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COMPARATIVE PERFORMANCE ANALYSIS OF SOLAR DRYERS WITH BACKUP INCINERATORS UNDER SUB-TROPICAL AND HUMID CLIMATE USING CASSAVA GRATES

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ABSTRACT

Solar dryer with a back up incinerator was designed and constructed with a view of comparing its performance under Nsukka sub-tropical and Makurdi humid climates both towns in Nigeria. Analyses of drying efficiencies were carried out for cassava grates. The dryer consists of solar collector, drying chamber, and incinerator. Drying was assumed to have taken place in the falling rate periods which enabled the use of only one drying constant. The 'no-load' test (control test) and the 'on-load' test (cassava grates) were done simultaneously. The respective weight losses were used to determine the reduction in moisture contents. Graphs of drying rates against time were plotted in each case and used to obtain the drying rate constant, K for the various conditions and locations. Comparison was made for the drying rate at the two locations. The efficiencies of the equipment at various locations were calculated and the drying rate efficiencies were also obtained. Results obtained showed that drying was fastest during the solar drying, and least during the incinerator drying and the control drying respectively. The drying rate was also faster at Nsukka tropical location than Makurdi humid location. The mean location drying rate efficiencies obtained were 98.8%, 94.7%, and 87.4% for solar dryer, solar-incinerator dryer and incinerator dryer respectively. The computed efficiencies for the equipment were 56%, 13% and 16% for solar dryer, solar incinerator dryer and incinerator dryer respectively. The results show that the dryer can be used as a substitute means for cassava garri dehydration and drying of other farm produce in rural and semi-urban areas for improved quality in both regions.

Keywords : *Performance evaluation, solar dryer, incinerator, humid climate, tropical*

1.0 INTRODUCTION

Solar energy is gaining acceptance as an alternative source of energy and steadily overcoming cultural acceptability. Agricultural crops need to be dehydrated to moisture content suitable for storage. The use of the sun under the open sky for drying agricultural crops has been the practice since ancient years [12, 9]. Despite the availability of modern methods of food drying in Nigeria, agricultural products are still being dried to a large extent by the open-air sun drying technique. In most cases, what would take a few hours to dry under modern techniques takes several days. Sun drying is however, unhygienic and exposed to infestation, and the product quality is generally poor while only small quantity can be dried at a time [1, 18, 19]. Moreover, it requires more labor in the

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day and night moment and during rains. The process is also time-consuming and requires large areas for spreading out the produce to dry effectively. Several attempts have been made by several researchers to improve the quality of the products. The artificial mechanical drying has also been practiced but it is capital intensive and this ultimately increases the product cost.

Solar drying is an alternative which offers several advantages over the open sun and mechanical methods of drying. It is economically viable and environmentally friendly. It saves energy, time, occupies less area, improves product quality, and makes processing industries to produce hygienic, good quality food products [6, 7, 8. 10]. At the same time, it can be used to promote renewable energy sources as an in-come generating option. In rural areas, different constructions of active solar dryers are hindered due to lack of conventional power [2, 13]. Most crops and grains are harvested during the peak periods of the raining season and preservation by sun drying proves difficult. These result in crops like cassava, pepper, okro and so on being dumped in villages and major cities as wastes [12]. This research therefore focuses on designing and constructing a solar dryer incorporating an incinerator to be used for drying the grated cassava without loss of its nutritional values to improve the quality of its by - products and suitable for drying of other agricultural produce like okro and pepper for storage. Its performance evaluated under Makurdi humid condition (7^0 20'N, 8^0 45'E) and Nsukka sub-tropical (6^0 51' 24"N, 7^0 23'45"E) climate. Makurdi is the capital city of Benue State in the Middle belt region while Nsukka is a town in Enugu State in the South East region both in Nigeria.

Cassava is one of the most important root crops in the world and provides a lot of energy to consumers due to the large amount of carbohydrates accumulated in the roots [19]. Cassava is highly perishable and deteriorates within three days of harvesting, partly due to high water content. It is therefore important to process it into various forms. One of such forms is *garri* (fried mashed cassava) which is a very popular meal in Nigeria, especially at the locations of the study. The final moisture content suitable for frying *garri* lies between 47 - 48%Wb from 65 - 75%Wb while the maximum allowable temperature is between 50 - 60^0C.

