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Comparative Analysis and Performance of Solar Dryers with Backup Incinerators for Nsukka Sub-tropical and Makurdi Humid Locations Using Selected Farm Produce

J. S. Ibrahim[1], A. C. Eloka-Eboka[1,2*] and E. Barki[1,3]

[1]Department of Mechanical Engineering, Federal University of Agriculture, P.M.B. 2373, Makurdi, Nigeria.
[2]Discipline of Mechanical Engineering, University of KwaZulu-Natal, Howard College, Durban, South Africa.
[3]Department of Mechanical Engineering, Benue State Polytechnic, Ugbokolo, Nigeria.

Authors' contributions

Author EB managed the literature searches, developed and designed the study, constructed the test equipment and ran the experiments, author ACEE performed the statistical analysis, wrote the protocol, the first draft of the manuscript and managed the revision/peer review of the paper and also, the corresponding author. Authors EB and ACEE managed the analyses of the study. Author JSI supervised and coordinated the entire work and paper. All authors read and approved the final manuscript.

Original Research Article

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ABSTRACT

A solar dryer and hybrids incorporating back up incinerators were designed and constructed for performance evaluation and analysis of efficiencies for selected farm produce of cassava grates, okra and chilli pepper in two climatic locations (sub-tropical of Nsukka and humid of Makurdi in Nigeria) at the University of Nigeria, Nsukka and Federal University of Agriculture, Makurdi, Nigeria. It consists of a solar collector, drying chamber, and incinerator. The dryer was used for drying at night; sunshine days and cloudy days. They were used for test drying, termed 'no-load' test (without any farm produce) and 'on-load' (cassava grates, okra and chilli pepper) as selected farm produce. Their respective weight losses were used to determine the reduction in moisture content. Drying was

**Corresponding author: E-mail: fatherfounder@yahoo.com;*

assumed to have taken place in the falling rate periods, which enabled the use of only one drying rate constant. 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 dryers can be used to substitute garri dehydration and drying of other farm produce in rural and semi-urban areas for improved quality.

Keywords: Performance evaluation; solar dryer; solar incinerator; Makurdi; humid climate; Nsukka; tropical climate; garri; okra; chili pepper.

1. INTRODUCTION

Solar energy is gaining acceptance as an alternative source of energy and steadily overcoming cultural acceptability. Agricultural crops need to be dehydrated of moisture content for suitability of storage. The use of the sun under the open sky for drying agricultural crops has been in practice since ancient years. The products under the open drying are of poor quality due to the unavoidable presence of rain, wind, moisture and dust. Also, they are attacked by insects and fungi among others [1]. The process is also time-consuming and requires large area for spreading out the produce to dry. Several attempts have been made by Okonkwo [2], Mumba [3] and others to improve the quality of the drying 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 [4]. At the same time, it can be used to promote renewable energy sources as an in-come generating option [5]. In rural areas, different constructions of active solar dryers are hindered due to lack of conventional power [6].

Most of our crops and grains are harvested during the peak periods of raining season, preservation by sun drying proves difficult. These result in crops like cassava, pepper, okra and so on being dumped in villages and major cities as wastes. This research therefore focuses on designing and constructing a solar dryer used for drying the grated cassava for making (cassava flour) without loss of its nutritional values to improve the quality of garri product and the drying of other agricultural crops like okra and pepper for storage. Dehydration process helps in preservation of vegetables, fruits, grains and so on, by reducing the moisture content and improving the shelf life up to 6 to 10 months [7]. Sun drying is only possible in areas where, in an average year, the weather allows foods to be dried immediately after harvest. The main advantages of sun drying are low capital and operating costs and the fact that little expertise is required. The main disadvantages of this method are as follows: contamination, theft or damage by birds, rats or insects; slow or intermittent drying and no protection from rain or dew that wets the product, encourages mold growth and may result in a relatively high final moisture content; low and variable quality of products due to over - or under-drying; large areas of land needed for the shallow layers of food; laborious since the crop must be turned, moved if it rains; direct exposure to sunlight reduces the quality (colour and vitamin content) of some fruits and vegetables. Moreover, since sun drying depends on uncontrolled factors, production of uniform and standard products are not expected.

