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EFFECT OF AIR INLET DUCT FEATURES AND GRATER THICKNESS ON COOKING BANANA DRYING CHARACTERISTICS USING ACTIVE INDIRECT MODE SOLAR DRYER

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ABSTRACT
The effect of air inlet duct area of an active indirect mode solar dryer on drying of cooking banana was studied. The factors considered for the experiment were: air inlet duct area and grater size of the product. The factors were considered at five different levels using the Central Rotatable Composite Design. The air inlet shapes considered were: square, rectangular, circular and triangular, while the product sizes were 4, 8, 12, 16 and 20 mm respectively. The experimental design gave a total of 52 runs for each experiment. The experiment was replicated three times with sun drying of the product as control. Data were obtained on a two hourly interval between 8:00 am to 6:00 pm on each drying day. Drying was achieved between 9 to 26 hours of drying, as compared to the control, which was between 15 to 37 hours depending on the grater size. The dryers were able to conserve between 26.67 to 37.84 % of the drying time for the products. The air inlet duct area had significant effect on the drying rate of the product at 5% level of significance.

Keywords: *Air inlet, drying rate, moisture content, sun drying, cooking banana.*

1. INTRODUCTION

Drying is the oldest method of food preservation. It involves removal of moisture from a material. Drying is the phase of post-harvest operation, during which the product is dried until it attains safe moisture level [1]. When an agricultural material is dried to a safe moisture level, the growth of bacteria, yeast and molds are minimized or completely eliminated. The shelf life of agricultural materials can be linked to the level of moisture available on the material; before, during and after drying or other post-harvest operations. Drying of food is accompanied by vapourizing the water that is contained in the food. To achieve this, the latent heat of vapourization must be known. Two basic processes that characterize the process of drying are: the transfer of heat to provide the needed latent heat of vapourization and movement of water or water vapour through the food materials and subsequent separation [8]. An indirect forced convection solar dryer was developed for Cassava in a bid to address concerns related to time of drying of cassava chip by other methods of drying [5]. Itodo, *et. al* [12] suggested that the air inlet duct area of an active solar dryer can affect the performance of the dryer. Their study recommended that studies should be carried out to examine the effect of air inlet duct area on the drying process. Cooking banana that are yellowish or brownish in colour are rich in pro-vitamin A carotenoids. New leaves develop within the plant from the ground. They grow and merge from the center. The flowers incidentally grow to banana bunch. According to the findings, there is huge demand for snacks made from cooking banana as well as plantain in the market, because of its huge nutritional value [2]. A wide range of products can be obtained from processing cooking banana, examples can be found in production of flour, banana chips, banana juice, and country wine

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amongst others. A solar drying system based on the principles of convective heat flow, with use of local materials for yam chip was designed by Alonge *et. al* [6]. It was observed that the drying time was reduced from 52 hours for sun drying to 45 hours for solar drying of yam chip. In designing an active solar drying system for some crops. Raju, *et. al* [15] used 40cm^2 as air inlet duct area, while Alamu [3] used 25 cm^2, although the shape of the inlet was not mentioned, but drying was reported as fairly efficient in both scenarios. Tonui, *et. al* [18] used air inlet spacing of 0.5m with an air flow rate of 227m^3/h, in designing solar grain dryer with backup heater to obtain a thermal efficiency of about 58% with average drying rate of 0.0077 kg/h. Despite variation in air inlet duct area used by many while developing solar dryers, there is no report highlighting the effect of air inlet duct area on drying rate and time taken to dry the product. This was identified as a gap the study aimed at bridging.

2. MATERIALS AND METHODS

The moisture content of the product was determined in three forms namely: oven drying, controlled experiment and the dryer. The moisture content (initial and final) obtained from the oven drying process served as a guide to the field experiments. The moisture content of the product to be dried (cooking banana) was determined on wet basis. A laboratory drying oven was employed for determining the moisture content of the product. Samples were weighed using an electronic weighing balance of 0.0lg accuracy. The oven temperature was set at a temperature recommended by ASABE [7] for fruits like banana. The average initial moisture content of the samples were determined using the relationship below [7]. This method was adopted by Alonge *et al.* [14], Ikejiofor and Okonkwo [10] and Onyinye *et al.* [14]in their respective studies.

$$M.C. = \left(\frac{W_w - W_d}{W_w}\right) 100\% \quad (1)$$

Where: *M.C.* (wb) is Moisture content of the sample on wet basis (%), W_w is Initial Weight of sample (g) and W_d is final weight of sample (g)

The angle of tilt (β) of a solar collector was located within Latitude 10^{o}N from the equation 2 derived by Eke [9]:

$$\beta = 2.66o + Lat\ ø \quad (2)$$

Where: β is the angle of tilt and Lat ø is the latitude of the collector location, truly facing south.

