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Research Article
Optimization of the Tunnel Drying Process of Cassava Chips Using Response Surface Methodology

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Abstract

Background and Objectives: Nigeria is the one of the largest producers of cassava chips in the world but the chips that are produced is often of low quality because of inadequate and ineffective methods drying techniques used to produce those chips. This study examined the critical factors in the optimization of the drying process of cassava chips in order to address the problem of low quality often occur in locally produced chips when compared to foreign ones. **Materials and Methods:** In this study, response surface methodology was used to investigate the effect of 3 drying factors [temperature (53-86°C), air velocity (0.98-5.0 m sec^{-1}) and loading density (3.32-6.68 kg m^{-2})] on the responses using central composite design (CCD). Process responses of the CCD recorded were moisture content, bulk density, water absorption capacity, swelling capacity, residual cyanide and color. **Results:** The optimum values of moisture content, bulk density, water absorption capacity, swelling capacity, residual cyanide and color were 10.22% (wet basis), 0.39 g cm^{-3}, 4.320 cm^3 g^{-1} sample, 2.26 g g^{-1} water sample, 3.78 mg kg^{-1} HCN sample and 0.25, respectively. **Conclusion:** Lower temperatures of drying minimally reduced the level of cyanide content and gave finest color to the chips. Contrariwise, higher drying temperatures reduced moisture content and bulk density of the chips.

Key words: Tunnel drying, cassava chips, optimization, response surface methodology, moisture content and bulk density

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Competing Interest: The author has declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Statistical tools are tremendously used in optimization Processes. One of such tools is response surface methodology (RSM). The RSM is a collection of statistical and mathematical techniques useful for optimization function primarily in simulation[1]. It is frequently used for the optimization of stochastic simulation model[2,3]. This methodology is based on approximation of stochastic objective function by a low order polynomial on a small sub-region of the domain. The coefficient of the polynomial are estimated by ordinary least square applied to number of observations of the probable objective function. To this end, the objective function is evaluated in an arrangement of points referred to as experimental design[3]. Based on the fitted polynomial, the local best point is derived, which is used as the current estimator of the optimum and as the centre point of the new region of interest where again the probable objective function is approximated by a low order polynomial[4]. The application of RSM to design optimization is aimed at reducing cost of expensive analysis methods (for example, finite element method) and their associated numerical noise.

Nigeria is the world's largest producer of cassava[5,6] and has a defined national policy to aggressively expand its production and processing for the economic development of the country. Cassava chips are the most common form in which dried cassava root are marketed and most exporting countries produce them, it is a rich source of cassava pellet, alcohol, industrial starches and cassava beer[7,8]. In 2004, the local demand of cassava chips in Nigeria rose to 1,500 t/ day[9] and estimated foreign demand from China alone was 1-million tonnes in 2012 as shown in a joint report by CBN., NIRSAL. and FMARD[10]. This demand could not be met due to the lack of effective technology. Tunnel drying technology could be advantageous for drying cassava chips because it has the potential to dry large volumes of product at a time. However, little or no recorded work has been done in Nigeria to adapt and improve cassava chip tunnel dryer design in order to optimize its drying capacity and energy efficiency for local use. There is need to optimize the drying of this product as it forms a major staple food and more so Nigeria happens to be highest producer of cassava worldwide.

Some researchers have used RSM for optimization process. For instance,[11] used RSM to evaluate thermo-mechanical process intensification for oil extraction from orange peelsand[12] optimized a microwave assisted banana drying process using RSM but the use of RSM tool for cassava chips drying optimization is scarce as far as literature is concerned. Therefore, in the present study, response surface methodology was employed to optimize drying process of cassava chips in other to evaluate the effect of process variables (process factors) on responses (quality factors) of the chips.

MATERIALS AND METHODS

Study area: The study was carried out in the year 2014 (15th January-10th July). The study area of experimentation and analysis was in Food Science and Engineering departmental laboratory, Ladoke Akintola University of Technology, Ogbomosho, Nigeria.

Cassava chips drying process: Freshly harvested cassava roots (TME 7) were procured from Ladoke Akintola University of Technology (LAUTECH) Teaching and Research Farm, Ogbomoso. The cassava were manually peeled with stainless knife and washed with distil water. They were then loaded into the chipping machine available in the Department of Food Science and Engineering (LAUTECH). The machine was adjusted to produce cassava chips of $5\times1\times0.1$ cm dimension. The chips were further loaded into the tunnel dryer built in the departmental laboratory for drying. Temperature and relative humidity condition in the dryer were 27°C and 47%, respectively.

Experimental design: Combinations of 3 drying variables (air velocity, loading density and temperature) were used in the drying cassava chips. Design expert 16.0 software was used for a 3 level central composite design (CCD) for the optimization process. Table 1 shows both the actual and coded experimental design for response surface analysis for the drying process. The independent variables (factors) employed were temperature (°C) designated as (A), air velocity (m sec^{-1}) designated as (B) and loading density (kg m^{-2}) designated as (C) while the dependent variables (responses) measured were moisture content (%), bulk density (g cm^{-3}), swelling capacity (g g^{-1} water sample), water absorption capacity (cm^3 g^{-1} sample), residual cyanide content (HCN mg kg^{-1}) and colour.