Direct solar dryers expose the substance to be dehydrated to direct sunlight. They have a black absorbing surface which collects the light and converts it to heat; the substance to be dried is placed directly on this surface. These driers may have enclosures; glass covers and/or vents to in order to increase efficiency. In indirect solar dryers, the black surface heats incoming air, rather than directly heating the substance to be dried. This heated air is then passed over the substance and exits through a chimney, taking moisture from the substance with it. There are mainly three types of solar dryers [8]. The absorption or hot box type dryers in which the product is directly heated by sun; the indirect or convection dryers in which the product is exposed to warm air which is heated by means of a solar absorber, or heat exchanger; and dryers combining the principles of the above two, where the product is exposed to the sun and a stream of pre-heated air simultaneously. Direct drying consists of using incident radiation only, or incident radiation plus reflected radiation. Most solar drying techniques that use only direct solar energy also use some means to reflect additional radiation onto the product to further increase its temperature [8]. An example of direct absorption dryer is the hot box dryer. This type of a dryer is mainly to improve product quality by reducing contamination by dust, insect infestation, and animal or human interference. It consists of a hot box with a transparent top and blackened interior surfaces. Ventilation holes in the base and upper parts of slide walls maintained a natural air circulation. Many types of drying systems utilize both direct and indirect solar radiation. In these types of systems, radiant energy from the sun falls directly onto the product being dried; however, in addition, a preheater also is used to raise the air temperature, which in turn, accelerates the drying rate [8]. Acceleration of drying rate can occur in two ways: hot air can transfer some of its heat to the product being dried, thus raising its vapour pressure causing a faster moisture loss; or as temperature of air mass increases, the water-holding capacity also increases [8,9]. Most solar dryers assumed any of the type of these three categories described.

A hybrid solar dryer has therefore been designed and constructed in this present work and its performance evaluated under Makurdi humid condition which was reported in the earlier works of Barki et al. [10]. The drying process with a hybrid solar dryer was continuous (both sunny days, cloudy days and at night) thereby preventing deterioration by microbial infestation as also reported by Arinze, [11] and Bala, [12] that continuous drying does not permit the build-up of microbes. This study however is assessing and comparing the performances of the solar dryer with backup incinerator for Nsukka sub-tropical and Makurdi humid climates on selected farm produce of cassava grates, okra and chilli pepper as case studies which is aimed at evaluating the improvement attained on the quality of the dried produce for storage. The study assumed that drying obeys the falling rate model, a piece of information which is invaluable for farmers in rural areas.

2. MATERIAL AND METHODS

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 favourable weather conditions and during night periods.

'No-load' test was carried out on the system from 17^{th} Jan., 2011 – 31^{st} Jan., 2011 at location 1 (University of Nigeria, Nsukka) and 7^{th} – 17^{th} March 2011 at location 2 (Federal University of Agriculture, Makurdi). The test involved measuring the temperature of the air stream and the ambient temperature using thermometer. A psychometer 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 humidities. 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.

'On-load' test were carried out in the two different locations. Location 1 was the Energy Research Centre premises, University of Nigeria Nsukka from 1^{st} Feb to 20th Feb 2011. Location 2 was at the Department of Mechanical Engineering, Federal University of Agriculture, Makurdi, Nigeria from 24^{th} March 2011 to 30^{th} April 2011. At each of the locations, cassavas tubers were peeled, grated and mashed. The mashed cassava was shared into two equal parts. One 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 shield 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 and the wind velocity measured to test the efficiency of the dryer. The control was tempered appropriately by sealing it in polythene bag at night to prevent it from rehydrating. Twelve batches were dried to a moisture content of about 47 – 48% ready for frying. Similarly, samples of okra (*Hibiscus esculentus*) and chilly yellow pepper (*Capsicum annum*) were dried until their weight became relatively stable [13].

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, okra, pepper were determined using Ohaus Moisture Analyser model MB 36 Halogen before charging it into the dryer. Samples of dehydrated garri by local producers were collected at Nsukka from farmers and the moisture content analyzed using the moisture analyser and average value found to be 47.5, whereas subsequent moisture contents were calculated based on the weight losses, which were measured and recorded every two hours until safe moisture content of about 47.5 or less was achieved in the trays sufficient for frying.

2.1 Description of the Solar Incinerator Dryer

The hybrid solar incinerator dryer which was designed, constructed and tested has three main components: The flats plate collector; the drying unit and the incinerator. The dimensions of the solar collector are 1.22m x 0.67m and made up of transparent cover, absorber plate and insulation. The transparent cover is 0.004m thick clear glass supported by a wooden casing of thickness 0.024m by 0.06m. The absorber plate was folded to a depth of 0.14m. The absorber plate was fixed inside the casing providing a channel through which air flows. Inlet air through the flat plate collector is heated as it flows over an absorber plate. The heated air gains kinetic energy and by natural convection rises into the drying chamber [8]. The dryer has dimensions, 54cm x 54cm x 43cm and houses a drying rack (9) measuring 51cm x 42cm x 20cm. The rack was made of angle bars and covered with perforated net for circulation of air within the drying chamber. The bottom plate of the dryer measuring 54cm x 54cm has an opening at the centre connected to a circular pipe of diameter 1.27m. The cover plate holds a chimney of height 34cm. The air moisture outlet vent of the chimney was made with a pipe of diameter 13cm. The dryer has a total height of 130cm. The collector exit air vent runs into the drying chamber at one side with a dimension 47.2cm x 12cm.