The amount of moisture removed from the products was obtained as in equation (3):

$$M_w = \frac{W_w(M_i - M_f)}{1 - M_f} \quad (3)$$

Where: M_w is the amount of moisture removed from the products (g), M_i is initial moisture content of product (%w.b.), M_f is final moisture content of product (% w.b.), W_w is Initial total weight of product (g). The quantity of heat required to raise the temperature of the product to the surface was obtained from equation (4):

$$Q_1 = WwCp\Delta T \quad (4)$$

Where Q_1 is Quantity of heat required to raise the temperature of the product to the surface (J), W_w is Initial Total Weight of Products, C_p is Specific Heat Capacity of Product (3800J/Kg), ΔT is Change in Temperature (K).

The quantity of heat required to evaporate moisture from the product surface was obtained from equation (5):

$$Q_2 = Mw\,L \quad (5)$$

Q_2 is Quantity of heat required to evaporate moisture from the product surface (J), M_w is Amount of moisture removed from the product (g), L is Latent heat of vapourization (J/Kg). Total heat required to remove water from the product was as in equation (6):

$$Q_T = Q_1 + Q_2 \quad (6)$$

The area of the collector was computed from the equation (7):

$$A_c = \frac{Q_T}{F_R T\,(IT_R - U_L(T_c - T_a)} \quad (7)$$

Where: A_c is Solar Collector area (m^2), Q is Collector useful heat gain required to dry a given quantity of agricultural product (W), T is Drying time (seconds), F_R is Collector heat removal factor (Dimensionless), I is Total solar radiation incident on the dryer (W/m^2), T_R is Cover Material Transitivity (Dimensionless), T_c is Collector air outlet temperature (°C), T_a is Ambient temperature (°C), U_L is Overall heat transfer coefficient (W/m^2 °C)

The drying rate of the product was computed from equation (8):

$$M_{dr} = \frac{M_w}{t_d} \quad (8)$$

Where: M_{dr} is Drying rate (g/hr), M_w is Mass of moisture to be removed by solar heat and t_d is Time taken to dry the product.

The equations (1) to (8) were in consonance with what was used by Oguntola *et al.* [13], Raju *et al.* [15] and

Sacilik [16] in designing various solar drying systems. The solar panels available for experiment were three (3) 150 Watts, 12 Volts monocrystalline solar panels, which jointly gave a total available input power of 450 Watts. Half of the available power was used to power the blowers, while the remaining 50% (225 Watts) was used to charge the 200 Ampere battery. The battery was necessary to compensate for losses and voltage drop arising from low solar intensity. Considering the amount of power available (225 Watts) and the number of dryers needed for the experiments, each individual blower required. Power required by individual dryer,

$$P = \frac{Total\ Power}{Number\ of\ blowers} \quad (9)$$

The total number of blowers needed for the experiment was 52. The power required by each individual blower was:

Power required by individual dryer, P = 225/52 = 4.33 Watts/blower (Theoretical)

Two blowers close to the above were 3.6 Watts (12 Volts, 0.3 Amperes) and 7.2 Watts (24 Volts, 0.3 Amperes). It was not feasible to use the 7.2 Watts blower, since the blower had a voltage (24V), 100% higher than what the solar panel provided (12V). However, the 3.6 Watts blower was chosen, since its voltage rating was in consonance with the rating of the solar panel (12V). The power utilized by each individual dryer was computed as thus:

Power utilized by individual dryer, P = 3.6 x 52 = 188 Watts.

