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Mathematical Modeling and Optimization of Plantain Chip Drying: A Parametric Study on Air Frying Conditions

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Abstract

Air frying is a promising technology for the production of healthy and nutritional snacks. The process optimization and parameters analysis of the drying of plantain chips was carried out using Buckingham's pi theorem. Studies were conducted to examine how various processing conditions affected the nutritional and sensory properties. The variables considered for the study were Drying temperature (80 – 100 °C), Air flow rate (0.25 – 0.45 m/sec), Chimney diameter (20 – 40mm), Chip thickness (0.5-1mm) while the responses were drying rate and drying efficiency. The Analysis of Variance (ANOVA) data showed that the variables affected the responses (drying rate and drying efficiency) significantly ($p < 0.05$). It was observed that for the optimal response values of 0.0161177 Kg/h and 88.88 % for the drying rate and efficiency respectively. The predictive models developed in the research work will be used for predicting process performance of drying plantain chips.

Keywords: *Plantain drying, Optimization, Analysis of variance, Tray drier*

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1. Introduction

Food preservation involves food processing techniques that decrease the oxidation of fats that cause rancidity and stop the growth of microbes like yeasts (however, other techniques work by adding harmless bacteria or fungi to the food). Among the oldest methods of preservation are drying, refrigeration, and fermentation. Modern methods include canning, pasteurization, freezing, irradiation, and the addition of chemicals. Advances in packaging materials have played an important role in modern food preservation. By definition, drying or dehydration is the process of removing water from food, either liquid or solid, or by evaporation to produce a solid product with a low enough water content [1].

A tropical fruit belonging to the banana family is called a plantain. Compared to bananas, they are bigger, starchier, and have thicker skin. In many tropical regions, including Africa, the Caribbean, and Latin America, plantains form a staple diet [2]. In addition to their nutritional properties, the extraction of fibers from banana and plantain species is of great significance across a multitude of sectors [3]. Their distinctive properties, such as their remarkable strength-to-weight ratio and inherent buoyancy, make them essential raw materials for a variety of applications. For instance, the remarkable strength and resilience of banana fibers are used to fabricate shipping cables [4, 5, 6]. However, recirculating drying air and mixing it with fresh air reduces energy consumption. Misha et al. [7] highlighted that the rotating/moving tray dryer can produce more uniform drying, but one of the main challenges facing processing industries during drying is the issue of using the best process combination to produce quality products. But however, for certain products, this process decreases its quality. Hancioglu et al. [8] suggested that the boundary temperature of the drying chamber should be reduced to obtain a lower energy loss and higher energy. He further stated that researchers should pay attention to the components where the greatest potential is destroyed and quantify the extent to which modification of one component affects, favorably or unfavorably, the performance of other components of the system. However, there is a need for serious research for suitable, cheap, less energy-consuming, and efficient process methods in the processing industries. Thus, the study presents the process optimization and parameters analysis of the drying of plantain chips.

2. Materials and Methods

For this research work, having considered all available plantain species in the research area, the horn plantain species (Fig. 1) was selected for this study because it is widely available in our research location, which is Nnewi in Anambra State, Nigeria.

Figure 1: The Image of Unripe (a) and Ripe (b) Horn Plantain Species

For optimal drying outcomes in traditional processes, a tray dryer is utilized [9]. This cabinet has two walls and either one or two doors. To prevent heat transfer, high-density fiberglass wool insulation is used to cover the space between two walls. Gaskets are included with doors. Figure 2 depicts the image of a locally produced tray dryer. The mobile trolley is topped with stainless steel trays. Features of the tray dryer include a digital temperature controller and indication, a control panel board, and a process timer. For the purpose of this study, a tray dryer in the National Engineering Design Development Institute (NEEDI) Nnewi will be used for the drying of the plantain chips and for the analysis and optimization.

Figure 2: Image of A locally produced Tray Dryer

2.2 Method

2.2.1 Sample preparation

For this study, a freshly harvested plantain bunch was procured from Nkwo Nnewi market and taken to the research area, National Engineering Design Development Institute. Thereafter, the plantain skin was manually peeled off, which proceeded with slicing it into sizes with a stainless knife. A vernier caliper was used to obtain the precise chip thickness measurement specified in Table 1 while the plantain was being sliced. After being weighed using a digital balance, the chips were put into the departmental laboratory's tray dryer machine to dry.

During the experiment, some process parameters like air flow velocity, drying temperature, and chimney diameter were constantly manipulated using the stipulated measures in the design table to get the optimal values of the drying rate and efficiency.

2.3 Development of Predictive Models

Model development for the plantain chips drying machine was developed using dimensional analysis (Buckingham pi theorem). Buckingham's pi theorem derives its name from Buckingham's use of the symbol "π" for the dimensionless variables in his original paper in 1914 [10]. The π-theorem tells us that, because all complete physical equations must be dimensionally homogeneous, a restatement of any such equation in an appropriate dimensionless form will reduce the number of independent quantities in the problem by k.