One of the sides of the drying chamber was fixed with a heat exchanger measuring 36cm x 36cm. The dryer has a door of dimension 54cm x 43cm. This enables the samples to be introduced into the dryer and its inspection from time to time. Glass of dimension 31cm x 54cm was used to cover the remaining parts of the drying chamber. Care was taken to prevent air leakage by sealing all air spaces with a flash band. The dryer was painted black. An additional heat supplying source (an incinerator) was connected to the drying chamber through the inlet port of the heat exchanger. The incinerator has the dimension 49cm x 124cm x 40cm and made of two layers. Between the layers was an insulating material. The internal dimensions of the incinerator were divided into three sections: the exchanger region, measuring 24cm x 41cm. In this region a pipe of length 130cm was run, supported by metal rods. The pipe runs through the incinerator walls to form the inlet and outlet ports of the incinerator. The combustion chamber measures 32cm by 41cm for burning of biomass (charcoal); the ash collector measures 10cm x 41cm. The top of the incinerator was made of slant cover with a chimney height of 34cm.Other components of the dryer are the two reservoirs for holding cold water and collecting hot water.

The outlet port of the incinerator was connected to the inlet port of the dryer. The inlet port of the incinerator is connected to the reservoir that contains water. The dryer can be operated both day and night and during cloudy weather. During the day, the collector and the dryer was used for the drying when the weather is sunny and/cloudy. Air flows in through the inlet port of the collector gets heated and by natural convention flows into the drying chamber through the outlet vent of the collector, circulates round the drying chamber and exit through the air-moisture vent of the dryer chimney. At nights, the incinerator and the drying unit are connected together. The circulation of air through the collector is same as during the clear weather. Water is allowed to flow by gravity through the incinerator when the burnt charcoal heats up the water which flows into the heat exchangers of the dryer. The heat exchanger of the dryer is attached with a fan that circulates the heat conducted by the heat exchanger into the drying chamber. The water flows out into the second reservoir. The incinerator was incorporated in the design for drying during cloudy weather and night periods [8]. Fig. 1 depicts the isometric auto inventor drawing of the solar incinerator dryer described. Fig. 2 shows the incinerator isolated for better description.

3. 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. Table 3 shows the mean mass (moisture) profile of pepper sample (control experiment) while Table 4 shows the respective mean mass (moisture) profile of okra samples for the control experiment. The analysis of drying rates and efficiencies of equipment for cassava drying for Nsukka and Makurdi locations are shown in Tables 5 and 6, respectively. Table 7 shows the analysis of drying rates and equipment for pepper drying. Table 8 shows the analysis of drying rates and efficiencies of equipment for okra drying. Fig. 3 shows the effect of ambient temperature on the efficiencies of the solar collectors for location 1 (Nsukka) during no-load tests while the effect of ambient temperature on the efficiencies of the collectors for location 2 (Makurdi) is as shown in Fig. 4. The drying rate distribution patterns for the three farm produce in the two locations are expressed in Figs. 5 - 7.