Mathematically, the second order polynomial equation was formulated to represent the drying operation such that:

$$y = b_0+b_1A+b_2B+b_3C+b_{12}AB+b_{13}AC+b_{23}BC+b_{11}A^2+b_{22}B^2+b_{33}C^2$$

(Source: Design Expert 16.0 software)

where, y is the predicted responses namely: Moisture content, bulk density, swelling capacity, water absorption capacity, residual cyanide content and colour, respectively. Factors, b_0, b_1, b_2, b_3, b_{12} and b_{13}, b_{23}, b_{11}, b_{22} and b_{33} are the coefficients of temperature (A), air velocity (B) and loading density (C).

Chemical analysis of the samples: Moisture content, bulk density, swelling capacity, water absorption capacity, residual cyanide content and colour were subjected to chemical analyses using method adopted by AOAC[13].

Statistical analysis of the samples: All the experimental treatments were conducted in 3 replicates so as to ensure to conformity and the average were used for data analysis. The experimental data were analysed using one-way analysis of variance (ANOVA) and separation/comparison was done using Duncan's multiple range test at 95% confidence level. The statistical analysis were run on SPSS 15.0 version software.

Table 1: Experimental design for response surface using central composite design

	Coded variables			Actual variables		
Runs	A	B	C	A	B	C
1	$-\sqrt{2}$	0	0	53.00	3.50	5.00
2	-1	-1	-1	60.00	2.00	4.00
3	-1	-1	+1	60.00	2.00	6.00
4	-1	+1	-1	60.00	5.00	4.00
5	-1	+1	+1	60.00	5.00	6.00
6	0	$-\sqrt{2}$	0	70.00	0.98	5.00
7	0	$+\sqrt{2}$	0	70.00	6.02	5.00
8	0	0	$-\sqrt{2}$	70.00	3.50	3.32
9	0	0	0	70.00	3.50	5.00
10	0	0	0	70.00	3.50	5.00
11	0	0	0	70.00	3.50	5.00
12	0	0	0	70.00	3.50	5.00
13	0	0	0	70.00	3.50	5.00
14	0	0	0	70.00	3.50	5.00
15	0	0	$+\sqrt{2}$	70.00	3.50	6.68
16	+1	-1	-1	80.00	2.00	4.00
17	+1	-1	+1	80.00	2.00	6.00
18	+1	+1	-1	80.00	5.00	4.00
19	+1	+1	+1	80.00	5.00	6.00
20	$+\sqrt{2}$	0	0	86.00	3.50	5.00

A: Temperature (°C), B: Air velocity (m sec^{-1}), C: Loading density (kg m^{-2})

RESULTS AND DISCUSSION

Results of quality characteristics of cassava chips as affected by temperature, air velocity and loading density: Table 2 shows the values of moisture content as affected by the drying variables (temperature, air velocity and loading density). The results also show that there were significant differences among the samples. However, there were no significant difference observed between samples dried at 70°C, 6.02 m sec^{-1}, 5 kg m^{-2} and samples dried at 70°C, 3.5 m sec^{-1}, 3.32 kg m^{-2}. With a moisture content of 11.34%, there was no significant difference at ($p<0.05$) between the samples dried at 70°C, 3.5 m sec^{-1}, 5 kg m^{-2} likewise at a moisture content value of 11.35%. It was also observed that there was no significant difference between samples dried at 60°C, 2 m sec^{-1}, 4 kg m^{-2} and samples dried at 60°C, 5 m sec^{-1}, 4 kg m^{-2}. Finally, there was no significant difference observed among samples dried at 80°C ($p<0.05$). It is clear from the table that as temperature increased, moisture content decreased. The same observation of inverse relationship of temperature was earlier reported by Ndukwu[14]. This suggests that drying at higher temperatures could be good for achieving lower moisture contents in good time. The same observation was reported by Malumba *et al.*[15] but at

Table 2: Results of response surface methodology analysis on the quality attributes of cassava chips as affected by temperature, air velocity and loading density

