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Drying Rate of Selected Varieties of Cassava at Different Times of Harvest- A Response Surface Study

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Authors' contributions

This work was carried out in collaboration between all authors. Author MOI designed the study, author ANA carried out the bench work, performed the statistical analysis, wrote the protocol and the first draft of the manuscript. All authors read and approved the final manuscript.

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ABSTRACT

Aims: To process cassava varieties-TME 419, TMS 30572 and TMS 98/0505 at different harvesting regimes by shredding with three shredding apertures-3 mm, 6 mm and 10 mm of a motorized cassava shredding machine and determine their drying rate.
Study Design: Cassava varieties were harvested at three months interval- 10, 13 and 16 months. They were shredded at each harvesting regime. A faced central composite design (k=4) was employed to study the linear, interactive and quadratic effects of the independent experimental variables- temperature, shred diameter, time of drying and time of harvesting on drying rate.
Place and Duration of Study: Cassava tubers were obtained from National Research Institute, Umudike, Abia State. Shredding was done at the Engineering workshop of National Research Institute, Umudike.
Methodology: Sixty nine (69) experimental runs were generated. Center points were replicated nine times, corner and star points were not replicated, data obtained were subjected to response surface analysis and Analysis of variance.

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Results: Drying rate of the cassava shreds ranged from 0.000248 g/sec (TMS 30572,5400sec, 3 mm,100ºC) to 0.001063 g/sec (TMS 30572,5400 sec,10 mm,100ºC) at the 10th month; 0.000173 g/sec (TMS 30572,3600sec,6 mm,80ºC) to 0.000958 g/sec (TMS 98/0505,1800 sec, 3 mm,100ºC) at the 13th month and 0.00004 g/sec (TME 419,3600 sec, 6 mm, 80ºC) to 0.000336 g/sec (TMS 30572,1800 sec,10 mm,100ºC) at the 16th month. Linear and quadratic effects of time of drying had significant effect on the drying rate of TME 419; interaction between shred diameter and time of drying had significant effect on the drying rate of TMS 30572. Linear and quadratic effects of time of drying and interaction between shred diameter and time of drying had significant effect on the drying rate of TMS 98/0505.

Conclusion: Drying rate increased with shred diameter and temperature and reduced with reduction in shredding aperture.

Keywords: Cassava varieties; response surface methodology; motorized shredder; shredding; shred diameter; drying rate.

ABBREVIATIONS

ANOVA: Analysis of Variance; TME: Tropical Manihot Elit; TMS: Tropical Manihot Select; ANOVA: Analysis of Variance; Y: The Response; te: Temperature, sd: Shred Diameter, ti: Time of Drying; th: Time of Harvesting; b_0: Intercept; b_1x_1-b_2x_2: Linear (first order) Effect; $b_{11}x_1^2$-$b_2x_2^2$: Quadratic (second order) Effect; $b_{12}x_1x_2$: Cross Product (interactive) Effect; R^2: Coefficient of Determination; P: Probability Value; DF: Degree of Freedom; F: Variance Factor; S=Standard Error.

1. INTRODUCTION

Among the root and tuber crops, cassava (*Manihot esculenta*) is perhaps the most important food and cash crop and the most widely grown [1,2]. Its importance is increasing in Africa because of its diverse uses, cheapness, tolerance to environmental stresses and high productivity where other crops fail [3]. The nutritive deficiencies associated with cassava need not be a cause for concern when it is consumed with supplementary foods [4]. Moreover, cassava products are rarely eaten alone but commonly in combination with relatively protein-rich items and vegetables [5]. Improved cassava varieties which includes TMS 30572, TME 419, TMS 98/0505 and TMS 99/6012 amongst others have higher resistance to the effects of destructive pests and diseases (e.g. green spider mites, cassava mealy and viral infections), high yield, low cyanide and wide ecological adaptation [1,5]. Rapid post-harvest deterioration in cassava means that processing is more important than for any other root crop [6,7] and manufacturers prefer to convert it into more stable forms so as to prolong its shelf-life [8,9]. The size of cassava roots is usually too large to process and hence, it is reduced prior to further processing. Size reduction shortens the drying time and ensures elimination of the cyanide component present in the fresh root [10]. Shredding is a size reduction process [11] not widely used in cassava processing. It increases the surface area of the cassava exposed to the air making the drying faster. Drying provides a solution to maintain the quality of the tubers, reduce the cyanogenic glucoside content and improve the storability of the products [12]. Well dried cassava shreds can be conveniently stored for more than 12 months making it the most stable cassava product [13] and using a motorized shredder will save a lot of labor and time (U.J. Etoamaihe, MOUAU, Unpublished results). Sun- drying requires the most time; an electric dehydrator requires the least. Dehydrators with thermostats are not affected by weather condition and allow better control over food quality than sun-drying method [14]. A solar or electric food dehydrator can greatly speed the drying process and ensure more consistent results. Drying rate can be used to find the time that the food should spend in the drier before the moisture content is low enough to prevent spoilage by micro-organisms. The rate of drying also has an important effect on the quality of the dried foods and (in artificial driers) the fuel consumption.