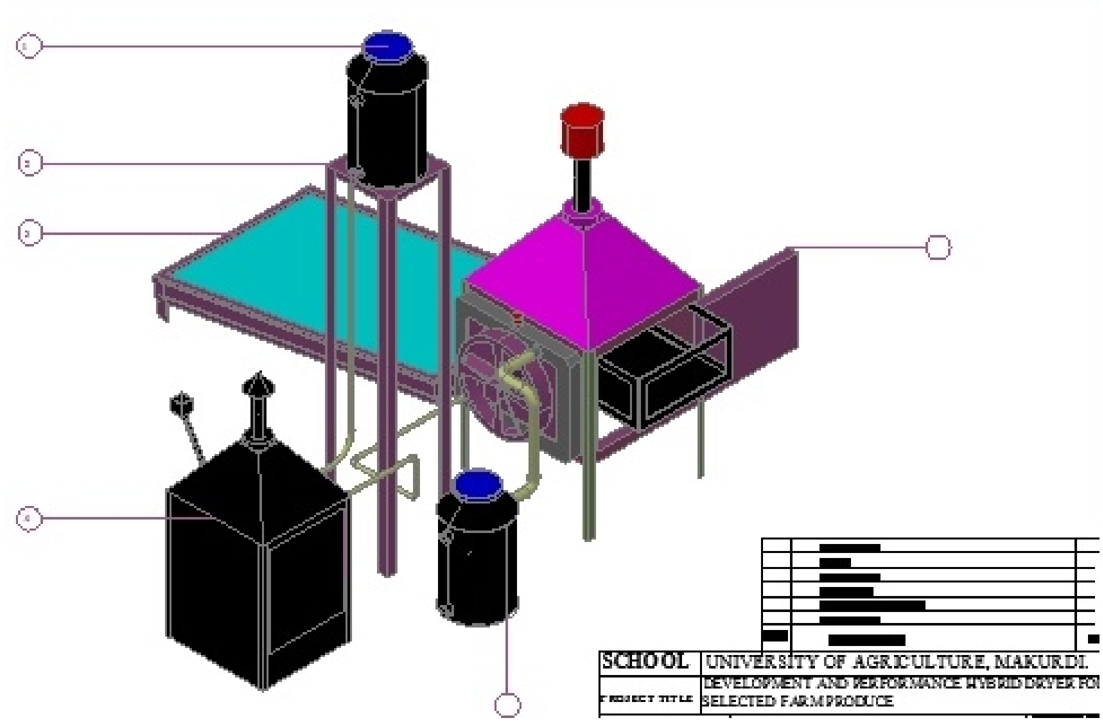

Fig. 1. Isometric drawing of the Developed Solar Incinerator Dryer used for the Experiment

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

Time (Hrs)	Mass before drying (W) (g)	Mass after drying Ws (g)	M (%)	M_o-M (%)	In (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; W = mass by weight of material before drying; Ws = mass by weight of material after drying

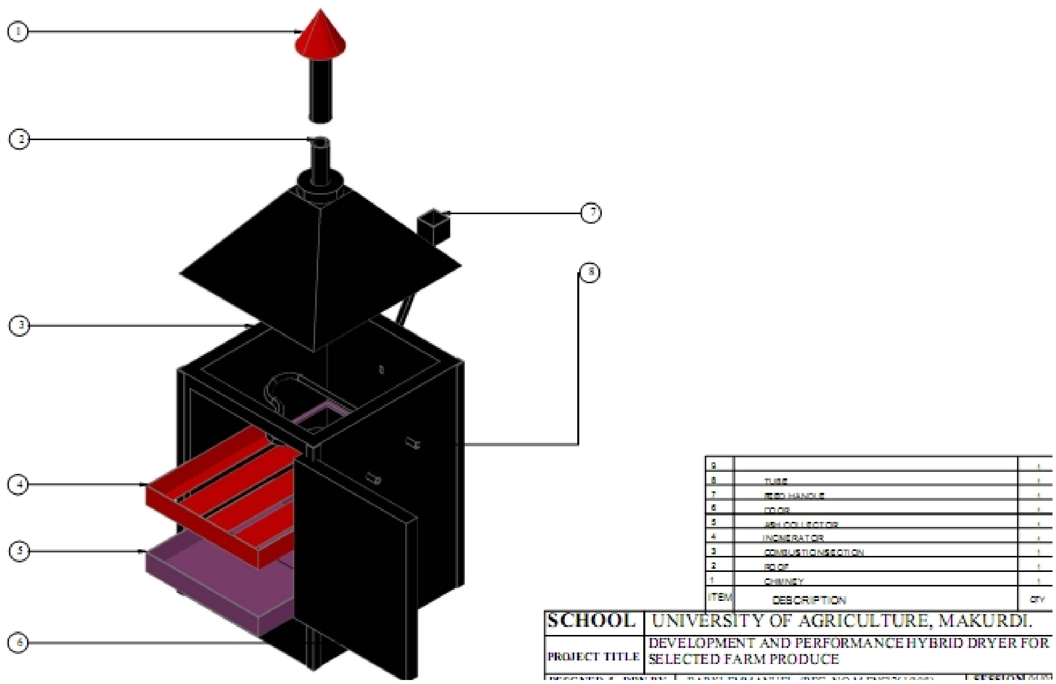

Fig. 2. Incinerator chamber isolated

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

Time (Hrs)	Mass before drying (W) (g)	Mass after drying Ws (g)	M (%)	M_o-M (%)	In (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. Mean mass (moisture) profile of pepper sample in Makurdi Location (Control)