Variables			Responses					
A	B	C	MC	BD	WAC	SC	Cyanide	Color
53	3.50	5.00	12.97±0.01^{j}	0.50±0.06^{a}	1.43±0.02^{a}	1.09±0.04^{a}	3.78±0.08^{a}	0.25±0.03^{a}
60	2.00	4.00	12.69±0.07^{h}	0.50±0.04^{a}	2.22±0.09^{c}	1.32±0.01^{b}	4.46±0.03	2.31±0.1^{bc}
60	2.00	6.00	12.86±0.06^{i}	0.48±0.04 ^{a}	2.01±0.01^{b}	1.35±0.02^{b}	4.32±0.06^{b}	2.48±0.08^{d}
60	5.00	4.00	12.67±0.01^{h}	0.48±0.01^{a}	2.23±0.10^{c}	1.32±0.^{11b}	4.45±0.^{07b}	2.21±0.05^{b}
60	5.00	6.00	12.71±0.02^{h}	0.48±0.01^{a}	2.12±0.06^{b}	1.34±0.04^{b}	4.33±0.03^{b}	2.44±0.05^{c}
70	0.98	5.00	11.46±0.02^{g}	0.47±0.02^{a}	2.80±0.01^{de}	1.67±0.04^{c}	6.45±0.05^{c}	8.79±0.06^{h}
70	6.02	5.00	11.27±0.02^{de}	0.46±0.02^{a}	2.8±0.05^{de}	1.68±0.02^{c}	6.44±0.03^{c}	7.44±0.02^{f}
70	3.50	3.32	11.23±0.23^{d}	0.46±0.03^{a}	2.99±0.01e	1.63±0.03^{c}	6.79±0.04^{d}	7.11±0.04^{e}
70	3.50	5.00	11.35±0.005^{ef}	0.46±0.04^{a}	2.88±0.03^{de}	1.68±0.03^{c}	6.43±0.04^{c}	8.24±0.03^{g}
70	3.50	5.00	11.34±0.04^{de}	0.47±0.04^{a}	2.89±0.02^{de}	1.68±0.04^{c}	6.44±0.33^{c}	8.23±0.10^{g}
70	3.50	5.00	11.35±0.03^{ef}	0.46±0.04^{a}	2.88±0.09^{de}	1.67±0.04^{c}	6.45±0.21^{c}	8.21±0.10^{g}
70	3.50	5.00	11.35±0.01^{ef}	0.47±0.02^{a}	2.89±0.09^{de}	1.68±0.06^{c}	6.44±0.02^{c}	8.22±0.01^{g}
70	3.50	5.00	11.34±0.02^{de}	0.46±0.05^{a}	2.88±0.05^{de}	1.68±0.01^{c}	6.46±0.03^{c}	8.22±0.01^{g}
70	3.50	5.00	11.34±0.01^{de}	0.46±0.03^{a}	2.88±0.02^{de}	1.67±0.06^{c}	6.43±0.3^{c}	8.21±0.21^{g}
70	3.50	6.68	11.49±0.01^{g}	0.46±0.03^{c}	2.72±0.06^{d}	1.7±0.11^{c}	6.32±0.08^{c}	8.22±0.20^{g}
80	2.00	4.00	10.46±0.02^{b}	0.41±0.03^{a}	4.00±0.10^{f}	1.98±0.04^{d}	8.02±0.08^{e}	12.48±0.02^{i}
80	2.00	6.00	10.76±0.05^{c}	0.43±0.07^{a}	3.97±0.02^{f}	2.00±0.2^{d}	7.89±0.10^{e}	15.44±0.04^{k}
80	5.00	4.00	10.77±0.01^{c}	0.41±0.03^{a}	4.01±0.02^{f}	1.98±0.02^{d}	8.01±0.03^{e}	12.41±0.03^{i}
80	5.00	6.00	10.78±0.01^{c}	0.43±0.03^{a}	3.98±0.33^{f}	2.02±0.03^{d}	7.88±0.07^{e}	15.13±0.05^{j}
86	3.50	5.00	10.22±0.01^{a}	0.39±0.02^{a}	4.32±0.06^{g}	2.26±0.02^{e}	9.89±0.02^{f}	20.02±0.02^{l}

MC: Moisture content, BD: Bulk density, WAC: Water absorption capacity, SC: Swelling capacity, means in a column followed by same letter are not significantly different ($p<0.05$), all values are means of triplicates temperatures above 80°C, the incidence of gelatinization of cassava starch had been earlier reported Daouda *et al.*[16]. Furthermore, the effect of loading density on moisture content shows that as loading density increased, the moisture content also increased. For instance, recorded moisture content increased from 12.69% (at loading density of 4 kg m^{-2}) to 12.86% (at loading density of 6 kg m^{-2}) which suggested that heat energy was more effective at lower loading density samples resulting in lower moisture content.

In other words, drying rate increased with decrease in loading density. The other reason for this can be attributed to the fact that low loading density correspond to the shorted diffusion path (for moisture) and vice versa as earlier reported by Prvulović *et al.*[17]. Bulk density decreased with increase in temperature. The bulk density of chips recorded was similar to earlier values reported by Audu and Ikhu-Omoregbe[18] which ranged from 0.17-0.55 g cm^{-3} and[19] 0.29-0.56 g cm^{-3}. The values obtained can be considered as good flour because of its lower bulk density which is useful during packaging and transportation for which costs are more effective. The summary observation was that increase in drying temperatures would decreased the bulk density of cassava chips[20]. As seen in Table 2, water absorption capacity increased as temperature increased from 53-86°C. It was observed that temperature affected water absorption capacity positively because as drying temperature increased, water absorption capacity increased. It has been reported that increase in temperature induced a decrease in moisture content of the chips[20] but increases the water absorption capacity. The swelling capacity increased linearly with increase in temperature. This nature of increase in swelling capacity with increase in temperature was in consonant with the related work of chestnut ours by Correia and Beirão-da-Costa[21]. There was a significant difference among the samples especially for samples dried at different temperatures. Notwithstanding, samples dried at the same temperature did not differ significantly from each other. Swelling capacity values obtained in this study were higher than the values reported by Inyang *et al.*[19] which ranged from 0.24-0.26 but were comparable to the values reported by Daouda *et al.*[16] which ranged from 1.0-5.0 g g^{-1} water sample. Swelling capacity is important in determining flour quality, the higher the swelling capacity the greater is its suitability in the formulation of products. The residual cyanide of the cassava chips increased with increase in temperature as shown in Table 2. The same pattern of observation was earlier reported by Kakou *et al.*[22]. The samples exhibited significant differences among themselves for those samples dried at different temperatures but not significantly different within samples dried at the same temperature. Residual level of cyanide recorded in this study was lower than corresponding values reported by Enidiok *et al.*[23] which is 12.76 mg kg^{-1} HCN solid. All the values of residual cyanide reported in this study fall within safe cyanide level recommended and approved by Bradbury[24] which is 10 mg kg^{-1} HCN solid. It is observed that residual cyanide reduction level was negatively affected by temperature. The higher the temperature of drying, the higher the residual cyanide content of the chips. Also, higher loading densities conferred lower cyanide content on the chips as shown in all samples dried at 60, 70 and 80°C. The reason for this may be that higher loading rates increased the residence time of drying during which most of the cyanide was removed[23].