Response surface methodology is a sequential form of experimentation used in predicting or optimizing response (dependent, outcome) variables. It is made up of a mathematical statistical model of several input (independent, predictor) factors [15]. A computer takes the experimental results and calculates models using Taylor second-order equations which define relationship between variables and responses. The models can then be used to calculate any and all combinations of variables and their effects within the test range [16]. The designs capable of generating a response surface include Central Composite and Box-Behnken designs [17]. Central composite designs are very efficient providing much information on experimental variable effects and over-all experimental error in a minimum number of required runs [17].

Improved processing using a motorized shredder will go a long way toward helping the world to maintain food security. This would contribute to increased cassava root availability and reliability which can provide self-sufficiency and also allow export to areas of the world where food is not available [18]. Also, it would greatly increase labor efficiency, incomes and living standards of cassava farmers and the urban poor by reducing the discomfort, health hazard and drudgery involved in traditional processing. Higher processing efficiency involved in the use of the shredding machine will improve the quality of the product and make them attractive and acceptable in a wider market. Cassava can be continuously harvested and marketed providing a consistent supply of product available for immediate processing at a fairly predictable price throughout the year making it preferable to other more seasonal crops such as grains, peas, beans and other food security crops [19]. Drying kinetics of food crops are generally affected by factors which include drying temperature and product sizes [20,21] and are crop specific [22]. The objective of the present work was to shred selected cassava varieties using a motorized shredder and investigate the effect of time of harvest, shred diameter, temperature and time of drying (in seconds) on the drying rate of the cassava shreds and to recommend the ideal combination of these parameters for quick drying of cassava shreds in order to prevent spoilage.

2. MATERIALS AND METHODS

2.1 Materials

Cassava roots of TME 419, TMS 98/0505 and TMS 30572 varieties were obtained from the National Root Crops Research Institute (NRCRI) Umudike, Abia State, Nigeria. These roots were monitored from planting and harvested at 10,13 and 16 months maturity respectively.

2.2 Methods

2.2.1 Shredding of cassava

The cassava varieties were washed and steamed in water for 20 minutes on a standard 80 cm diameter gas ring and later cooled. When cool, they were washed and peeled. The peeled, steamed cassava tubers were placed into the hopper of motorized cassava shredding machine and shredded by the shredding plate which has protruding perforations designed to shred the peeled tubers as they slide on top of it because of its reciprocating motion. The speed of the machine is 650 rpm with pulley size of 15 cm (U.J. Etoamaihe, MOUAU, Unpublished results). The shredded tuber strands were discharged beneath the shredding plate to the collection base. Three varying shredding disc apertures (3 mm, 6 mm and 10 mm) of the machine were used for the shredding process.

2.3 Determination of Drying Rates of Cassava Shreds

The shreds that emerged from the different shredding disc apertures of the machine were dried in trays in an oven at three arbitrarily selected temperatures of 60℃, 80℃ and 100℃.The shreds were weighed using electronic weighing balance before oven drying and removed from the oven after every 30 minutes (1800 sec.), reweighed and quickly placed back into the oven to continue the drying process. This was allowed to continue till 90 minutes. The drying rates between successive readings were obtained as (U.J. Etoamaihe, MOUAU, Unpublished results);

$$D_r = \frac{W_1 - W_2}{T} \quad (1)$$

Where,

W1= initial weight of cassava shreds (gms)
W2= weight of shreds after 30 minutes (gms)
T = time (30 mins)