Time (Hrs)	Mass before drying (W) (g)	Mass after drying Ws (g)	M (%)	M_o-M (%)	ln (M_o - M)	Time (days)
1000 – 1200	1000	824	21.30	65.30	4.17	
1200 – 1400	824	805	24.08	62.52	4.13	
1400 – 1600	805	809	23.50	63.10	4.14	1
1600 – 1800	809	786	27.09	59.51	4.08	
0800 – 1000	786	773	29.31	7.29	4.05	
1000 – 1200	773	765	30.60	56.00	4.02	
1200 – 1400	765	761	31.33	55.27	4.01	2
1400 – 1600	761	722	38.49	48.11	3.87	
1600 – 1800	722	707	41.34	45.26	3.81	
0800 – 1000	707	677	47.60	39.00	3.66	
1000 – 1200	677	671	48.98	37.62	3.62	
1200 – 1400	671	683	46.30	40.30	3.69	3
1400 – 1600	683	657	51.99	34.61	3.54	
1600 – 1800	657	611	63.43	23.17	3.14	
0800 – 1000	611	595	67.89	18.71	2.93	
1000 – 1200	595	553	80.67	5.93	1.78	
1200 – 1400	553	556	79.23	7.37	1.99	4
1400 – 1600	556	552	81.13	5.47	1.69	
1600 – 1800	552	537	86.21	0.39	- 0.94	

Table 4. Mean mass (moisture) profile of Okra sample in Makurdi Location (Control)

Time (Hrs)	Mass before drying (W) (g)	Mass after drying Ws (g)	M (%)	M_o-M (%)	ln (M_o - M)	Time (days)
1000 – 1200	840	678	23.80	56.2	4.03	
1200 – 1400	678	668	25.61	54.39	3.99	
1400 – 1600	668	674	24.46	55.54	4.02	1
1600 – 1800	674	668	25.71	54.29	3.99	
0800 – 1000	668	651	29.03	50.97	3.93	
1000 – 1200	651	637	31.74	48.26	3.88	
1200 – 1400	637	610	37.66	42.34	3.74	2
1400 – 1600	610	581	44.56	35.44	3.57	
1600 – 1800	581	560	49.81	30.19	3.41	
0800 – 1000	560	535	56.73	23.27	3.15	
1000 – 1200	535	521	61.13	18.87	2.94	
1200 – 1400	521	514	63.27	16.73	2.82	3
1400 – 1600	514	498	68.56	11.44	2.44	
1600 – 1800	498	493	70.17	9.83	2.29	
0800 – 1000	493	487	72.28	7.72	2.04	
1000 – 1200	487	473	77.33	2.67	0.98	
1200 – 1400	473	466	80.03	0.03	-3.50	4

Table 5. Analysis of drying rates and efficiencies of equipment for cassava drying (Makurdi)

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 ≤ $_{crit}$; Ha: F>F_{crit}					**α = 0.05**	

Table 6. Analysis of drying rates and efficiencies of equipment for cassava drying (Nsukka)

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**	

Table 7. Analysis of drying rates and efficiencies of equipment for Pepper drying

Source of Variation	SS	df	MS	F	P-value	F_{crit}
Rows	13.52167	12	1.126806	3.20109	0.007363	2.18338
Columns	3.030236	2	1.515118	4.304229	0.025268	3.402826
Error	8.448164	24	0.352007			
Total	25.00007	38				
Ho: F ≤F_{crit}; Ha: F>F_{crit}					**α = 0.05**	

Table 8. Analysis of drying rates and efficiencies of equipment for Okra drying

Source of Variation	SS	df	MS	F	P-value	F_{crit}
Rows	15.82559	8	1.978198	1.817634	0.147075	2.591096
Columns	7.942807	2	3.971404	3.649057	0.049476	3.633723
Error	17.41339	16	1.088337			
Total	41.18179	26				
Ho: F ≤ F_{crit}; Ha: F>F_{crit}					**α = 0.05**	

The grated cassava was at initial moisture content of 69.8%. It took the solar dryer 11hrs to dehydrate the grated cassava to moisture content 47.19%, 16hrs, for solar –incinerator to dehydrate the grated cassava sample to a moisture content of 47.28%, 20hrs for the incinerator dryer to dehydrate the sample to a moisture content of 47.62%. The open sun drying took 20hrs to dehydrate the grated cassava to a 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 samples 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.

In the analysis, SS is the sum of square value, df is the degree of freedom, MS is the mean square value, P-value is the probability value, F is the statistics. Ho is null hypothesis and Ha is alternate hypothesis which would be rejected when the null hypothesis is accepted.