The solar battery was deployed to compensate for the difference in power that was provided by the same solar panel and what was utilized by the blowers. The dryer was made up of the solar collector section, the drying chamber and the inlet and outlet vents, solar panels, dry cell battery and blowers. The inlet vent was of various shapes and sizes, while the outlet vent of the dryers was of the same size. The dryer had sawdust as its insulation material at the base and beneath the collector and the drying chamber of known thickness. Glass of 3mm thickness was used as transparent cover material. Plywood was used as construction material. The dryer was inclined at an angle due south and optimum slope angle of 8° from the horizontal plane of the area of study. The length, width and air plenum of the collector section was obtained with respect to literature reviewed on the course of the study. The values were chosen and 40 cm and 40 cm for length and width respectively, while the air plenum was 6 cm as used by Aziz, *et. al* [8]. All construction work were done at the Department of Agricultural and Bioresources Engineering, Michael Okpara University of Agriculture, Umudike. The dryers were designed on force convection principle. The outlet vents were uniform (5mm radius).

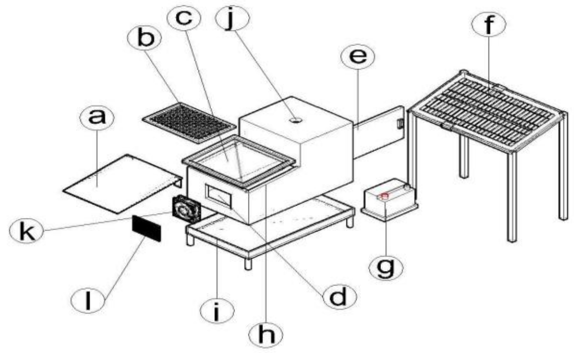

Figure 1: Exploded view of the dryer

Legend:

A – Absorbent plate
B – Drying tray
C – Transparent cover material
D – Drying chamber
E – Drying chamber lid/door
F – Solar panel
G – D.C. battery
H – Drying cabin
I – Dryer telescopic leg
J – Blower

Figure 2 shows the constructed dryers displayed in the experimental site.

2.1 Experimental Design

The experiment was designed to examine the effect of air inlet duct area on drying time and drying rate of cooking banana. The two independent variables considered were air inlet duct area of the dryer and grater size of the product. The two factors were considered at five levels each using factorial Central Composite Rotatable Design (CCRD), which gave 13 experimental runs, and a total of 52 experimental runs when multiplied with the respective inlet shapes considered (Square, Rectangular, Circular and Triangular). Taheri-Varagand, *et. al* [17] Used similar design for drying process of banana. For factor 1 (air inlet duct area), the levels were obtained 4, 16, 36, 64 and 100 cm^2 for the square shaped inlet, 8, 24, 40, 48 and 80 cm^2 for rectangular air shaped inlet, 3.142, 12.568, 28.278, 50.272 and 78.55 cm^2 for circular shaped inlet and 8, 16, 24, 32 and 40 cm^2 for triangular shaped inlet.

Figure 2: Experimental site

The area was respectively calculated based on the dimensions of the air inlet duct area and use of relevant equation as applicable to the respective shape orientations. For factor 2 (grater size), the levels of were selected as 4 (P_1), 8(P_2), 12(P_3), 16(P_4) and 20 mm (P_5). The variation was necessary because there is no optimum grater size recommended for drying the product.

2.2 Sample Preparation and Data Collection

Fresh samples of cooking banana were bought from a local market in Umudike and its environs, where the analyses was done; to ensure location proximity. The samples were pealed, the endocarp washed and grated. The grated products were weighed using an electronic weighing balance (Kerro BL 5002 model, with accuracy 0.01 g) and placed on a tray. The trays were positioned in the drying chamber. Open sun drying of the product served as control. The samples were dried in batches of three replicate. Data collection was designed in a manner that readings were taken after every two hours from 8:00am to 6:00pm, daily for each drying batch.

3. RESULTS AND DISCUSSION

3.1 Drying Time

The drying time varied with respect to the different grater sizes and air inlet duct area. The table 1 show the drying time of the control experiment for the various grater sizes. The drying rate of the product with respect to the air inlet duct area and product size is captured in Table 2.

Table 1: Drying time for open sun (control)

Grater Size (mm)	Time (Hours)
P_1(4)	15
P_2(8)	22
P_3(12)	25
P_4 (16)	30
P_5 (20)	37

Table 2: Summary of drying time, grater size and air inlet duct area

Dryer Number	Shape of Inlet	Air Inlet Area (cm^2)	Product Size (mm)	Drying Time (Hours)
1	Square	S_1(4)	12	17
2	Square	S_2(16)	8	12
3	Square	S_2(16)	12	18
4	Square	S_3(36)	4	9
5	Square	S_3(36)	12	18
6	Square	S_3(36)	12	15
7	Square	S_3(36)	12	17
8	Square	S_3(36)	12	17