2.4 Experimental Design and Statistical Analysis

A faced central composite design (k=4) was employed to study the linear, interactive and quadratic effects of the independent experimental variables. The statistical design with the model fitted to each set of data is shown below:

$$Y = \beta_0 + \beta_1x_1 + \beta_2x_2 + \beta_3x_3 + \beta_4x_4 + \beta_{11}x_{12} + \beta_{22}x_{22} + \beta_{33}x_{32} + \beta_{44}x_{42} + \beta_{12}x_1x_2 + \beta_{13}x_1x_3 + \beta_{14}x_1x_4 + \beta_{23}x_2x_3 + \beta_{24}x_2x_4 + \beta_{34}x_3x_4 + \epsilon \quad (2)$$

Key: Y= dependent response variable – drying rate, β_0 = intercept, β_1……….. β_{34} = estimated regression coefficients, x_1, x_2, x_3, x_4 = independent variables in the model (te, sd, ti, th), ϵ= random error.

The experimental variables- temperature (te), shred diameter (sd), time of drying (ti) and time of harvesting (th) were of three levels as shown in Table 1 while the experimental design with coded terms is as shown in Table 2. The center points were te=80℃, ti=3600 sec, th=13 months, sd=6 mm; corner points were te=100℃, ti= 5400 secs, th=16 months, sd=10 mm while the star points are te=60℃, ti=1800 secs, th= 10 months and sd=3 mm. The center points were replicated nine times, corner and star points were not replicated [23]. Drying rate was determined for the three harvesting regimes giving a total of sixty nine (69) experimental runs.

Data on each run was statistically regressed and analyzed for variance using Minitab software. Statistical significance was accepted at 5% probability levels (P=0.05). Plots of the fitted significant responses were made using Matlab software (version r2012a) to visualize these effects more clearly. Statistical Package for Social Sciences (SPSS–version 20) was used to obtain mean, standard deviation and analysis of variance (ANOVA) was done and judged for significance at P=0.05. Means were separated using Duncan's Multiple Range Test (DMRT).

Table 1. Experimental variables used in the faced-central composite design

Independent variables	Variable levels		
	-1	**0**	**1**
Temperature (ºC)	60	80	100
Shred diameter(mm)	3	6	10
Time (sec)	1800	3600	5400
Time of harvesting (months)	10	13	16

3. RESULTS AND DISCUSSION

Results of the drying rate of the cassava shreds are shown in Tables 3-5. The drying rate of the cassava shreds at the 10th month (Table 3) ranged from 0.000248 g/sec (5400 sec, 3 mm, 100ºC) to 0.001063 g/sec (5400 sec,10 mm,100ºC) with cassava shred from the cassava variety TMS 30572 having the highest and the

Table 2. Experimental design for determination of drying rate

Run	X_1 (Temperature ^oC)	X_2 (Shred diameter mm)	X_3(Time sec.)	X_4 (Time of harvest months)
1	-1	-1	-1	-1
2	-1	-1	1	-1
3	-1	1	-1	-1
4	-1	1	1	-1
5	1	-1	-1	-1
6	1	-1	1	-1
7	1	1	-1	-1
8	1	1	1	-1
9	-1	0	0	-1
10	1	0	0	-1
11	0	-1	0	-1
12	0	1	0	-1
13	0	0	-1	-1
14	0	0	1	-1
15	0	0	0	-1
16	0	0	0	-1
17	0	0	0	-1
18	0	0	0	-1
19	0	0	0	-1
20	0	0	0	-1
21	0	0	0	-1
22	0	0	0	-1
23	0	0	0	-1