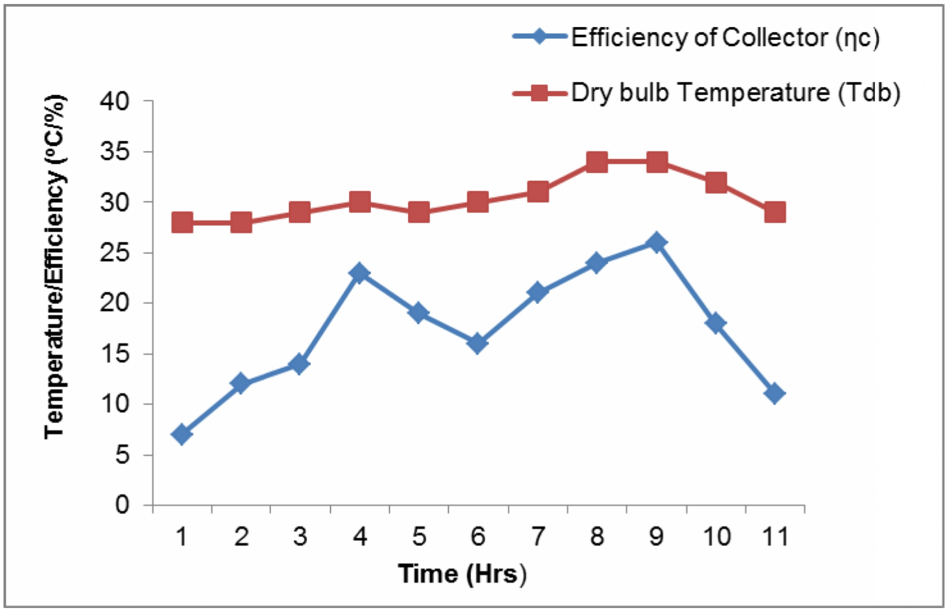

Fig. 3. Effect of Ambient temperature on Efficiency of Collectors (Location 1) on-load test

The analysis shows that there is a significant difference between the drying rates of the equipment at 5% significant level. More-so, 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 equipment 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. Drying rates and efficiencies of equipment for okra drying has no significant difference between the drying rates but there is a significant difference between the efficiencies of the equipment. The same level of significant trails the drying rates and efficiencies of equipment for pepper drying.

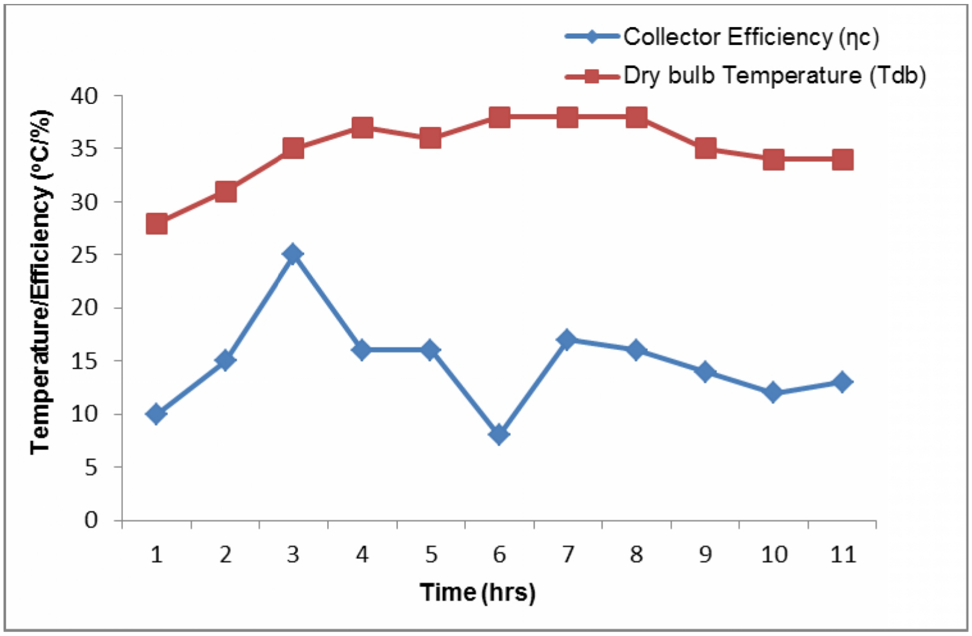

Fig. 4. Effect of Ambient temperature on Efficiency of Collectors (Location 2) on-load test

Fig. 3 is the effect of ambient temperature on the efficiency of collector during no-load at Nsukka (Location1). At 0800hrs, ambient temperature 27ºC, the efficiency of the collector was 8%. The efficiency increases with increase in the ambient temperature. A maximum efficiency of 24% was recorded at 11.00hrs, ambient temperature of 30ºC. A fall or decline in efficiency was observed from 1200hrs and 1300hrs. At 1300hrs where there was a sharp fall in the collector efficiency, the average temperature and the average velocity of air readings were 32ºC and 4.5m/s. The average value of the air velocity for 13 hours was the highest air velocity recorded at location 1 during the no-load test period. The collector efficiency increases with increase in ambient temperature and started declining after the 1600hrs and recorded a very low efficiency at 1800hrs where the ambient temperature was 27ºC.