Effect of temperature, loading density and air velocity on the quality of the chips (as shown by response plots and pareto charts): Figure 1 shows the response surface behaviour of moisture content in relation to temperature and air velocity. The graph shows that an inverse relationship existed between temperature and moisture content because as the drying temperature increased moisture content decreased. The drying parameters that mostly affected the moisture content is temperature. However, loading density also affected the moisture content as clearly represented in the pareto chart in Fig. 2. The optimized condition of the chips shows that temperature and loading density affected the moisture content while air velocity had no effect on the moisture content. This similar observation has been reported by Ajala *et al.*[25]. Figure 3 represents the domain of bulk density of dried cassava chips samples. The slope descended in a concave nature; however, the pareto chart in Fig. 4 shows that the optimum parameters that affected the bulk density was primarily temperature, followed by loading density and air velocity was the least. Figure 5 shows the response plot of water absorption capacity of the cassava chips with a straight line slope with positive gradient. This shows that with increase in temperature, water absorption capacity also increased but the pareto chart in Fig. 6 shows that loading density affected water absorption in direct opposite with that of temperature. Therefore, the optimum condition of water absorption capacity of the chips was based on drying temperature and loading density of the chips. This similar findings was reported by Ajala *et al.*[25]. Figure 7 presents the effect of drying parameters on the swelling capacity of cassava chips and shows the positive gradient of the surface at which the model operated. In comparison to Fig. 6, the pareto chart of Fig. 8 shows that both temperature and loading density affected swelling capacity in the same direction. Hence, air

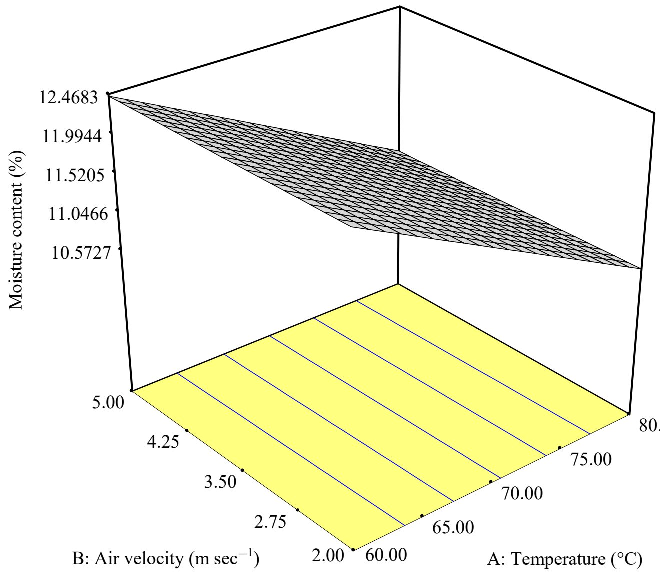

Fig. 1: Response surface: Moisture content of the chips as a function air velocity and temperature

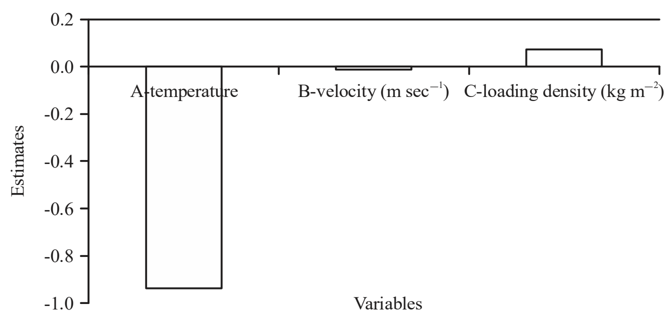

Fig. 2: Pareto chart: Effect of temperature, air velocity and loading density on moisture content of the chips

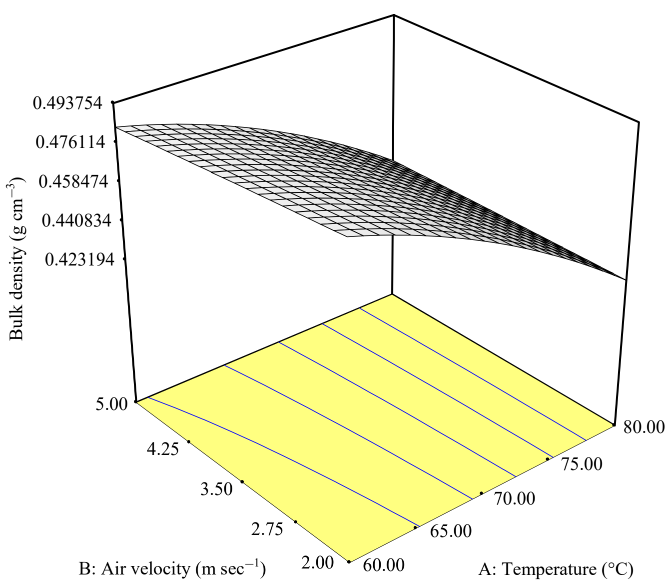

Fig. 3: Response surface: Bulk density of the chips as a function air velocity and temperature