lowest drying rate. At the 13th month (Table 4), the drying rate ranged from 0.000173 g/sec (3600 sec, 6 mm, 80ºC) to 0.000958 g/sec (1800 sec, 3 mm, 100ºC) with cassava shred from the cassava variety TMS 30572 having the lowest and cassava shred from the cassava variety TMS 98/0505 having the highest. Cassava shred from the cassava variety TME 419 had the lowest drying rate- 0.00004 g/sec (3600 sec, 6 mm, 80ºC) at the 16th month (Table 5) while cassava shred from the cassava variety (TMS 30572) had the highest drying rate- 0.000336 g/sec (1800 sec, 10 mm,100ºC). It was observed that drying rate increased with increase in shred diameter and temperature and reduced with reduction in shredding aperture. Mohammed [24] reported the same result for cassava chips and he noted that smaller sizes and thicknesses of cassava chips, dry faster when compared to larger sizes and thicknesses. When chips are thick, the outer layer easily compacts, thereby preventing the free air movement through the mass [25]. Thick slices may appear dry on the surface but their internal moisture content will still be high. Therefore, for effective drying, the chips shape/size and loading rate should permit air and moisture to readily pass through the mass when drying [26]. Also, Onipede and Agbetoye [27] reported higher drying rate at higher temperature irrespective of the shapes of cassava chips considered for their experiment, because as the temperature of air increases, the drying air is warm, dry and able to heat up the product, move over the product and provide latent heat for moisture evaporation thereby increasing the driving force for drying. Several authors reported considerable increases in drying rates when higher temperatures were used for drying fruits, vegetables and crops. These include; Doymaz [28], Erenturk et al. [29] and Madamba et al. [30]. Higher drying rate was recorded at the 10th and 13th month more than the 16th month. This can be attributed to the fact that the cassava varieties had more water at the 13th and 16th month because of rainfall and less water at the 16th month because of the short drought experienced at that time. Kormawa [31] confirmed this and reported that the rate of drying depends on moisture content of the food sample being dried in addition to its size and loading density. Regression coefficients for drying rate of cassava shreds are shown in Tables 6-8.

Table 3. Drying rate (g/sec.) of the cassava shreds (10 months)

Run	Temperature (°C)	Shred diameter (mm)	Time (sec.)	TME 419	TMS 30572	TMS 98/0505
1	60	3	1800	0.00053	0.0005	0.0006
2	60	3	5400	0.00021	0.00035	0.000289
3	60	10	1800	0.00057	0.000672	0.000643
4	60	10	5400	0.00031	0.000297	0.000291
5	100	3	1800	0.00064	0.000603	0.000795
6	100	3	5400	0.00031	0.000248	0.000334
7	100	10	1800	0.00048	0.000418	0.000386
8	100	10	5400	0.00082	0.001063	0.000772
9	60	6	3600	0.00041	0.000377	0.00034
10	100	6	3600	0.00044	0.000396	0.000434
11	80	3	3600	0.00045	0.000441	0.000472
12	80	10	3600	0.00049	0.000453	0.000521
13	80	6	1800	0.00097	0.000772	0.001002
14	80	6	5400	0.00049	0.000279	0.000437
15	80	6	3600	0.0005	0.000397	0.000505
16	80	6	3600	0.00056	0.000472	0.000659
17	80	6	3600	0.00049	0.0005	0.00067
18	80	6	3600	0.00051	0.000399	0.00061
19	80	6	3600	0.00064	0.00048	0.000499
20	80	6	3600	0.00042	0.00053	0.0005
21	80	6	3600	0.00057	0.00049	0.00055
22	80	6	3600	0.00057	0.0005	0.00048
23	80	6	3600	0.00059	0.00047	0.00051

Table 4. Drying rate (g/sec.) of the cassava shreds (13 months)

Run	Temperature (℃)	Shred diameter (mm)	Time(sec.)	TME 419	TMS 30572	TMS 98/055
1	60	3	1800	0.000413	0.000381	0.000428
2	60	3	5400	0.000247	0.000216	0.000281
3	60	10	1800	0.000381	0.000293	0.000348
4	60	10	5400	0.000180	0.000211	0.000198
5	100	3	1800	0.000733	0.000721	0.000958
6	100	3	5400	0.000315	0.000283	0.000317
7	100	10	1800	0.000616	0.000478	0.000596
8	100	10	5400	0.000180	0.000231	0.000251
9	60	6	3600	0.000202	0.000256	0.000263
10	100	6	3600	0.000259	0.000282	0.000397
11	80	3	3600	0.000331	0.000311	0.000329
12	80	10	3600	0.000267	0.000301	0.000328
13	80	6	1800	0.000443	0.000394	0.000463
14	80	6	5400	0.000201	0.000196	0.000207
15	80	6	3600	0.000282	0.000287	0.000290
16	80	6	3600	0.000258	0.000346	0.000355
17	80	6	3600	0.000314	0.000291	0.000328
18	80	6	3600	0.000285	0.000494	0.000279
19	80	6	3600	0.000303	0.000173	0.000219
20	80	6	3600	0.000224	0.000239	0.000212
21	80	6	3600	0.000286	0.000255	0.000249
22	80	6	3600	0.000284	0.000242	0.000235
23	80	6	3600	0.000257	0.000310	0.000225