Table 1: Design of Experiment Formulation

	Factor 1	Factor 2	Factor 3	Factor 4	Response 1	Response 2
Run	A: Drying Temperature	B: Air flow rate	C: Chimney Diameter	D: chips thickness	Drying rate	Drying efficiency
	^oC	m/sec	Mm	mm	Kgh-1	%
1	100	0.25	20	0.5		
2	100	0.25	20	0.5		
3	85	0.45	20	0.75		
4	85	0.3	20	1		
5	85	0.25	30	1		
6	100	0.45	40	0.75		
7	80	0.45	20	1		
8	100	0.45	40	1		
9	85	0.45	30	1		
10	100	0.25	30	0.75		
11	80	0.25	20	0.75		
12	100	0.3	20	1		
13	80	0.3	40	1		
14	80	0.25	40	0.5		
15	80	0.3	40	1		
16	100	0.25	40	1		
17	80	0.3	20	0.5		
18	80	0.45	40	0.5		
19	100	0.3	40	0.5		
20	80	0.45	30	0.75		
21	100	0.45	20	0.5		
22	85	0.25	40	0.75		

2.3.1 Drying/thermal efficiency model

The efficiency of the plantain chips drying machine depends on the drying temperature, air flow rate, weight of the plantain, chimney diameter, thickness of the dryer tray, and chip thickness (Table 2). Therefore, the efficiency in terms of dimensionless parameters is expressed as:

Table 2: Basic dimension of variables for drying/thermal efficiency Model

S/N	VARIABLES	SYMBOL	UNITS	DIMENSION UNIT
1	Thermal efficiency	η_{th}	%	-
2	Air flow velocity	v	m/s	LT^{-1}
3	Chips thickness	T_H	mm	L
4	Thickness of the tray	N_T	mm	L
5	Chimney diameter	D_c	mm	L
6	Plantain weight	Wp	Kg	M
7	Drying air temperature	T_i	K	θ

$$R_D = f\,(v.\ \rho.\ N_T.\ D_c.\ Mc.\ T_i) \quad (1)$$

Dependent = independent

The functional relationship between dependent and independent variable can be written as:

$$f = (R_D\ v.\ \rho.\ N_T.\ D_c.\ Mc.\ T_i) = 0 \quad (2)$$

Therefore, the total number of variables n, equals 7, i.e. n =7

Number of fundamental dimension m, equals 3, i.e. m = 3

Number of π-terms, can be determined by n – m. However, π-term is 7 – 3 = 4

$$\longrightarrow f(\pi_1, \pi_2, \pi_3, \pi_4) = 0 \quad (3)$$

Also, geometry Dc, flow properties v, Bulk density ρ , were selected as the repeated factor Therefore:

$$\pi_1 = (D_c^{a_1} v^{b_1} \rho^{c_1} R_D) \quad (4)$$

$$\pi_2 = (D_c^{a_2} v^{b_2} \rho^{c_2} Mc) \quad (5)$$

$$\pi_3 = (D_c^{a_3} v^{b_3} \rho^{c_3} T_i) \quad (6)$$

$$\pi_4 = (D_c^{a4} v^{4} \rho^{c_4} N_T) \quad (7)$$

Therefore, equate the dimension units of the known factors to get the values of π_1, π_2, π_3, π_4

$$\mathbf{M^0L^0T^0} = L^{(a1)} . LT^{-1(b1)} . ML^{-3(c1)} . \mathbf{MT^{-1}} \quad (8)$$

$0 = C_1 + 1$

$C_1 = -1$

$L^0 = L^{a1} + L^{b1} L^{-3c1}$

$0 = a_1 + b_1 - 3c_1$

$a_1 = -b_1 - 3$

$T^0 = T^{-b1} T^{-1}$

$1 = -b_1$

$a_1 = 1 - 3$

$a_1 = -2$

$$\pi_1 = (D_c^{-2} v^{-1} \rho^{-1} R_D) \quad (9)$$

Solving for π_2, we have:

$$\mathbf{M^0L^0T^0} = L^{(a2)} . LT^{-1(b2)} . ML^{-3(c2)} . \mathbf{M^0L^0T^0} \quad (10)$$

$M^0 = M^{c2}$

$c_2 = 0$

$L^0 = a_2 - 3c_2 + b_2$

$a_2 = -b_2$

$T^0 = T^{-1(b2)}$

$0 = -b_2$
$a_2 = 0$

$$\pi_2 = (D_c^0 V^0 \rho^0 M_c) \quad (11)$$

$$\pi_2 = (M_c)$$

(12)

Solving for π_3, we have:

$$M^0L^0T^0 = L^{(a3)} . LT^{-1(b3)} . ML^{-3(c3)} . \Theta \quad (13)$$

$M^0 = M^{c3}$
$C_3 = 0$
$L^0 = L^{a3} L^{b3} L^{-3c3}$
$-a_3 = b_3$
$T^0 = T^{-b3}$
$a_3 = 0$

$$\pi_3 = (Dc^0 V^0 \rho^0 T_i) \quad (14)$$

$$\pi_3 = Ti$$

(15)