Fig. 4 shows significant effect of ambient temperature on the efficiency of collector during the No-load test in Makurdi (Location 2). The efficiency of the collector was 10% at 0800 Hrs. Average ambient temperature of 28ºC. The graph shows that as the ambient temperature increased, there was a corresponding increase in the collector efficiency. The highest efficiency was recorded at 10.00hrs with 35ºC as the average ambient temperature. A decrease in the collector efficiency was observed with it lowest value at 1300hrs. After the 1300hrs a relationship of the collector efficiency increasing with increase in temperature was also observed. While Figs. 5 -7 compares the three dryers studied with particular reference to the solar incinerator dryer.

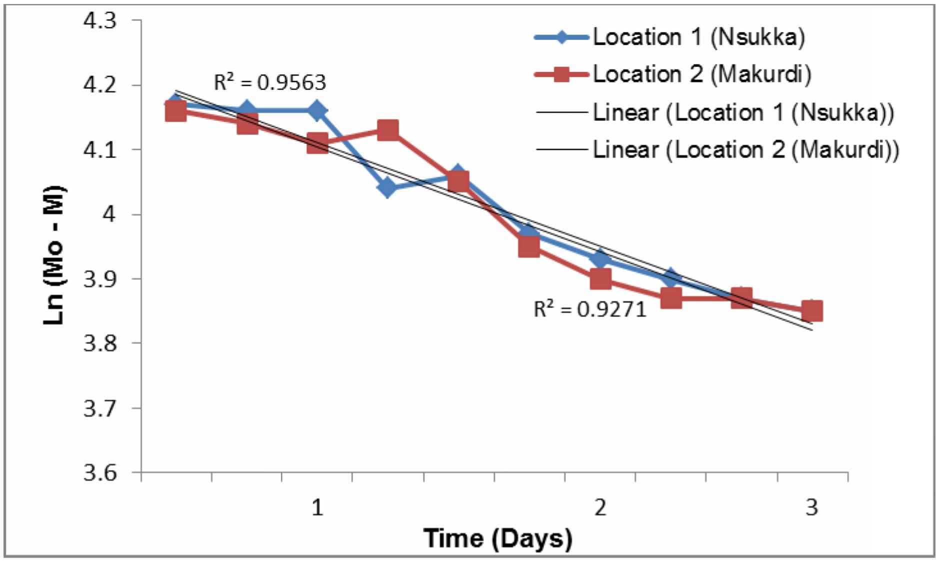

Fig. 5. Drying rate of Open air sun drying for Nsukka and Makurdi (grated cassava)