Dryer Number	Shape of Inlet	Air Inlet Area (cm^2)	Product Size (mm)	Drying Time (Hours)
9	Square	S_3(36)	12	16
10	Square	S_3(36)	20	23
11	Square	S_4(64)	8	14
12	Square	S_4(64)	16	20
13	Square	S_5(100)	12	17
14	Rectangular	R_1(8)	12	19
15	Rectangular	R_2(24)	8	13
16	Rectangular	R_2(24)	12	19
17	Rectangular	R_3(48)	4	10
18	Rectangular	R_3(48)	12	18
19	Rectangular	R_3(48)	12	17
20	Rectangular	R_3(48)	12	17
21	Rectangular	R_3(48)	12	18
22	Rectangular	R_3(48)	12	16
23	Rectangular	R_3(48)	20	26
24	Rectangular	R_4(80)	8	13
25	Rectangular	R_4(80)	16	23
26	Rectangular	R_5(40)	12	20
27	Circular	C_1(3.142)	12	17
28	Circular	C_2(12.568)	8	13
29	Circular	C_2(12.568)	12	19
30	Circular	C_3(28.278)	4	11
31	Circular	C_3(28.278)	12	18
32	Circular	C_3(28.278)	12	17
33	Circular	C_3(28.278)	12	17
34	Circular	C_3(28.278)	12	18
35	Circular	C_3(28.278)	12	18
36	Circular	C_3(28.278)	20	26
37	Circular	C_4(50.272)	8	14
38	Circular	C_4(50.272)	16	21
39	Circular	C_5(78.55)	12	19
40	Triangular	T_1 (8)	12	16
41	Triangular	T_2(16)	8	13
42	Triangular	T_2(16)	12	16
43	Triangular	T_3(24)	4	9
44	Triangular	T_3(24)	12	16
45	Triangular	T_3(24)	12	15
46	Triangular	T_3(24)	12	16
47	Triangular	T_3(24)	12	16
48	Triangular	T_3(24)	12	15
49	Triangular	T_3(24)	20	25
50	Triangular	T_4(32)	8	12
51	Triangular	T_4(32)	16	21
52	Triangular	T_5(40)	12	16

From the table, for products of grater size P_1 (4mm), drying was achieved in an average of 10 hours, as against 15 hours it took to get the same product of equal grater size dried on open sun. About 35% of the drying time was conserved. The dryer with the least time of drying (9 hours) had an air inlet duct area of 36 cm^2. For products of grater size P_2 (8mm), the products were observed to have dried between 12 to 14 hours. In comparison with the control, about 41% of the drying time was saved in the process. For products of grater size P_3 (12mm), drying was achieved on an average of 16 hours, as compared to open dun drying (25 hours). Similar trend was observed for grater size P_4 (16mm), and P_5 (20mm) respectively, as they showed more than 30% variation when compared to open sun drying. The results obtained were quite close to what was obtained by Umoh and Garba [19] for some selected crops in Kano, Nigeria. Wakjira, *et. al* [20] developed a solar dryer for banana and considered the air inlet duct area as 25 cm^2, and achieved drying between 4 to 5 days for grater size range of 1 to 6mm. These findings were quite dissimilar to what was obtained in the study. The variation could be traced to the nature of the dryer and feature, as the former was a passive solar dryer.

3.2 Drying Rate

For open sun drying which served as control, the drying rates of the products were obtained as in Table 3.

Table 3: Drying rate of control

Grater Size (mm)	Drying Rate (g/hr)
P_1 (4)	1.48
P_2 (8)	1.88
P_3 (12)	2.31
P_4 (16)	2.74
P_5 (20)	2.89

The drying rates of products in the dryer with respect to air inlet duct area and product size are as given in Table 4.