The drying with a hybrid solar dryer is continuous (during sunny days, cloudy days and at night) thereby preventing deterioration by microbial infestation [11, 14, 15]. The study is aimed at comparing its performance with a simple solar dryer as well open sun drying. The study assumed that the mechanism for drying is that for the falling rate period which is a piece of information which is invaluable for farmers in rural areas. Natural convection drying in the falling rate period can be represented with the following model.

$$\frac{dM}{dt} = e^{-kt} \tag{1}$$

where M = moisture content at time t and k = drying constant. Hence,

$$dM = e^{-kt}\, dt \tag{2}$$

Integrating in the appropriate limits, we obtain

$$\int_{m_o}^{m} dM = \int_{t_o}^{t} e^{-kt} dt \tag{3}$$

Considering the fact that the negative power of *e* indicates that $M_o > M$ and since $t_o = 0$, we may write

$$(M_o - M) = e^{kt} \tag{4}$$

where, M_o is the initial moisture content. Introducing natural logarithms, we have

$$\ln (M_o - M) = kt \tag{5}$$

The efficiency of a solar system with a back-up heater is determined with respect to different drying conditions [5, 15 - 17]. These include

a. Collector efficiency during day time (when solar radiation is available).

$$\eta_c = \frac{\dot{m}_a C\dot{p}_a (T_c - T_o)}{H_c I_g} \quad (6)$$

b. system drying efficiency of the solar dryer efficiency in day time /dull weather during solar – incinerator drying

$$\eta_c = \frac{M_w h_L}{A_c I_t t + Q_{\dot{m}}} \quad (7)$$

c. Solar dryer efficiency in daytime using solar drying only

$$\eta_c = \frac{M_w h_L}{A_c I_t t} \quad (8)$$

d. Solar dryer efficiency in night time.
Drying with hot water flow from the incinerator only

$$\eta_c = \frac{M_w h_L}{Q_{\dot{m}}} \quad (9)$$

e. The heat transfer by the heat exchanger is given by

$$q = UA\Delta T \quad (10)$$

where, U is the overall heat transfer coefficient, A is the area of the heat exchanger and ΔT is an average effective temperature difference for the entire heat exchanger. The overall heat transfer coefficient U is given by

$$U = \frac{1}{\frac{1}{h_o} + \frac{L}{k} + \frac{1}{h_i}} \quad (11)$$

where, subscripts *i* and *o* represent the inside and the outside surfaces of the wall respectively, *k* is thermal conductivity and h the film coefficient The usual assumptions were applied [3, 4].

2.0 MATERIALS AND METHOD

The efficient solar dryers were designed and constructed at Energy Research Centre, University of Nigeria, Nsukka and Department of Mechanical Engineering of the Federal University of Agriculture, Makurdi. It comprises of three major units namely the flat plate collector; an incinerator and the drying chamber. The incinerator was incorporated in the design for drying during cloudy weather conditions and during night periods. This is shown in Figure 1.

Fourteen days pre experimental test, 'No-load' test was carried out on the system at both locations. The test involved measuring the temperature of the air stream and the ambient temperature using thermometer. A psychrometer was used to measure the dry and wet bulb temperature of the drying chamber. A psychometric chart was used to determine the ambient and exit relative humidity. The average velocity of air delivered into the drying chamber was also measured using a cup anemometer. The biomass to be used in the incinerator (charcoal) was burnt and the heat conveying fluid (water) was allowed to flow by gravity. The initial and final temperatures of the fluid were measured and the temperature of the dryer was also measured using a thermometer.