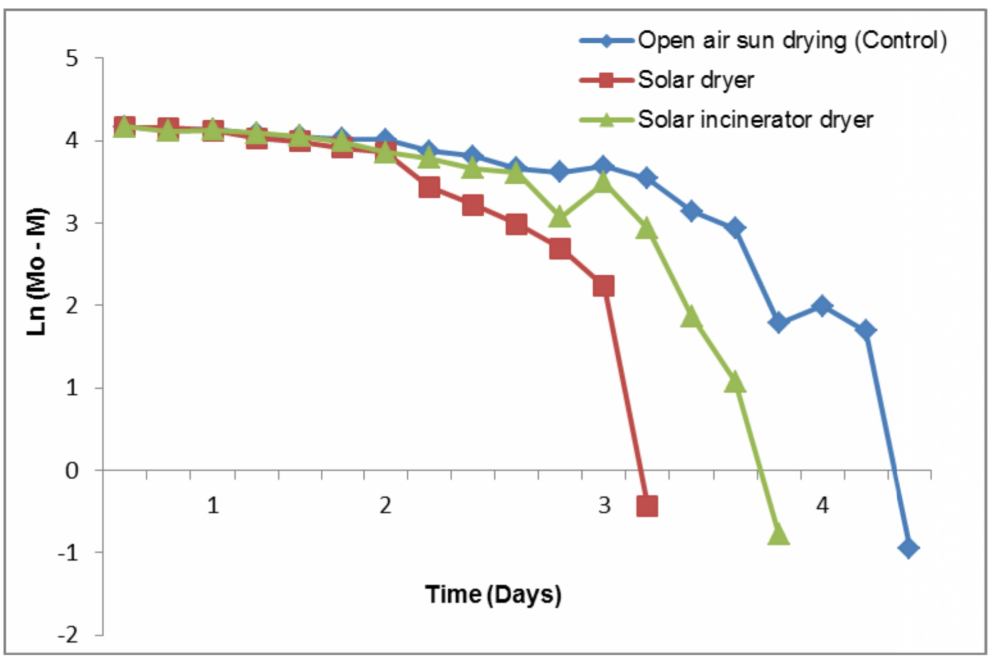

Fig. 6. Distribution rates for Pepper drying

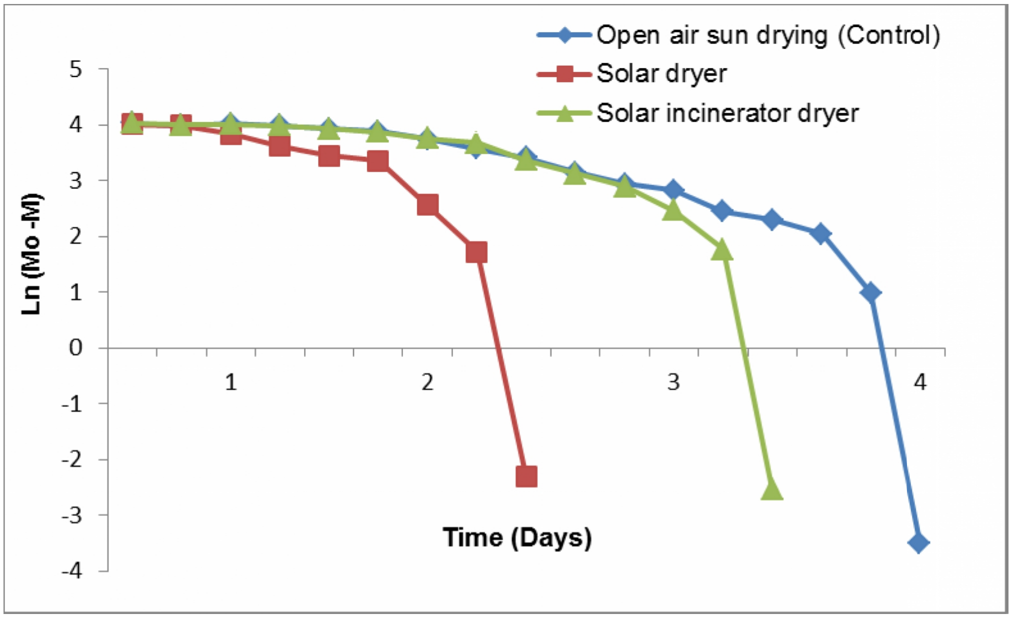

Fig. 7. Drying pattern distribution rates for Okra drying

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 67ºC atambient temperature of 39ºC, relative humidity of 50%. The drying chamber temperature was 50ºC (Nsukka). At location 2, Makurdi, the maximum air temperature reached by the solar collector was 68ºC at ambient temperatures of 40ºC, relative humidity of 50.5%, respectively; absorber plate temperature, glass temperature and dryer temperature of 73ºC, 55ºC and 50ºC respectively. The maximum collector temperatures attained during solar–incinerator drying for Nsukka location are 53ºC and an average dryer temperature of 47ºC. At Makurdi, the maximum collector exit temperature was 56ºC and average dryer temperature of 48.3^{o}C. The average dryer temperature for the incinerator dryer was 37.5ºC and 41.3ºC for locations 1 and location 2, respectively. The same pattern is displayed for the selected farm produce of okra and chilli pepper. But in comparison with the three dryers studied, solar incinerator dryer's performance is best due to its incineration enhancement. The curve shows extended hours/day than solar dryer which allows for controlled and proper drying within the maximum allowable temperature; natural convection drying being employed in a most enhanced process.

4. CONCLUSION AND RECOMMENDATIONS

The following conclusions were obtained within the limits of the study conditions: The mean efficiency of the collector was 0.17 while the dryer efficiency for solar dryer, solar-incinerator dryer was 0.29 and 0.23 respectively; Location 1 and location 2 do not significantly affect the dryer performance.

The solar dryer has the most efficient drying rate. The dryer can be used efficiently during dull, rainy bright weather conditions and at nights. The project can be commercialized if improved upon. The dryer can be used to substitute the garri dehydration means in rural areas for improved quality of garri.

The solar dryerhas a better performance when compared with the research work of Amer et al. [14] on experimental determination of the drying rate of chilly yellow pepper. The dryer constructed by Okonkwo (2006) took 4 days to dehydrate the expellable moisture content of chilli pepper whereas this efficient dryer took 3 days.It is hereby recommended that further study be undertaken to include a DC pump to improve the system performance. Further research on chemical analysis of garri dehydrated by the dryer should be carried out for general acceptability. On the present level of development, the system can be adopted in rural areas for drying of agricultural produce.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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