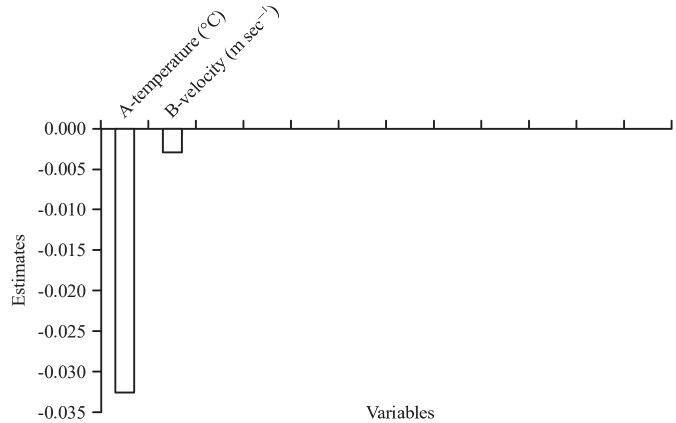

Fig. 4: Pareto chart: Effect of temperature, air velocity and loading density on bulk density of the chips

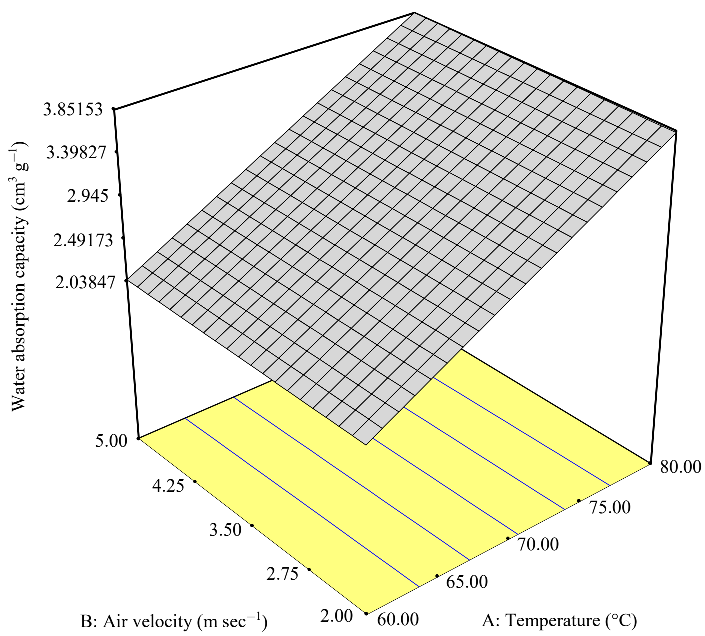

Fig. 5: Response surface: Water absorption capacity of the chips as a function air velocity and temperature

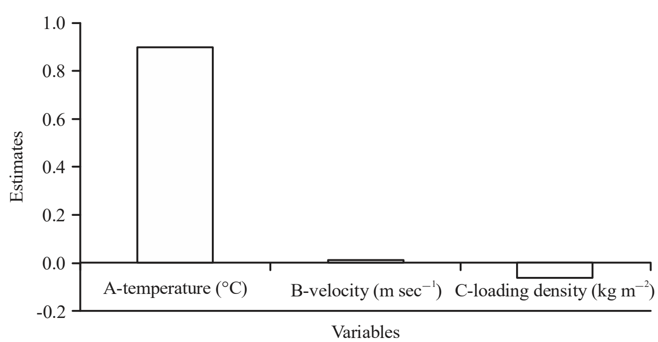

Fig. 6: Pareto chart: Effect of temperature, air velocity and loading density on water absorption capacity of the chips

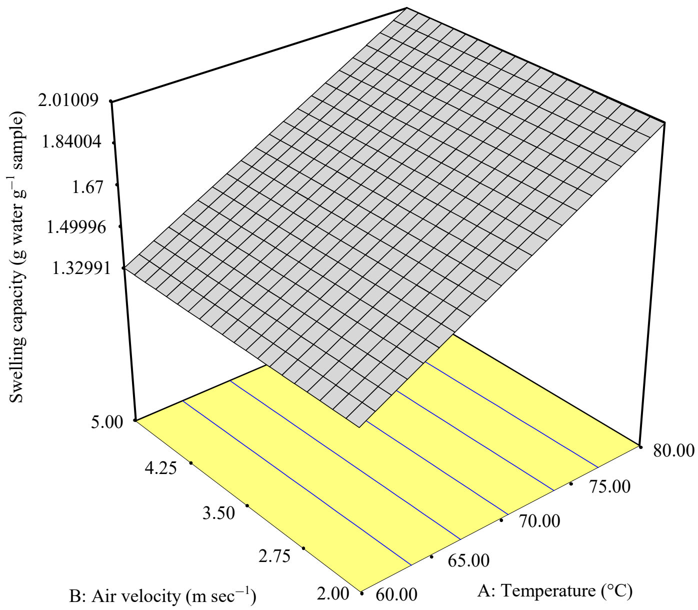

Fig. 7: Response surface: Swelling capacity of the chips as a function air velocity and temperature