Solving for π_4, we have:

$$M^0L^0T^0 = L^{(a4)} . LT^{-1(b4)} . ML^{-3(c4)} . MLT^{-3}\theta^{-1} \quad (16)$$

$M^0 = M^{c4} + M$
$C_4 = -1$
$L^0 = L^{a4} + L^{b4} + L^{-3c4} + L$
$-b_4 = a_4 + 4$
$T^0 = T^{-b4} + T^{-3}$
$b_4 = -3$
$a_4 = -1$

$$\pi_4 = (D_c^{-1} V^{-3} \rho^{-3} N_T$$

(17)

Therefore,

$$f(\pi_1, \pi_2, \pi_3, \pi_4) = 0$$

$$f(D_c^{-2} v^{-1} \rho^{-1}, Mc, Ti, D_c^{-1} v^{-3} \rho^{-1} N_T) \quad (18)$$

$$(D_c^{-2} v^{-1} \rho^{-1}) = \phi(Mc, Ti, D_c^{-1} v^{-3} \rho^{-1} N_T) \quad (19)$$

According to Shefh *et al*. [11], combining the dimension terms to reduce it to a manageable level can be achieved by multiplication and division. However, equation 20 can be expressed as:

$$\Pi_5 = \frac{\pi_4 \times \pi_3}{\pi_2} \quad (20)$$

$$\Pi_5 = \frac{T_i}{M_c} \times \frac{N_T}{D_c V^3 \rho}$$

$$\Pi_5 = \frac{N_T T_i}{M_c D_c V^3 \rho} \quad (21)$$

Equating Eq.21 into Eq.19 to determine the R_D we have:

$$R_D = \emptyset\left(\frac{T_i N_T Dc^2}{M_c V^3}\right) \quad (22)$$

Six process parameters, namely air flow velocity, chimney diameter, Chip thickness, tray thickness, and drying temperature were used for this experimentation (Table 3). The experiment was conducted with the DESIGN EXPERT SOFTWARE 12.0. The optimal (custom) design was employed in such a way that it developed a flexible design structure to accommodate custom models, categorical factors, and irregular (constrained) regions. Runs were determined by a selection criterion chosen during the build.

Table 3: Data used to determine drying efficiency coefficient

S/N	Drying Temperature	Air flow velocity	Chimney Diameter	chips thickness	Plantain weight	Thickness of tray	Drying efficiency	Π_1	Π_5
	°C	m/sec	Mm	mm	Kg	mm	%		
1	100	0.25	20	0.5	10	0.5	90.1	90.1	100
2	100	0.25	20	0.5	10	0.5	90.1	90.1	100
3	85	0.45	20	0.75	10	0.5	88.7	88.7	56.67
4	85	0.3	20	1	10	0.5	88.75	88.75	42.5
5	85	0.25	30	1	10	0.5	88.7	88.7	42.5
6	100	0.45	40	0.75	10	0.5	89.5	89.5	66.67
7	80	0.45	20	1	10	0.5	88.5	88.5	40
8	100	0.45	40	1	10	0.5	88.25	88.25	50
9	85	0.45	30	1	10	0.5	88.7	88.7	42.5
10	100	0.25	30	0.75	10	0.5	89.75	89.75	66.67
11	80	0.25	20	0.75	10	0.5	89	89	53.33
12	100	0.3	20	1	10	0.5	88.75	88.75	50
13	80	0.3	40	1	10	0.5	88.5	88.5	40
14	80	0.25	40	0.5	10	0.5	88.2	88.2	80
15	80	0.3	40	1	10	0.5	88.5	88.5	40
16	100	0.25	40	1	10	0.5	88.75	88.75	50
17	80	0.3	20	0.5	10	0.5	89.5	89.5	80
18	80	0.45	40	0.5	10	0.5	88.9	88.9	80
19	100	0.3	40	0.5	10	0.5	89.5	89.5	100
20	80	0.45	30	0.75	10	0.5	88.5	88.5	53.33
21	100	0.45	20	0.5	10	0.5	89.7	89.7	100
22	85	0.25	40	0.75	10	0.5	89	89	56.67

2.3.2 Analysis of Variance (ANOVA)

This method was utilized to predict any significant difference in the experiment's mean. However, Tables 4, Table 5, Table 7 and Table 8 show ANOVA results developed from calabash fiber composite based on the experimental results.