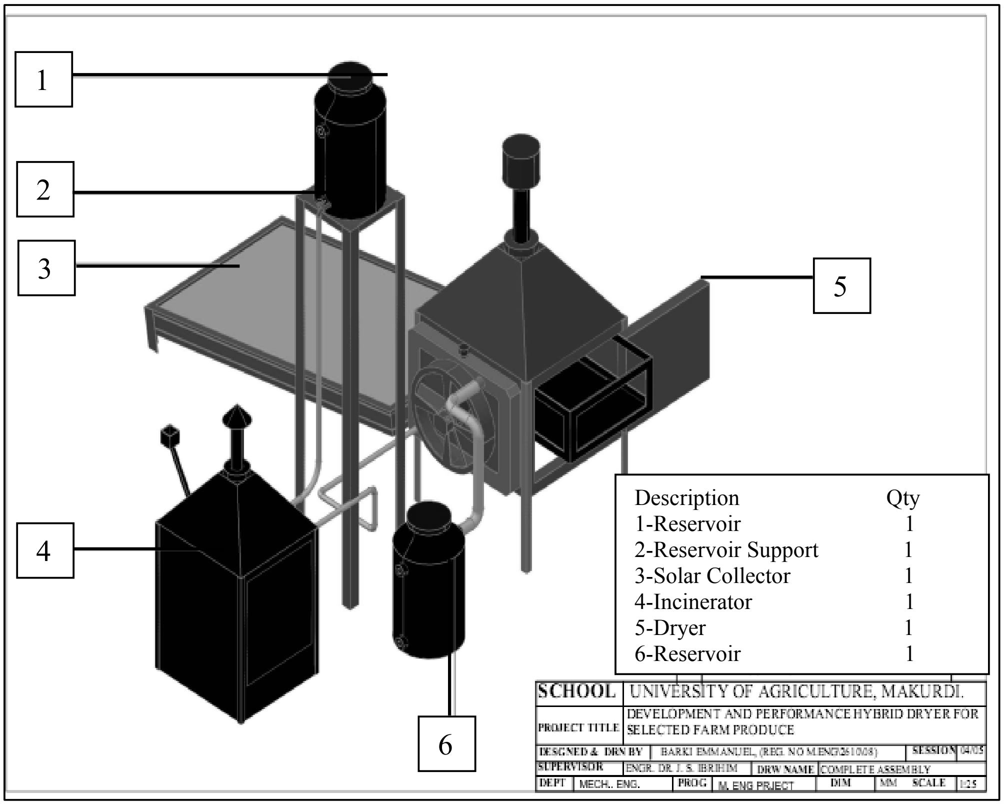

Figure 1: The complete system

'On-load' test were carried out in the two different locations during the dry (harmattan) season in the month of February to enable fair comparison. At each of the locations, cassava was peeled and grated and the mashed cassava shared into two equal parts (1kg each). One part was charged into the dryer while the other was sun-dried as the control. The dryer was first connected to the flat plate collector without the incinerator and the temperatures of the air stream, ambient and exit air relative humidity were measured and recorded. The wind velocity was also measured. Thereafter, the incinerator was connected, experiments were repeated and the same readings were measured. The dryer was also loaded in a shielded environment with the inlet air space for the collector closed and the collector covered with plywood and the temperatures of the air stream, ambient and exit air relative humidity as well as the wind velocity measured to test the efficiency of the dryer. The control was tempered appropriately by sealing it in polyethene bag at night to prevent it from rehydrating. Twelve batches of cassava grates were dried to a moisture content of about 47 – 48% ready for frying.

The 'no-load' tests were carried out from 08.00 hours to 18.00 hours. The rate of heat loss and thermal energy output were evaluated and used to compute the efficiency of the collector and dryer respectively. The initial moisture content of the mashed cassava was determined using Ohaus Moisture Analyzer model MB 36 Halogen before charging it into the dryer. Samples of dehydrated *garri* from local producers were collected from local producers and the moisture content analyzed using the moisture analyzer and the average value found to be 47.5%. The moisture contents of each sample were calculated based on the weight losses.

3.0 RESULTS AND DISCUSSION

The mean mass (moisture) profile of grated cassava for control equipment at location 1 (Nsukka) and location 2 (Makurdi) is shown in Tables 1 and 2 respectively. The analysis of drying rates and efficiencies of equipments for cassava drying for Nsukka and Makurdi locations are shown in Tables 3 and 4 respectively.

Table 1: Mean mass (moisture) profile of grated cassava in Nsukka Location (Control)

Time (Hrs)	Mass b/4 drying, W (g)	Mass after drying, W_s (g)	M (%)	M_o-M (%)	ln (M_o - M)	Time (days)
1000 – 1200	2500	2044	22.36	47.44	3.86	
1200 – 1400	2044	1982	26.08	43.72	3.78	
1400 – 1600	1982	2003	24.80	45.00	3.81	1
1600 – 1800	2003	1944	28.6	41.20	3.72	
0800 – 1000	1944	1921	30.11	39.69	3.68	
1000 – 1200	1921	1900	31.51	38.29	3.65	
1200 – 1400	1900	1880	32.94	36.86	3.61	2
1400 – 1600	1880	1788	39.79	30.01	3.40	
1600 – 1800	1788	1757	42.24	27.56	3.32	
0800 – 1000	1757	1696	47.56	22.44	3.11	3

M = percentage moisture content; M_o = Initial moisture content = 69.8%; Control = Open sun drying.