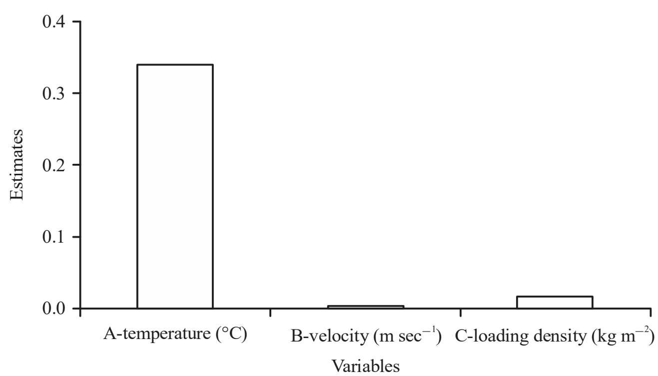

Fig. 8: Pareto chart: Effect of temperature, air velocity and loading density on swelling capacity of the chip

velocity did not affect the optimum condition of the chips[26]. The relationship between the input variables (temperatures, air velocity and load density) on the residual cyanide is presented in Fig. 9 which shows that as the temperature of drying increased, the level of cyanide also increased. However, Fig. 10 clearly shows that at the optimum level, both temperature and loading density affected the cyanide content in opposite direction while air velocity was redundant[22]. Figure 11 presents the response surface of total colour difference for cassava chip samples. The figure also confirms that as the temperature of drying increased, the total colour difference also increased. This means that as the drying temperature increased, the chips colour continued to deviate from the colour of fresh chips. Hence, drying the chips at a lower temperature between 50-70°C would give optimum condition and prevent gelatinisation of the product. This implies that increase in air temperature would increase the colour degradation due to higher heat transfer rate into the chips. Apart from temperature, loading density affected the colour difference in the same direction with temperature but air velocity affected the colour in an opposite direction with loading density as shown in Fig. 12. Other authors such as Velić *et al.*[27] had studied colour change of granny smith apple and Mohammadi *et al.*[28] studied the colour change of kiwi fruit slices. Good cassava chips are whitish in colour, hence, consumers generally look for white colour in the product. Therefore, it is advisable for the processors to apply lower temperatures (50-70°C) during drying to prevent browning effect of the non-enzymatic type.

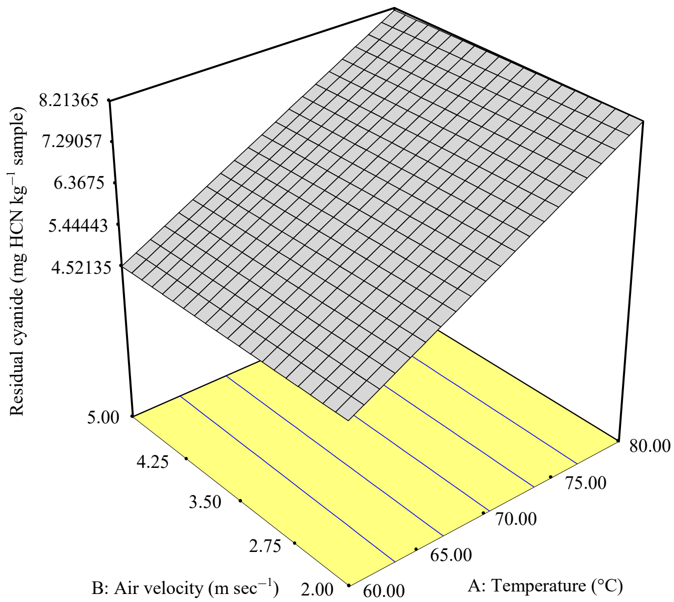

Fig. 9: Response surface: Residual cyanide of the chips as a function air velocity and temperature

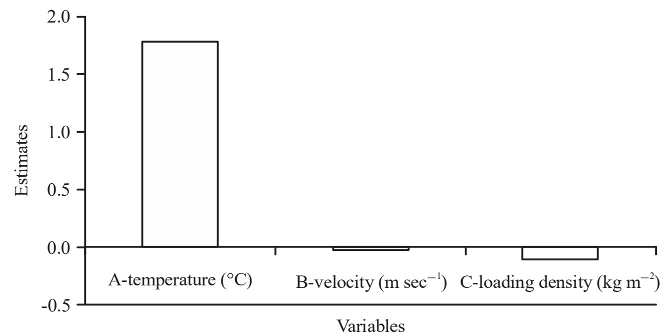

Fig. 10: Pareto chart: Effect of temperature, air velocity and loading density on residual cyanide of the chips