Table 4: Showing the Coefficients in Terms of Coded Factors for drying rate

Term	Coefficient Estimate	df	Standard Error	95% CI Low	95% CI High	VIF
Intercept	0.0167	1	0.0001	0.0165	0.0169	
A-Drying Temperature	-0.0005	1	0.0000	-0.0005	-0.0004	1.56
B-Air flow rate	-0.0001	1	0.0000	-0.0001	-0.0000	1.20
C-Chinmey Diameter	-0.0001	1	0.0000	-0.0001	-0.0000	1.48
D[1]	0.0002	1	0.0000	0.0002	0.0003	
D[2]	0.0000	1	0.0000	-0.0000	0.0001	
AB	-0.0000	1	0.0000	-0.0001	0.0000	1.41
AC	0.0001	1	0.0000	0.0001	0.0002	1.45
AD[1]	-0.0001	1	0.0000	-0.0002	-0.0000	
AD[2]	0.0000	1	0.0000	-0.0001	0.0001	
BC	4.891E-07	1	0.0000	-0.0000	0.0001	1.26
BD[1]	0.0000	1	0.0000	-0.0000	0.0001	
BD[2]	-0.0001	1	0.0000	-0.0002	-0.0001	
CD[1]	-0.0002	1	0.0000	-0.0002	-0.0001	
CD[2]	0.0001	1	0.0000	8.220E-06	0.0002	
A^2	0.0002	1	0.0001	0.0001	0.0004	1.59
B^2	-0.0004	1	0.0000	-0.0005	-0.0002	1.74
C^2	-0.0001	1	0.0000	-0.0002	0.0000	1.54

For the Final Equation in Terms of L Pseudo Components, the model is written as:

Drying rate = +0.0167 - 0.0005A - 0.0001B - 0.0001C + 0.0002D[1] + 0.0000 D[2] - 0.0000AB + 0.0001AC - 0.0001AD[1] + 0.0000 AD[2] + 4.891E-07BC + 0.0000 BD[1] - 0.0001 BD[2] -0.0002 CD[1] +0.0001 CD[2] +0.0002 A^2- 0.0004 B^2-0.0001

The equation in terms of coded factors can be used to make predictions about the response for given levels of each factor. By default, the high levels of the factors are coded as +1 and the low levels are coded as -1. The coded equation is useful for identifying the relative impact of the factors by comparing the factor coefficients. Again, the equation in terms of actual factors can be used to make predictions about the response for given levels of each factor. Here, the levels should be specified in the original units for each factor. This equation should not be used to determine the relative impact of each factor because the coefficients are scaled to accommodate the units of each factor and the intercept is not at the center of the design spac Thus, Final Equation in Terms of Actual Components is written as:

Equation for the drying rate when the chip thickness is 0.5 mm

Drying rate = 0.039657 - 0.000506 Drying Temperature + 0.025779 Air flow rate - 0.000091chimney Diameter - 0.000014 Drying Temperature * Air flow rate+1.33839E-06 Drying Temperature * chimney Diameter+ 4.89132E-07 Air flow rate * chimney Diameter +2.28466E-06 Drying - 0.035488Temperature² Air flow rate²-9.34281E-07 chimney Diameter²

Equation for the drying rate when the chip thickness is 0.75 mm

Drying rate = +0.038159 - 0.000494 Drying Temperature+0.024324 Air flow rate - 0.000064 chimney Diameter-0.000014 Drying Temperature * Air +1.33839E-06flow rate Drying Temperature * chimney Diameter+4.89132E-07 Air flow rate * chimney Drying Temperature²+2.28466E-06Diameter-0.035488 Air flow rate²-9.34281E-07 chimney Diameter²

Equation for the drying rate when the chip thickness is 1.00 mm

Drying rate = +0.036439-0.000486 Drying Temperature+0.026187 Air flow rate-0.000062 chimney Diameter-0.000014 Drying Temperature * Air +1.33839E-06flow rate Drying Temperature * chimney Diameter+4.89132E-07 Air flow rate * chimney Diameter+2.28466E-06 Drying Temperature²-0.035488 Air flow rate²-9.34281E-07 chimney Diameter

Table 5: Showing the Coefficients in Terms of Coded Factors for drying efficiency

Term	Coefficient Estimate	df	Standard Error	95% CI Low	95% CI High	VIF
Intercept	89.22	1	0.1959	88.67	89.76	
A-Drying Temperature	0.2310	1	0.0462	0.1028	0.3592	1.56
B-Air flow rate	-0.0988	1	0.0417	-0.2147	0.0171	1.20
C-Chinmey Diameter	-0.0974	1	0.0452	-0.2228	0.0280	1.48
D[1]	0.3547	1	0.0615	0.1840	0.5254	
D[2]	0.1101	1	0.0607	-0.0585	0.2787	
AB	-0.1402	1	0.0496	-0.2780	-0.0024	1.41
AC	0.0929	1	0.0479	-0.0400	0.2259	1.45
AD[1]	0.1030	1	0.0613	-0.0673	0.2733	
AD[2]	0.1822	1	0.0676	-0.0055	0.3699	
BC	0.1301	1	0.0481	-0.0035	0.2637	1.26
BD[1]	0.1695	1	0.0601	0.0028	0.3363	
BD[2]	-0.1151	1	0.0561	-0.2709	0.0407	
CD[1]	-0.2416	1	0.0612	-0.4114	-0.0718	
CD[2]	0.1491	1	0.0701	-0.0455	0.3437	
A^2	-0.1452	1	0.1349	-0.5199	0.2294	1.59
B^2	-0.1183	1	0.1329	-0.4873	0.2506	1.74
C^2	0.0221	1	0.1081	-0.2779	0.3221	1.54