Table 2: Mean mass (moisture) profile of grated cassava in Makurdi Location 2 (Control)

Time (Hrs)	Mass b/4 drying, W (g)	Mass after drying, W_s (g)	M (%)	M_o-M (%)	ln (M_o - M)	Time (days)
1000 – 1200	2500	2032	23.03	46.77	3.85	
1200 – 1400	2032	1977	26.40	43.40	3.77	
1400 – 1600	1977	1950	28.20	41.40	3.72	1
1600 – 1800	1950	1965	27.21	42.59	3.75	
0800 – 1000	1965	1923	29.99	39.81	3.68	
1000 – 1200	1923	1900	31.53	38.27	3.64	
1200 – 1400	1900	1879	33.01	36.79	3.61	2
1400 – 1600	1879	1806	38.42	31.38	3.45	
1600 – 1800	1806	1748	43.01	26.79	3.28	
0800 – 1000	1748	1700	47.01	22.79	3.12	3

Table 3 : Analysis of drying rates and efficiencies of equipments for cassava drying (Makurdi Location)

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	0.382638	5	0.076528	8.34972	0.000606	2.901295
Columns	0.570046	3	0.190015	20.73208	1.36E-05	3.287382
Error	0.137479	15	0.009165			
Total	1.090163	23				

Ho: F ≤ F crit; Ha: F□Fcrit

α = 0.05

Table 4 : Analysis of drying rates and efficiencies of equipments for cassava drying (Nsukka Location)

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Rows	0.384738	5	0.076947	10.35981	0.000191	2.901295
Columns	0.501213	3	0.167071	22.49355	8.33E-06	3.287382
Error	0.111413	15	0.007428			
Total	0.997363	23				

Ho: F ≤ F crit;

Ha: F> F crit

α = 0.05

Figure 2 shows the variations of ambient temperature with time for the two locations during no-load tests while the variations of the efficiencies of the collectors for the two locations is shown in Figure 3. Figures 4 and 5 show the effect of ambient temperature on the collector efficiency for locations 1 and 2.

The grated cassava with an initial moisture content of 69.8% was dehydrated to a moisture content of 47.19% 12hrs in the solar dryer, 16hrs for the solar – incinerator to dehydrate the sample to a moisture content of 47.28%, and 20hrs for the incinerator dryer to dehydrate the sample to a moisture content of 47.62%. The open sun drying took 20hrs also to dehydrate the grated cassava to moisture content of 47.56%. This showed a significant reduction in time in the order solar dryer, solar - incinerator dryer and incinerator dryer with solar, dryer having the highest time reduction and incinerator the lowest time reduction. More so, the sample dried in the dryer were clean and of high quality with no contamination through dust or insects and did not change colour while those under open air sun dry showed change in colour indicating signs of deterioration in quality. No colour change was observed for solar samples dehydrated in the dryer.