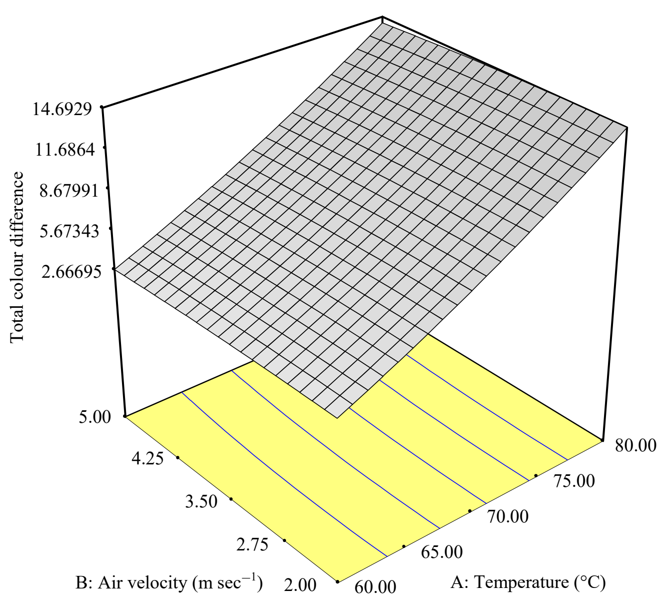

Fig. 11: Response surface: Total colour difference of the chips as a function air velocity and temperature

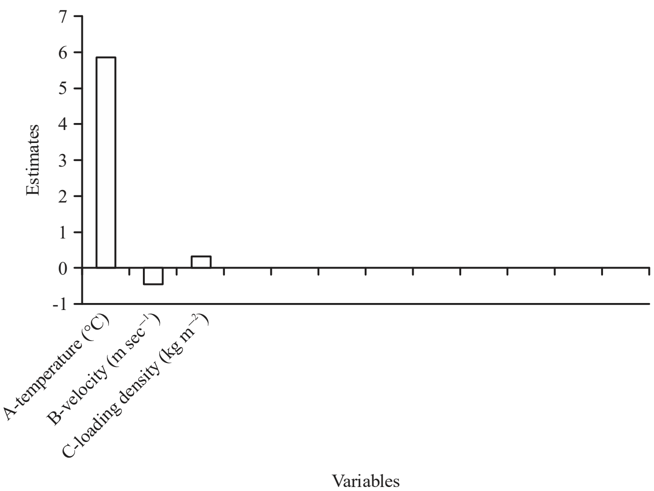

Fig. 12: Pareto chart: Effect of temperature, air velocity and loading density on total colour difference of the chips

Table 3: Summary of the result of analysis of variance (ANOVA)

Parameters	Source	Sum of square	Degree of freedom	Mean square	F-value	Prob>F
Moisture content (%)	Models	12.04	3	4.01	79.83	<0.0001
	Lack of fit	0.80	11	0.073	2436.69	<0.0001
Bulk density (g cm^{-3})	Models	0.015	12	1.26E-3	39.30	<0.0001
	Lack of fit	9.27E-5	2	4.63E-5	1.74	<0.0267
Water absorption capacity (water g g^{-1} solid)	Models	11.02	3	3.67	287.51	<0.0001
	Lack of fit	0.20	11	0.019	696.67	<0.0001
Swelling capacity (cm^3 g^{-1})	Models	1.57	3	0.52	3794.56	<0.0001
	Lack of fit	2.06E-4	11	1.87E-4	7.05	<0.0215
Residual cyanide (HCN mg kg^{-1})	Models	44.13	3	14.71	266.63	<0.0001
	Lack of fit	0.88	11	0.08	586.78	<0.0001
Total colour difference	Models	476.80	13	36.68	226.78	<0.0001
	Lack of fit	0.97	1	0.97	6611.22	<0.0001

Table 4: Summary of the statistical criteria to prove the reliability of the optimization models

Parameters	R^2	Adjusted R^2	Predicted R^2	Adequate precision
Moisture content (%)	0.9374	0.9256	0.8946	31.405
Bulk density (g cm^{-3})	0.9854	0.9603	0.5813	24.000
Water absorption capacity (g g^{-1} water sample)	0.9818	0.9784	0.9682	59.629
Swelling capacity (cm^3 g^{-1})	0.9986	0.9983	0.9976	216.88
Residual cyanide (HCN mg kg^{-1})	0.9804	0.9767	0.9643	57.497
Total colour difference	0.9980	0.9936	0.5526	58.757

Regression analysis of central composite design of the optimization conditions of the chips: Optimization of the cassava chips production was studied with 6 responses as earlier highlighted. For these responses, methods of analyzing the model include sum of squares, degree of freedom, mean square, F-value and probability. Others are R^2, adjusted R^2, predicted R^2 and adequate precision.

Analysis of variance (ANOVA) of the optimization model for moisture content (Eq. 1) is as shown in Table 3. The linear model was significant because the F-value of 79.83 was not significant relative to noise, that means there could be 0.0001 (that is 0.01%) chance that a model F-value could occur due to noise. This further implies that the model did represent the data within 95% confident interval. Furthermore, from Table 4, value of the coefficient of determination (R^2), adjusted R^2 and predicted R^2 are 0.9374, 0.9256 and 0.8946, respectively. The high values of these statistical criteria demonstrate the reliability of the model. The quadratic model of bulk density of samples is as shown in Eq. 2.