Drying Efficiency

For the Final Equation in Terms of L_Pseudo Components, the model is written as;

Drying efficiency = 89.22+0.2310 A-0.0988 B-0.0974 C+0.3547 D [1] +0.1101 D[2] -0.1402 AB+0.0929 AC+0.1030 AD[1] +0.1822 AD[2] +0.1301 BC+0.1695 BD[1] -0.1151 BD[2] -0.2416 CD[1] +0.1491 CD[2] -0.1452 A^2-0.1183 B^2+0.0221 C^2

The equation in terms of coded factors can be used to make predictions about the response for given levels of each factor. By default, the high levels of the factors are coded as +1 and the low levels are coded as -1. The coded equation is useful for identifying the relative impact of the factors by comparing the factor coefficients. Again, the equation in terms of actual factors can be used to make predictions about the response for given levels of each factor. Here, the levels should be specified in the original units for each factor. This equation should not be used to determine the relative impact of each factor because the coefficients are scaled to accommodate the units of each factor and the intercept is not at the center of the design space. Thus, Final Equation in Terms of Actual Components is written as:

Equation for the drying rate when the chip thickness is 0.5 mm

Drying efficiency = +73.77898+0.315987 Drying Temperature+17.70729 Air flow rate-0.176354 chimney Diameter-0.140211 Drying Temperature * Air flow rate+0.000929 Drying Temperature * chimney Diameter+0.130112 Air flow rate * chimney Diameter-0.001452 Drying Temperature^2-11.83464 Air flow rate^2+0.000221 chimney Diameter^2

Equation for the drying rate when the chip thickness is 0.75 mm

Drying efficiency = +72.64531+0.323910 Drying Temperature+14.86135 Air flow rate-0.137284 chimney Diameter-0.140211 Drying Temperature * Air flow rate+0.000929 Drying Temperature * chimney Diameter+0.130112 Air flow rate * chimney Diameter-0.001452 Drying Temperature^2-11.83464 Air flow rate^2+0.000221 chimney Diameter^2

Equation for the drying rate when the chip thickness is 1.00 mm

Drying efficiency = +76.23447+0.277170 Drying Temperature+15.46790 Air flow rate-0.142941 chimney Diameter-0.140211 Drying Temperature * Air flow rate+0.000929 Drying Temperature * chimney Diameter+0.130112 Air flow rate * chimney Diameter-0.001452 Drying Temperature^2-11.83464 Air flow rate^2+0.000221 chimney Diameter^2

3. Results and Discussion

3.1 Analysis Result

To study the effect of process parameter conditions of the dryer machine on the dried plantain chips, a full quadratic model for each response was selected based on the best fit of the experimental data. Thus, a statistical significance of the developed models was evaluated using an Analysis of variance (ANOVA), and the accuracy of the models was further justified through a regression analysis and a normal plot of residuals. This method was utilized to predict if there is any significant difference in the mean of the experiment. The experimental results obtained at different combinations of processing conditions are presented in Table 4.

Table 6: Experimental Design and response results

	Factor 1	Factor 2	Factor 3	Factor 4	Response 1	Response 2
Run	A: Drying Temperature	B: Air flow rate	C: Chimney Diameter	D: chips thickness	Drying rate	Drying efficiency
	°C	m/sec	mm	mm	Kgh-1	%
1	100	0.25	20	0.5	0.0163	90.1
2	100	0.25	20	0.5	0.0163	90.1
3	85	0.45	20	0.75	0.0165	88.7
4	85	0.3	20	1	0.0165	88.75
5	85	0.25	30	1	0.0164	88.7
6	100	0.45	40	0.75	0.016	89.5
7	80	0.45	20	1	0.0168	88.5
8	100	0.45	40	1	0.016	88.25
9	85	0.45	30	1	0.0164	88.7
10	100	0.25	30	0.75	0.0163	89.75
11	80	0.25	20	0.75	0.0173	89
12	100	0.3	20	1	0.016	88.75
13	80	0.3	40	1	0.0168	88.5
14	80	0.25	40	0.5	0.0169	88.2
15	80	0.3	40	1	0.0168	88.5
16	100	0.25	40	1	0.016	88.75
17	80	0.3	20	0.5	0.018	89.5
18	80	0.45	40	0.5	0.0169	88.9
19	100	0.3	40	0.5	0.0163	89.5
20	80	0.45	30	0.75	0.0169	88.5
21	100	0.45	20	0.5	0.0162	89.7
22	85	0.25	40	0.75	0.0167	89