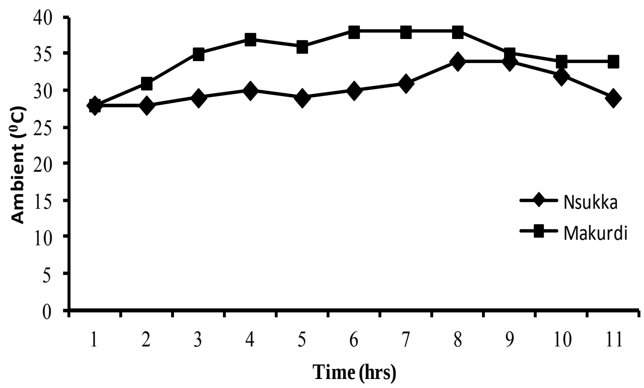

Figure 2 : Variation of Ambient Temperatures with time for the two locations

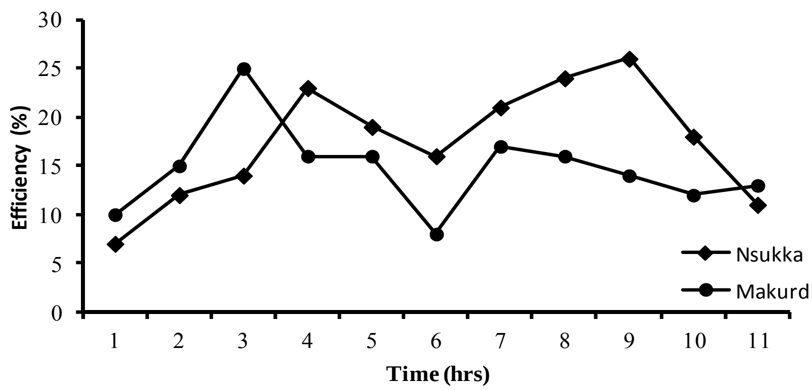

Figure 3: Variation of Solar Collector Efficiency with time for the two locations

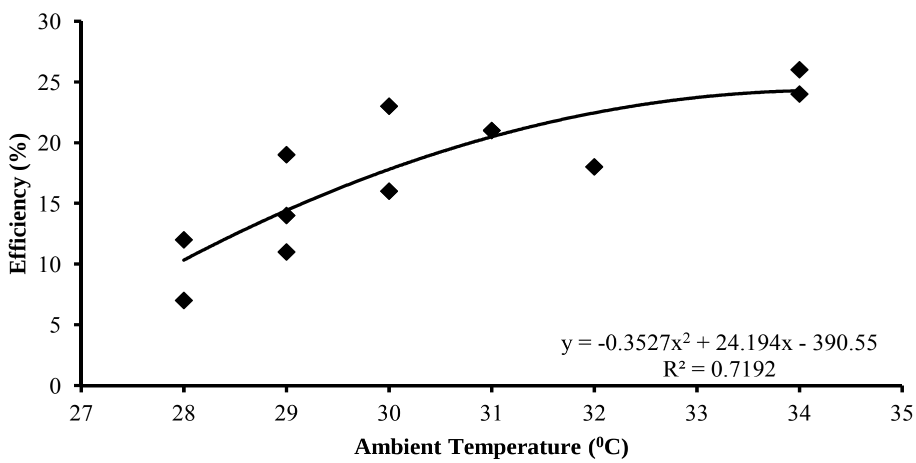

Figure 4: Effect of Ambient Temperature on the Collector Efficiency for Location 1

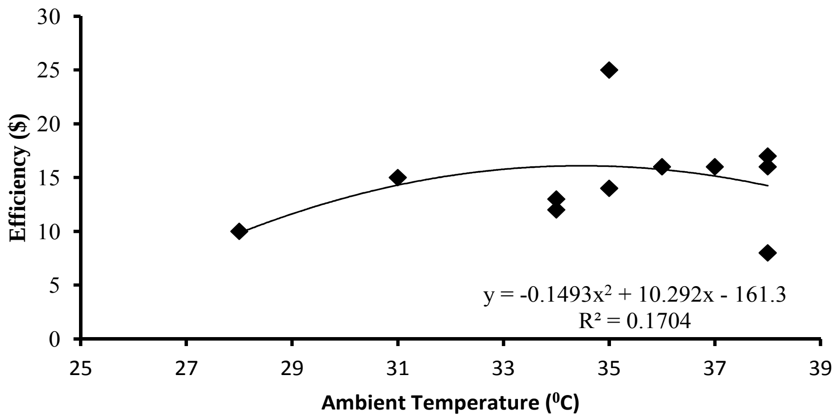

Figure 5: Effect of Ambient Temperature on the Collector Efficiency for Location 1