Table 5. Drying rate (g/sec.) of the cassava shreds (16 months)

Run	Temperature (℃)	Shred diameter (mm)	Time(sec.)	TME 419	TMS 30572	TMS 98/0505
1	60	3	1800	0.000128	0.000231	0.000119
2	60	3	5400	0.000107	0.000102	0.000089
3	60	10	1800	0.000151	0.000142	0.000193
4	60	10	5400	0.000067	0.000073	0.000093
5	100	3	1800	0.000142	0.000275	0.000251
6	100	3	5400	0.000050	0.000111	0.000106
7	100	10	1800	0.000217	0.000336	0.000178
8	100	10	5400	0.000098	0.000094	0.000094
9	60	6	3600	0.000154	0.000105	0.000223
10	100	6	3600	0.000155	0.000227	0.000178
11	80	3	3600	0.000107	0.000145	0.000121
12	80	10	3600	0.000151	0.000158	0.000146
13	80	6	1800	0.000242	0.000253	0.000242
14	80	6	5400	0.000117	0.000093	0.000114
15	80	6	3600	0.000108	0.000173	0.000113
16	80	6	3600	0.00004	0.000138	0.000130
17	80	6	3600	0.000106	0.000155	0.000112
18	80	6	3600	0.00014	0.000167	0.000129
19	80	6	3600	0.000125	0.000166	0.000127
20	80	6	3600	0.000105	0.000144	0.000113
21	80	6	3600	0.000107	0.000138	0.000140
22	80	6	3600	0.000111	0.000172	0.000103
23	80	6	3600	0.000107	0.000136	0.000113

3.1 Drying Rate for Cassava Variety TME 419

Regression coefficients for drying rate of cassava variety TME 419 are shown in Tables 6 (a) and (b). Only the linear and quadratic effects of time of drying are significant. The resulting polynomial after removing non- significant terms for the analysis becomes:

$$\text{Drying rate} = 0.0010 - 3.3966e^{-7}ti + 2.5205e^{-11}ti^2 \quad (3)$$

The time of drying accounted for 81.8% of the variation in the response. This is in agreement with the work of Onipede and Agbetoye [27], who reported that drying rate increases as drying temperature and air flow rate increases but decreases as drying time increases. Alonge and Adeyemi [32] also reported that drying rate decreases with increase in drying time. From the analysis of variance, temperature, time of harvesting and time of drying were significant (P=0.05). Response surface curves of effects of shred diameter, time, temperature and time of harvest on the drying rate of the cassava variety TME 419 are shown in Figs. 1 to 3.

3.2 Drying Rate for Cassava Variety TMS 30572

Regression coefficients for drying rate of cassava variety TMS 30572 are shown in Tables 7 (a) and (b) and the response surface curve is shown in Fig. 4.

Table 6. Estimated regression coefficients and analysis of variance (ANOVA) for drying rate of cassava variety- TME 419

(a) Regression coefficients

Term	Coefficient	SE coefficient	P
Constant	0.0010	8.1381e-4	0.2156
te	2.0559e-5	1.4466e-5	0.1610
sd	6.6412e-6	5.2157e-5	0.8992
ti	-3.3966e-7	1.0332e-7	0.0018*
th	-7.6427e-5	7.9519e-5	0.3408
te*sd	1.1402e-7	2.8163e-7	0.6872
te*ti	5.3241e-11	5.487e-10	0.9231
te*th	-3.3083e-7	3.6067e-7	0.3631
sd*ti	4.8095e-9	3.1293e-9	0.1301
sd* th	-6.6439e-7	2.0492e-6	0.7470
ti* th	5.3148e-9	4.0074e-9	0.1903
te*te	-9.5008e-8	8.3702e-8	0.2614
sd*sd	-1.8229e-6	2.7980e-6	0.5174
ti*ti	2.5205e-11	1.0334e-11	0.0180*
th*th	8.1884e-7	2.7461e-6	0.7667
S= 9.3659e-9	R^2= 81.8%		R^2(adj)= 77.1%