Table 7: Analysis of Variance results for Drying rate

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	4.859E-06	17	2.858E-07	82.66	0.0003	significant
A-Drying Temperature	2.943E-06	1	2.943E-06	851.09	< 0.0001	
B-Air flow rate	1.716E-07	1	1.716E-07	49.63	0.0021	
C-Chimney Diameter	1.647E-07	1	1.647E-07	47.64	0.0023	
D-chips thickness	5.186E-07	2	2.593E-07	74.99	0.0007	
AB	1.925E-09	1	1.925E-09	0.5566	0.4971	
AC	1.943E-07	1	1.943E-07	56.18	0.0017	
AD	9.441E-08	2	4.720E-08	13.65	0.0163	
BC	2.570E-12	1	2.570E-12	0.0007	0.9796	
BD	1.007E-07	2	5.037E-08	14.57	0.0146	
CD	2.479E-07	2	1.239E-07	35.84	0.0028	
A^2	7.129E-08	1	7.129E-08	20.62	0.0105	
B^2	1.774E-07	1	1.774E-07	51.30	0.0020	
C^2	1.859E-08	1	1.859E-08	5.38	0.0813	
Residual	1.383E-08	4	3.458E-09			
Lack of Fit	1.383E-08	2	6.916E-09			
Pure Error	0.0000	2	0.0000			
Cor Total	4.873E-06	21				

The Model F-value of 82.66 implies the model is significant. There is only a 0.03% chance that an F-value this large could occur due to noise. P-values less than 0.0500 indicate model terms are significant. In this case A, B, C, D, AC, AD, BD, CD, A^2, B^2 are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve the model. In order words, the co-efficient of regression R2 value 0.9989 indicated that competently represented the relationship between significant model terms and the drying rate. Thus, the Predicted R^2 of 0.1182 is not as close to the Adjusted R^2 of 0.9972 as one might normally with a difference of less than 0.2. Thus, the ratio of 37.970 indicated an adequate signal, meaning that this model can be used to navigate the design space.

For the process parameters, the ANVOA for the selected factorial model is seen below:

Table 8: Analysis of Variance results for Drying efficiency

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	6.79	17	0.3995	16.07	0.0078	significant
A-Drying Temperature	0.8322	1	0.8322	33.47	0.0044	
B-Air flow rate	0.2025	1	0.2025	8.14	0.0462	
C-chimney Diameter	0.4015	1	0.4015	16.15	0.0159	
D-chips thickness	1.72	2	0.8591	34.55	0.0030	
AB	0.1984	1	0.1984	7.98	0.0476	
AC	0.0937	1	0.0937	3.77	0.1242	
AD	0.5916	2	0.2958	11.90	0.0207	
BC	0.1819	1	0.1819	7.31	0.0538	
BD	0.2140	2	0.1070	4.30	0.1007	
CD	0.3900	2	0.1950	7.84	0.0413	
A^2	0.0288	1	0.0288	1.16	0.3424	
B^2	0.0197	1	0.0197	0.7933	0.4234	
C^2	0.0010	1	0.0010	0.0419	0.8478	
Residual	0.0995	4	0.0249			
Lack of Fit	0.0995	2	0.0497			
Pure Error	0.0000	2	0.0000			
Cor Total	6.89	21				

The model F-value of 16.07 implies the model is significant. There is only a 0.78% chance that an F-value this large could occur due to noise. P-values less than 0.0500 indicate model terms are significant. In this case, A, B, C, D, AB, AD, and CD are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve the model. In other words, the coefficient of regression R^2 value of 0.9856 indicated that it competently represented the relationship between significant model terms and the drying rate. Thus, a negative Predicted R^2 implies that the overall mean may be a better predictor of your response than the current model. In some cases, a higher-order model may also predict better.

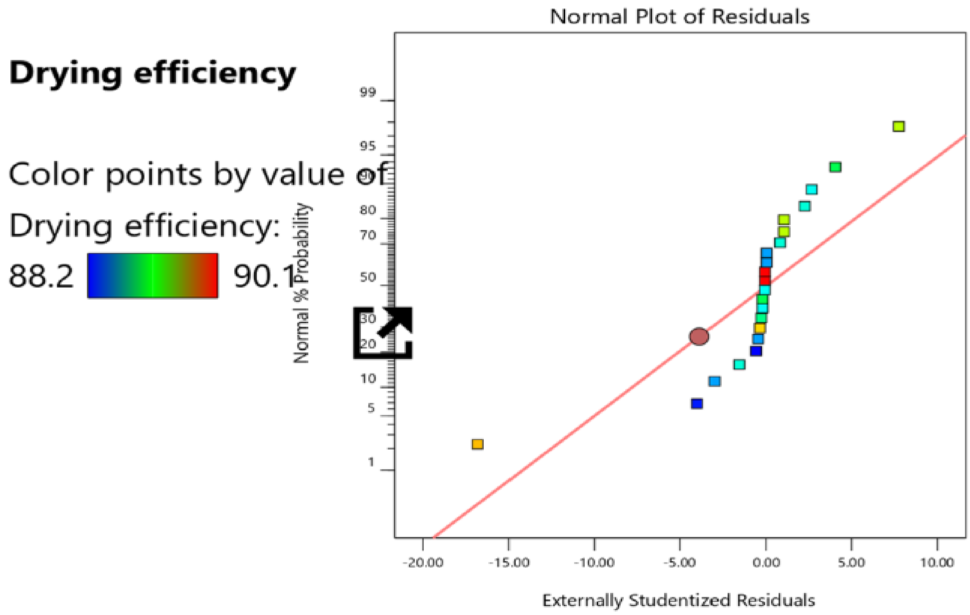

Figure 3a: Normal probability-residual;

