDITIONS

Table 5 is a validation table showing the values of actual and predicted responses under the optimal drying condition. The validation of the optimum drying conditions suggested by RSM was achieved by drying the parboiled paddy in a continuous dryer using the optimized drying conditions of 5.000 mm/s conveyor speed, 110.529 ^{o}C drying temperature and 2.484 m/s drying air speed. The experimental (test) values of the responses obtained at the optimized drying conditions were: 9.860 kg/h for drying output capacity; 75.217 % head rice yield; 31.8968 min for drying time. These test values are relatively close to the predicted values of responses, hence confirming the validity of the optimized results and consistency of the regression models generated by the RSM software. From Table 5, it can be observed that the percentage error (PE) calculated for all the responses was less than 10%, meaning that the difference between the experimental (test) data and the predicted is within the acceptable limit thus confirming the suitability of the optimal conditions produced from the RSM.

Table 5: Predicted and test values of response variables under optimal conditions.

Optimized drying condition			Responses	Test value	Predicted value	Percentage error (PE)
Conveyor speed (mm/s)	Drying temp. (°C)	Drying airspeed (m/s)				
5.000	110.529	2.484	Output capacity (kg/h)	9.860	10.058	2.01
			Head rice yield (%)	75.217	76.667	1.93
			drying time (min)	31.8968	29.914	6.21

CONCULUSION

Response surface methodology (RSM) was used to optimize the drying condition of a continuous flow dryer. The input parameters used were conveyor speed, drying temperature and drying air speed, while the output parameters used were drying output capacity; total milling yield; head rice yield; time taken for complete drying. The optimum values of response variables obtained at optimum drying condition (of 5.000 mm/s conveyor speed, 110.529 °C drying temperature and 2.484 m/s drying air speed) were: 10.058 kg/h of drying output capacity, 76.667 % head rice yield, and 29.914 minutes total drying time. The validation of the model was conducted and the test values of responses obtained at the optimum drying condition were: 9.860 kg/h for drying output capacity; 75.217 % head rice yield; 31.8968 min for drying time. This is an indication that the RSM adequately described the developed models within the acceptable range of performance responses. It is recommended that the dryer can be improved by increasing the size of the conveyor and the number of heating elements to address the low output capacity of the continuous dryer.

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