**Significant at P=0.05*

(b) Analysis of variance

Source	SS	DF	MS	F	P
te	3.27608e-008	1	3.27608e-008	4.3	0.0443*
sd	1.08e-010	1	1.08e-010	0.01	0.9058
ti	2.98305e-007	1	2.98305e-007	39.19	0.0000*
th	1.33576e-006	2	6.6788e-007	87.75	0.0000*
te*sd	1.176e-009	1	1.176e-009	0.15	0.6963
te*ti	8.81667e-011	1	8.81667e-011	0.01	0.9148
te*th	3.67751e-008	4	9.19376e-009	1.21	0.3221
sd*ti	1.98375e-008	1	1.98375e-008	2.61	0.1141
sd* th	6.06104e-008	4	1.51526e-008	1.99	0.1139
ti *th	7.08442e-008	4	1.77111e-008	2.33	0.0723
Error	3.12052e-007	41	7.61103e-009		
Total	2.7801e-006	68			

Table 7. Estimated regression coefficients and analysis of variance (ANOVA) for drying rate of cassava variety- TMS 30572

(a) Regression coefficients

Term	Coefficients	SE coefficient	P
Constant	0.0010	9.0732e-4	0.2662
te	7.1095e-6	1.6128e-5	0.6611
sd	-7.5931e-6	5.8150e-5	0.8966
ti	-2.0192e-7	1.1579e-7	0.0853
th	-4.6807e-5	8.8656e-5	0.5997
te*sd	2.9150e-7	3.1400e-7	0.3574
te*ti	1.9560e-10	6.1179e-10	0.7504
te*th	-1.1833e-7	4.0211e-7	0.7697
sd*ti	7.0984e-9	3.4889e-9	0.0468*
sd*th	-3.9856e-6	2.2846e-6	0.0868
ti*th	-3.3333e-10	4.4679e-9	0.9408
te*te	-3.4631e-8	9.3320e-8	0.7120
sd*sd	1.0314e-6	3.1195e-6	0.7422
ti*ti	1.3420-11	1.1521e-11	0.2492
th*th	1.1087e-6	3.0616e-6	0.7187
S= 1.1642e8	R^2= 72.1%		R^2(adj)=64.9%

(b) Analysis of variance

Source	Sum of square	DF	MS	F	P
te	6.2136e-008	1	6.2136e-008	4.73	0.0354*
sd	2.0935e-009	1	2.0935e-009	0.16	0.6917
ti	2.51286e-007	1	2.51286e-007	19.15	0.0001*
th	9.68851e-007	2	4.84426e-007	36.91	0.0000*
te*sd	9.24338e-009	1	9.24338e-009	0.7	0.4062
te*ti	1.19004e-009	1	1.19004e-009	0.09	0.7648
te*th	8.32263e-009	4	2.08066e-009	0.16	0.9580
sd*ti	4.429e-008	1	4.429e-008	3.37	0.0735
sd*th	7.37321e-008	4	1.8433e-008	1.4	0.2495
ti*th	1.91359e-008	4	4.78398e-009	0.36	0.8324
Error	5.38049e-007	41	1.31231e-008		
Total	2.25552e-006	68			

Significant at P=0.05

Table 8. Estimated regression coefficients and analysis of variance (ANOVA) for drying rate of cassava variety- TMS 98/0505

(a) Regression coefficients

Source	Coefficient	SE coefficient	P
Constant	9.8791e-4	9.3065e-4	0.2932
te	2.0319e-5	1.6543e-5	0.2247
sd	3.4838e-6	5.9645e-5	0.9536
ti	-3.6644e-7	1.1815e-7	0.0031*
th	-6.0512e-5	9.0936e-5	0.5086
te*sd	-2.5078e-7	3.2207e-7	0.4396
te*ti	-2.3148e-10	6.2752e-10	0.7137
te*th	-3.9e-7	4.1245e-7	0.3486
sd*ti	7.4462e-9	3.5785e-9	0.0422*
sd* th	-3.3871e-7	2.3434e-6	0.8856
ti* th	7.5556e-9	4.5828e-9	0.1050
te*te	-6.2889e-8	9.5719e-8	0.5140
sd*sd	-7.7843e-7	3.1997e-6	0.8087
ti*ti	2.4643e-11	1.1817e-11	0.0418*
th*th	3.3816e-8	3.1403e-6	0.9914
S= 1.2248e-8	R^2= 78.6%		R^2(adj)= 73.0%