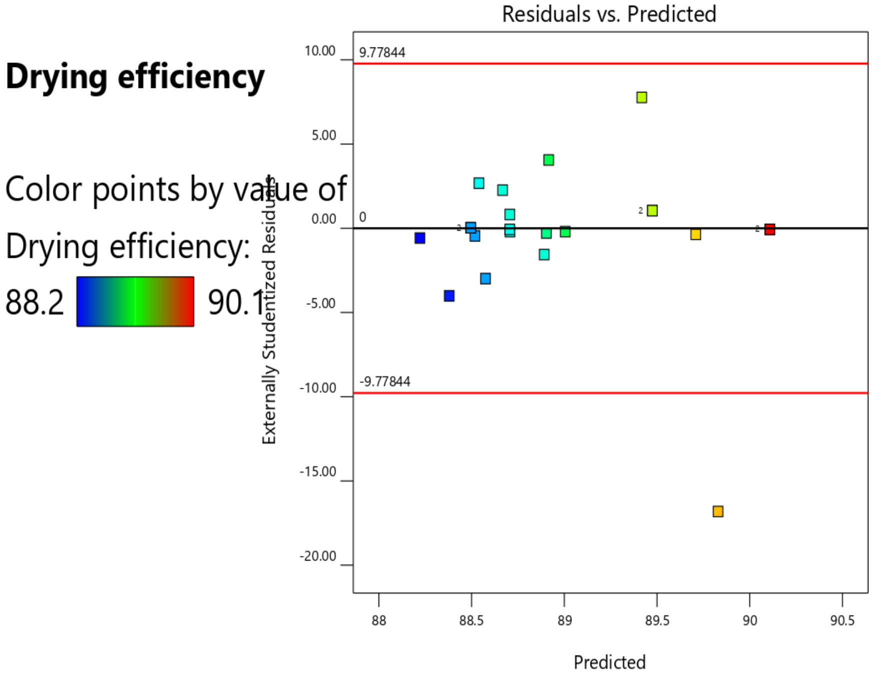

Figure 3b: externally studentized residuals-predicted response

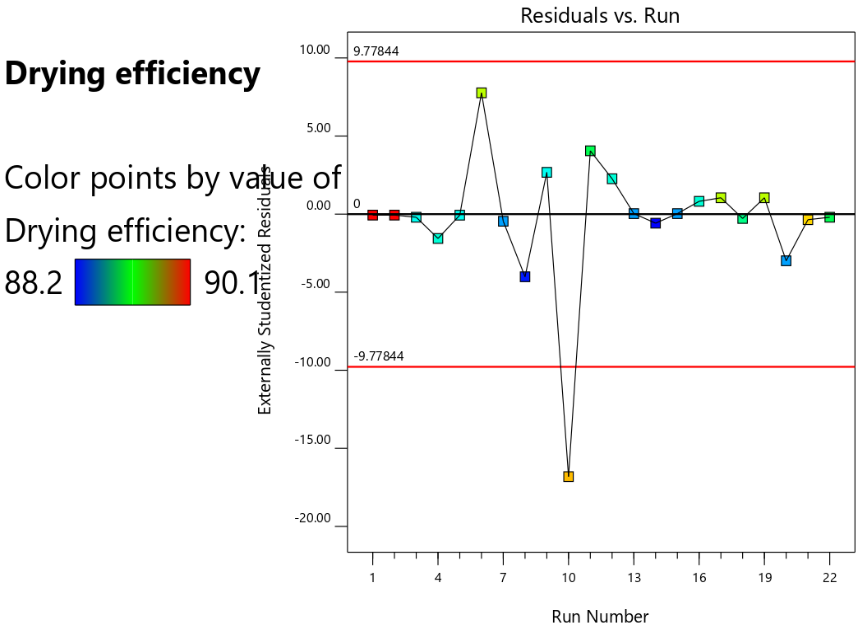

Figure 3c: externally studentized residuals-run following drying rate.