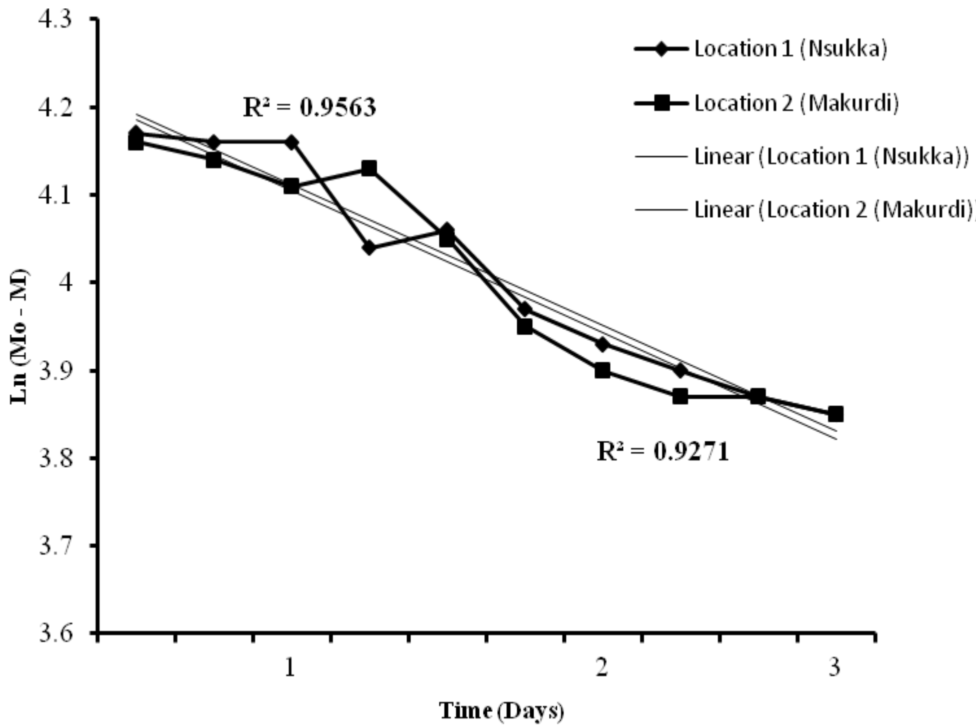

Figure 6 : Drying rate of open air sun drying for Nsukka and Makurdi (grated Cassava)

The analysis shows that there is a significant difference between the drying rates of the equipment at 5% significant level. Moreso, a significant difference exists between the efficiencies of the equipment at Nsukka location 2. This shows a significant reduction in time of dehydrating the samples. There is also a significant difference between the efficiencies of equipments at 95% confidence level. The drying pattern of grated cassava for Nsukka and Makurdi (control) shows the same level of significance between the drying time of the locations but no significant difference between the two locations.

The drying factor distribution for Nsukka and Makurdi (open air sun drying) (control) shows that at 1hr, the free percentage moisture content was slightly higher than that at Nsukka location. At 5hrs to 7hrs, Makurdi and Nsukka had the same percentage free moisture. Generally, the percentage free moisture increases with time. The plots of drying rates of open air sun drying for Nsukka and Makurdi (grated cassava) indicates that the rate constant K (the slope of the graph) for grated cassava are 0.883 and 0.845 for location 1 (Nsukka) and location 2 (Makurdi) respectively. The graph shows that drying rate of open sun drying is higher in Nsukka than Makurdi (0.883 and 0.845 respectively).

For Makurdi location, the solar drying rate constant is 0.980 slightly lower than that of Nsukka location (0.996). Factors that could be responsible include low humidity and the high air velocity in Nsukka location. The maximum air temperature reached by the solar collector was 67^{o}C at ambient temperature of 39^{o}C, relative humidity of 50%. The drying chamber temperature was 50^{o}C (Nsukka). At location 2, Makurdi, the maximum air temperature reached by the solar collector was 68^{o}C at ambient temperatures of 40^{o}C, relative humidity of 50.5% absorber plate temperature, glass temperature and dryer temperature of 73^{o}C, 55^{o}C and 50^{o}C respectively. The maximum collector temperatures attained during solar–incinerator drying for Nsukka location are 53^{o}C and an average dryer temperature of 47^{o}C. At Makurdi, the maximum collector exist temperature is 56^{o}C and average dryer temperature of 48.3^{o}C. The average dryer temperature for the incinerator dryer was 37.5^{o}C and 41.3^{o}C for locations 1 and location 2 respectively.

4.0 CONCLUSIONS

The mean efficiency of the collector was 0.17 while the dryer efficiency for solar dryer and solar-incinerator dryer are 0.29 and 0.23 respectively. The solar dryer has the most efficient drying rate. Location 1 and location 2 did not significantly affect the dryer performance. The dryer can be used efficiently during dull, raining and bright weather conditions and at nights. The improved system can be commercialized. It can be used to substitute the *garri* dehydration means in rural areas for improved quality of *garri.* A D.C pump could be used to improve the system performance. On the present level of development, the system can be adopted in rural areas for drying of agricultural produce.

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