(b) Analysis of variance

Source	SS	DF	MS	F	P
te	6.99213e-008	1	6.99213e-008	7.56	0.0088*
sd	2.97675e-009	1	2.97675e-009	0.32	0.5735
ti	3.81277e-007	1	3.81277e-007	41.24	0.0000*
th	1.32272e-006	2	6.61359e-007	71.53	0.0000*
te*sd	8.214e-009	1	8.214e-009	0.89	0.3514
te*ti	1.66667e-009	1	1.66667e-009	0.18	0.6734
te*th	1.18215e-007	4	2.95537e-008	3.2	0.0225*
sd*ti	4.95042e-008	1	4.95042e-008	5.35	0.0258*
sd*th	4.54814e-008	4	1.13703e-008	1.23	0.3132
ti*th	9.91378e-008	4	2.47845e-008	2.68	0.0448*
Error	3.79066e-007	41	9.24551e-009		
Total	3.0873e-006	68			

**Significant at P= 0.05*

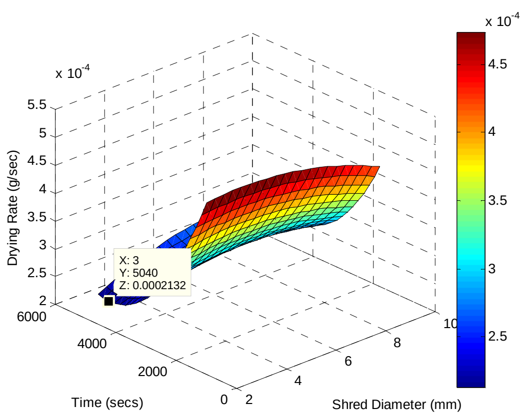

Fig. 1. Response surface curve of effects of time (secs) and shred diameter (mm) on the drying rate of cassava variety- TME 419

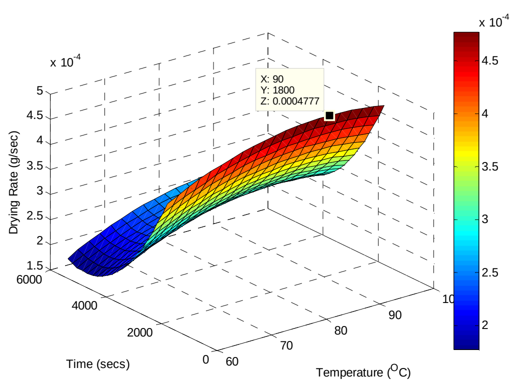

Fig. 2. Response surface curve of effects of time (secs) and temperature (ºC) on the drying rate of cassava variety-TME 419

The interaction between shred diameter and time of drying were significant (P=0.05) and these accounted for 72.1% variation in the drying rate of the cassava variety TMS 30572. Cassava shreds produced from the smallest shred diameter of 3 mm dried faster than others. Similar result was reported by Caitlyn and Sarah [33] who noted that thinner layers of cassava at higher temperature will dry much faster than thicker layers. The resulting polynomial after removing non-significant terms for the analysis becomes:

$$\text{Drying rate} = 0.0010 + 7.0984e\text{-}9 \text{ sd. ti} \qquad (4)$$

Analysis of variance shows that temperature, time of drying and time of harvesting significantly affected the drying rate of the cassava variety TMS 30572.

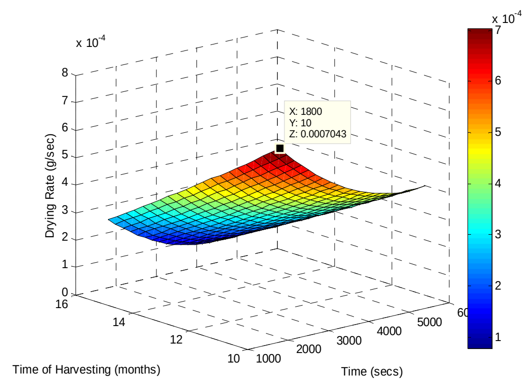

Fig. 3. Response surface curve of effects of time of harvesting (months) and time (secs) on the drying rate of cassava variety-TME 419

3.3 Drying Rate for Cassava Variety TMS 98/0505

Regression coefficients for drying rate of cassava variety TMS 98/0505 are shown in Tables 8(a) and (b).