Adeq Precision measures the signal-to-noise ratio. A ratio greater than 4 is desirable. The ratio of 13.227 indicates an adequate signal, meaning that this model can be used to navigate the design space. Furthermore, the diagnostics plots of (a) normal probability distribution vs. studentized residuals, (b) studentized residuals and predicted as well as (c) studentized residuals Residual and experimental runs for drying efficiency are shown in Figure 3a, Figure 3b, and Figure 3c. Figure 3c actually proved that the residuals follow a normal distribution and fit the data well. The contour plot in Figure 4 shows the interaction between airflow rate and drying temperature against the drying rate. The increase in temperature with the accompanying decrease in air flow rate will result in an increase in the efficiency of the dried chips. Fig. 5 shows the combined effect of air flow rate and drying temperature on drying efficiency. The trend showed that a combination of shorter air flow rate with lower drying temperature will result in higher drying efficiency.

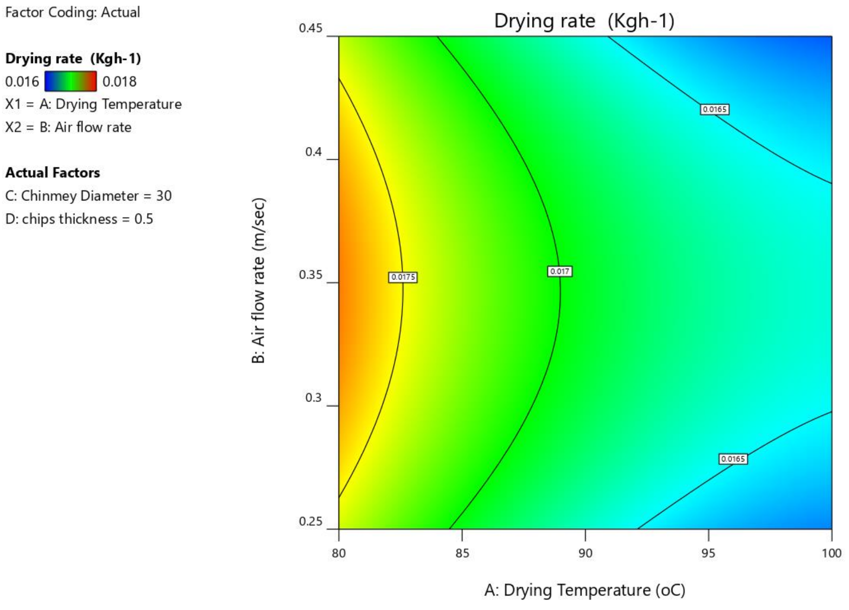

Figure 4: Contour plots of the response (Drying rate)

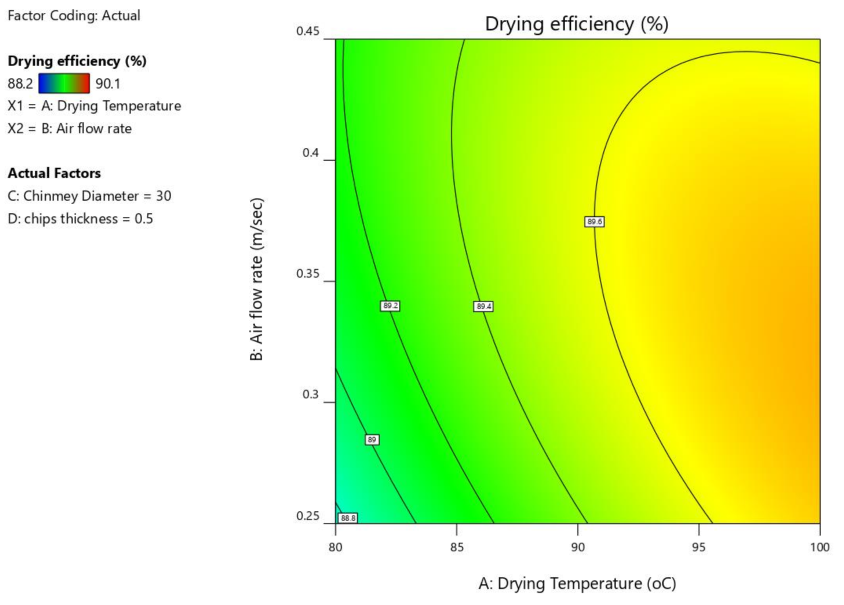

Figure 5: Contour plots of the response (Drying efficiency)

Conclusion

- From the preceding intentions achieved during the study, the following is the summary of findings:
- Some relevant process parameters that are required for the optimum drying of plantain chips were identified as airflow velocity of the dryer, diameter of the chimney, chip thickness, initial bulk density of the plantain, drying temperature, etc., and drying rate. Drying efficiency can be described with developed predictive mathematical models.
- The predictive models developed in the research work will be used for predicting the performance of the drying process of plantain chips.
- The ANOVA data showed that the variables affected the responses (drying rate and drying efficiency) significantly.
- The optimal process parameter values were 91.9775℃ for the drying temperature, 0.279371 m/sec for the air flow velocity, 21.9722 mm for the chimney diameter, and 1 m for the chip thickness. And for the optimal response values of 0.0161177 Kg/h and 888.88%for the drying rate and efficiency, respectively.

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Competing interests: The authors declare no competing interests.

Data Availability The authors confirm that the data supporting the findings of this study are available within the article.

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