Table 4: Drying rate of products dried in the respective dryers

Dryer Number	Shape of Inlet	Air Inlet Area (cm^2)	Product Size (mm)	Drying Rate (g/hr)
1	Square	S_1(4)	12	3.12
2	Square	S_2(16)	8	3.19
3	Square	S_2(16)	12	3.16
4	Square	S_3(36)	4	2.46
5	Square	S_3(36)	12	3.12
6	Square	S_3(36)	12	3.88
7	Square	S_3(36)	12	3.11
8	Square	S_3(36)	12	3.14
9	Square	S_3(36)	12	3.32
10	Square	S_3(36)	20	3.99
11	Square	S_4(64)	8	3.02
12	Square	S_4(64)	16	3.78
13	Square	S_5(100)	12	3.49
14	Rectangular	R_1(8)	12	2.85
15	Rectangular	R_2(24)	8	2.99
16	Rectangular	R_2(24)	12	3.03
17	Rectangular	R_3(48)	4	2.19
18	Rectangular	R_3(48)	12	2.94

Dryer Number	Shape of Inlet	Air Inlet Area (cm^2)	Product Size (mm)	Drying Rate (g/hr)
19	Rectangular	R_3(48)	12	3.20
20	Rectangular	R_3(48)	12	3.10
21	Rectangular	R_3(48)	12	3.36
22	Rectangular	R_3(48)	12	3.38
23	Rectangular	R_3(48)	20	3.84
24	Rectangular	R_4(80)	8	3.01
25	Rectangular	R_4(80)	16	3.44
6	Rectangular	R_5(40)	12	2.63
27	Circular	C_1(3.142)	12	3.13
28	Circular	C_2(12.568)	8	2.98
29	Circular	C_2(12.568)	12	2.75
30	Circular	C_3(28.278)	4	1.95
31	Circular	C_3(28.278)	12	2.97
32	Circular	C_3(28.278)	12	3.10
33	Circular	C_3(28.278)	12	3.12
34	Circular	C_3(28.278)	12	2.87
35	Circular	C_3(28.278)	12	3.02
36	Circular	C_3(28.278)	20	3.77
37	Circular	C_4(50.272)	8	2.91
38	Circular	C_4(50.272)	16	3.64
39	Circular	C_5(78.55)	12	2.91
40	Triangular	T_1 (8)	12	3.74
41	Triangular	T_2(16)	8	3.18
42	Triangular	T_2(16)	12	3.35
43	Triangular	T_3(24)	4	2.44
44	Triangular	T_3(24)	12	3.33
45	Triangular	T_3(24)	12	3.64
46	Triangular	T_3(24)	12	3.36
47	Triangular	T_3(24)	12	3.32

Dryer Number	Shape of Inlet	Air Inlet Area (cm^2)	Product Size (mm)	Drying Rate (g/hr)
48	Triangular	T_3(24)	12	2.24
49	Triangular	T_3(24)	20	3.93
50	Triangular	T_4(32)	8	3.26
51	Triangular	T_4(32)	16	3.55
52	Triangular	T_5(40)	12	3.47

From the tables, product of grater size P_1 (4 mm), averagely had a drying rate of 2.52 g/hr, as against 1.48 g obtained for the control experiment of the same grater size. There was a variation of 42%, in comparing the two processes. Similar trend was recorded for P_2 (8 mm), and P_3 (12 mm), respectively, as the drying rates showed about 40% variation. The air inlet duct area corresponding to the grater sizes, were between 16 and 100 cm^2. The average drying rate of P_4 (16 mm) and P_5 (20 mm), recorded a variation of 30%, when comparing their drying rates with open sun drying. Similar trend was reported by Irtwange, and Adeboye [11] for corn. Figure 3 shows variation in drying rate with air inlet area and product size for various air inlet shapes.
Analysis of variance of the drying rate of the product in the respective inlet shape orientation is given in Tables 5 to 8.