Linear and quadratic effects of time of drying and interaction between shred diameter and time of drying significantly affected the drying rate of the cassava variety, TMS 98/0505. These combination of variables accounted for 78.6% in the variation of the drying rate. The resulting polynomial after removing non-significant terms for the analysis becomes:

$$\text{Drying rate} = 9.8791e^{-4} - 3.6644e^{-7}ti + 7.4462e^{-9}sd.ti + 2.4643e^{-11}ti^{2} \qquad (5)$$

This observation is in line with Fourier's law of heat transfer which states that drying is a function of the temperature, thickness of the object and time of drying [34]. From analysis of variance, temperature, time, time of harvesting, interaction between temperature and time of harvesting, shred diameter and time and interaction between time of drying and time of harvesting were significant. The response surface curves are shown in Figs. 5 and 6.

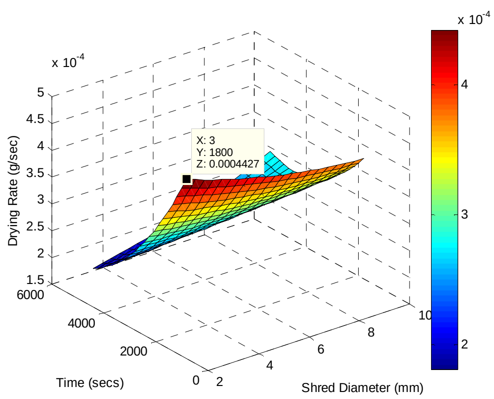

Fig. 4. Response surface curve of effects of time (secs) and shred diameter (mm) on the drying rate of cassava variety TMS 30572

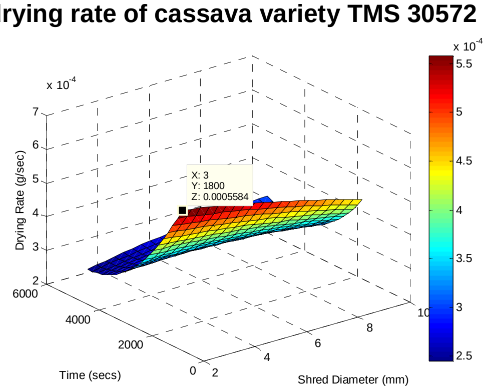

Fig. 5. Response surface curve of effects of time (secs) and shred diameter (mm) on the drying rate of cassava variety TMS 98/0505

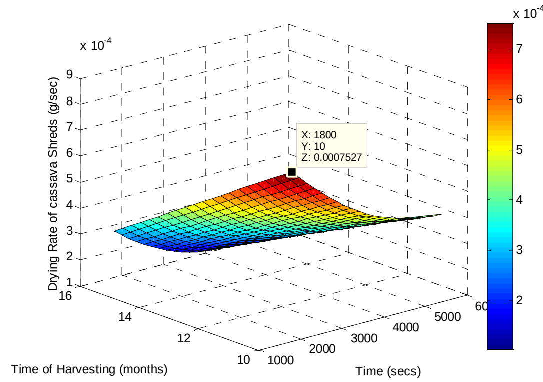

Fig. 6. Response surface curve of effects of time of harvesting (months) and time of drying (secs) on the drying rate of cassava variety TMS 98/0505

4. CONCLUSION

Drying rate increased with increase in shred diameter and temperature. However, it reduced with reduction in shredding aperture. There was variation in the drying rate of the cassava shreds as a result of differences in moisture content of the cassava varieties and influence of the experimental variables on the cassava shreds. The highest drying rate (0.001063 gm/sec) was recorded at the 10th month from the cassava variety TMS30572 while the lowest (0.00004 gm/sec) was recorded at the 16th month from the cassava variety TME419.Higher drying rate was recorded at the 10th and 13th month more than the 16th month. This is because the cassava varieties had more water at the 13th and 16th month due to rainfall and less water at the 16th month because of the short drought experienced at that time. To produce cassava shreds that will dry fast, shred diameter should be 3mm, harvesting period- December and temperature of drying should be 100ºC.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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