The analysis of variance of the model was significant because the value of 39.30 had 0.01% chance for noise to occur. Therefore, the model could represent the data well within 95% confidence interval. Furthermore, in Table 4, the R^2 was as high as 0.9854 with an adjusted R^2 of 0.9603 which proves that the model was effective in its predictive power. The linear model summary for water absorption capacity is as presented in Eq. 3 while Table 3 shows the relationship between the input variables and the response. The model generated was significant because the F-value of 287.51 implied the model was significant since there was only a

0.01% chance for noise to occur. The lack of fit F-value of 696.67 was significant as there was only a 0.01% chance this lack of fit F-value could occur due to noise: The reason for the significant lack of fit was that outliers values were significant in the model. However, from Table 4, the R^2 was as high as 0.9818 which proved that the model was reliable and the predicted R^2 of 0.9682 was in reasonable agreement with the adjusted R^2 of 0.9784. This further justified the value of R^2. Also, adequate precision confirmed further that the model was reliable in that the adequate precision measures the signal to noise ratio and a ratio greater than 4 is sufficient. Therefore, the ratio of 59.629 from Table 4 indicated that the model is reliable.

Optimization equations:

$$\text{Moisture content} = 11.52\text{-}0.94A\text{-}0.012B\text{+}0.07C \quad (1)$$

$$\text{Bulk-density} = 0.46\text{-}0.033A\text{-}2.973E\text{-}003B\text{-}7.54E\text{-}003A^2\text{-}4.685E\text{-}04B^2\text{-}2.23E\text{-}03C^2\text{+}1.25E\text{-}03AB\text{+}6.25E\text{-}03AC\text{+}1.25E\text{-}03BC\text{+}1.723E\text{-}03A^2B\text{+}3.75E\text{-}0.3A^2C\text{+}1.453E\text{-}03AB^2 \quad (2)$$

$$\text{Water absorption capacity} = 2.95\text{+}0.90A\text{+}0.011B\text{-}0.061C \quad (3)$$

$$\text{Swelling capacity} = 1.67\text{+}0.34A\text{+}1.964E\text{-}003B\text{+}0.017C \quad (4)$$

$$\text{Residual cyanide} = 6.38\text{+}1.80A\text{-}2.696E\text{-}003B\text{-}0.096C \quad (5)$$

$$\text{Colour} = 8.24\text{+}5.88A\text{-}0.4B\text{+}0.33C\text{+}0.56S2\text{-}0.15B2\text{-}0.31C2\text{-}0.03AB\text{+}0.66AC\text{-}0.022BC\text{+}0.34A2C\text{-}0.13AB2\text{-}0.037ABC \quad (6)$$

Where:

A = Temperature (°C)
B = Air velocity (m sec^{-1})
C = Loading density (kg m^{-2})
E = Exponential

The linear model governing the swelling capacity is as presented in Eq. 4. Table 3 shows the ANOVA that the F-value of 3794.56 implied the model was significant because there was only a 0.01% chance that noise could occur. The R^2 in Table 4 of the model is 0.9986 and the predicted R^2 of 0.9976 was in reasonable agreement with the adjusted R^2 of 0.9983 which further confirmed the reliability of the model. Adequate precision which measures the signal to noise ratio in which a ratio greater than 4 is desirable, therefore, the ratio of 216.88 in Table 4 shows an adequate signal in the model. Hence, this model can be used to navigate the design space. Equation 5 present the linear optimization model for cyanide content and Table 2 shows the ANOVA that the F-value of 266.63 implied the model was significant because there was only a 0.01% chance that noise could occur. Furthermore, R^2 value was 0.9804 and the predicted R^2 of 0.9643 was in reasonable agreement with the adjusted R^2 of 0.9767. Adequate precision which measures signal to noise ratio requires a value of 4 for a good model but Table 4 shows a ratio of 57.479 which indicated a good model. Therefore, this model is reliable in its predictive power. The quadratic model parameter for total colour difference (E) is presented in Eq. 6. In this case A, A2, C2, AC are significant model terms as confirmed by the pareto chart plot of Fig. 12. The ANOVA in Table 3 shows that the model F-value of 226.78 implied the model was significant. There was only a 0.01% chance that a noise could occur.

The overall implication of the study is that optimisation of cassava chip drying process is achievable in tunnel dryer and this could be applied for commercial production purpose. The temperature regimes of 50-80°C is recommended as higher temperatures above 80°C could gelatinize the chips. However the limitation of the study lies on the limited quality attributes of cassava chips being examined namely moisture content, bulk density, water absorption capacity, swelling capacity and cyanide content. Further work should be carried out on other physical, chemical, thermal and microbiological properties of the chips.

CONCLUSION

From the experiments carried out, optimization results showed that the models generated were reliable as all values of R^2 were greater than 0.9. Also, increase in temperature increased the values of water absorption capacity, swelling capacity, residual cyanide and total colour difference while the values of moisture content and bulk density reduced.

SIGNIFICANCE STATEMENT

This study discovers the possible synergetic effect of air temperature, loading density and air velocity on quality production of cassava chips. This study will help the researcher to uncover critical optimization parameters that many researchers were not able to explore during drying. Thus, a new theory on the combinations of these parameters to generate new optimization models for the drying of cassava chips may be arrived at. Effective application of this theory will address the lacuna in the optimization process technology for large-scale drying of cassava chips in tunnel dryers.

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