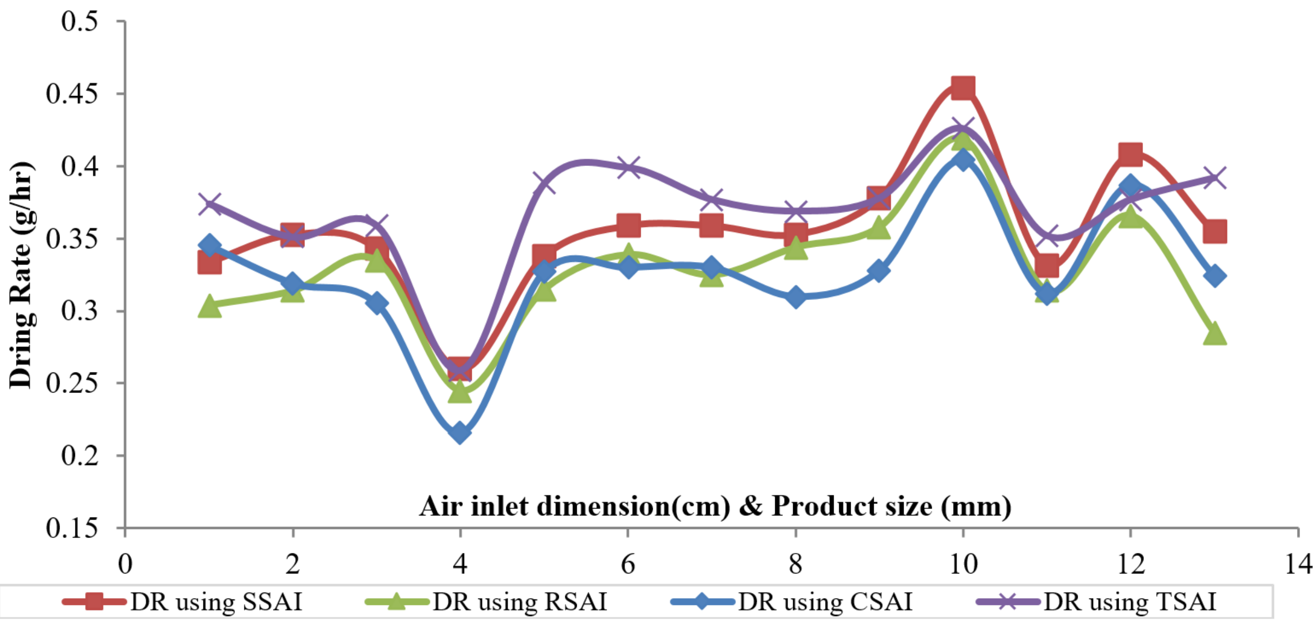

Figure 3: Variation in drying rate with air inlet dimension and product size for various air inlet shapes.

Where: SSAI is Square Shape Air Inlet; RSAI is Rectangular Shape Air Inlet
CSAI is Circular Shape Air Inlet; TSAI is Triangular Shape Air Inlet

Table 5: Analysis of Variance for drying rate for square shape air inlet

Source	Sum of Square	df	Mean Square	F-Value	P-Value
Air Inlet Dimensions (cm)	0.1180	1	0.11801	1.67	0.225
Product Size (mm)	1.1970	1	1.19701	16.97	0.002
Error	0.7055	10	0.07055		
Total	2.0205	12			

Table 6: Analysis of Variance for drying rate for rectangular shape air inlet

Source	Sum of Square	df	Mean Square	F-Value	P-Value
Air Inlet Dimensions (cm)	0.00001	1	0.00001	0.00	0.992
Product Size (mm)	1.18441	1	1.18441	15.03	0.003
Error	0.78809	10	0.07881		
Total	1.97251	12			

Table 7: Analysis of Variance for drying rate for circular shape air inlet

Source	Sum of Square	df	Mean Square	F-Value	P-Value
Air Inlet Dimensions (cm)	0.01203	1	0.01203	0.15	0.707
Product Size (mm)	1.42830	1	1.42830	17.81	0.002
Error	0.80216	10	0.08022		
Total	2.24249	12			

Table 8: Analysis of Variance for drying rate for triangular shape air inlet

Source	Sum of Square	df	Mean Square	F-Value	P-Value
Air Inlet Dimensions (cm)	0.00563	1	0.005633	0.03	0.859
Product Size (mm)	0.98613	1	0.986133	5.83	0.036
Error	1.69171	10	0.169171		
Total	2.68348	12			

From the Tables, the air inlet duct area had significant effect on the drying rate of the product at 5% level of significance, since all *p*-values obtained were higher than 0.05. On the contrary, the grater size had no significant effect on the drying rate, since all its *p*-values were less than the desired probability level.

4. CONCLUSIONS AND RECOMMENDATIONS

The air inlet duct area of the dryers had effect on the drying time of the products. Drying was achieved within 9 to 26 hours (depending on the respective grater sizes) as against open sun, which drying was achieved between 15 to 37 hours. The dryers conserved between 26.67 to 37.84 % of the drying time. The drying rate of the products increased from 2.24 to 3.93 g/hr. There was a reported variation of between the field experiment and the control was averagely 36 %. The air inlet duct area had significant effect on the drying rate of the product at 5% level of significance, while the grater size had no significant effect on the drying rate of the product. It is recommended that the air inlet duct area of the dryer and grater size of the product be optimized, to ascertain the conditions that will give more optimum drying of the product.

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