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Research paper

COMPARATIVE ANALYSIS AND PERFORMANCE OF SOLAR DRYERS WITH BACKUP INCINERATORS FOR NSUKKA SUB-TROPICAL AND MAKURDI HUMID LOCATIONS USING SELECTED FARM PRODUCE

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 chilly 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. Each consists of solar collector, drying chamber, and incinerator. The dryer was used for drying at night; sunshine days and cloudy days drying were assumed to have taken place in the falling rate periods which enabled the use of only one drying constant. They were used for test drying, termed 'no-load' test (without any farm produce) and 'on-load' (cassava grates, okra and chilly pepper) as selected farm produce. Their respective weight losses were used to determine the reduction in moisture contents. Drying was 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 gari 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, gari, okra, chilly 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 (Esper, 1988). The process is also time-consuming and requires large area for spreading out the produce to dry. Several attempts have been made by Okonkwo (2004),

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Mumba (1995) 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. At the same time, it can be used to promote renewable energy sources as an in-come generating option (Muller, 1999). In rural areas, different constructions of active solar dryers are hindered due to lack of conventional power (Forson, 2007). 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 beign 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 gari product and the drying of other agricultural crops like okra and pepper for storage.

A hybrid solar dryer has therefore been designed and constructed in this present work and its performance evaluated under Makurdi humid condition. The drying with a hybrid solar dryer is continuous (both sunny days, cloudy days and at night) thereby preventing deterioration by microbial infestation (Arinze, 1999; Bala, 1994). The study is aimed at improving the quality of 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. 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 and weather conditions and during night periods.

'No-load' test was carried out on the system from 17th Jan., 2011 – 31st Jan., 2011 at location 1 (University of Nigeria, Nsukka) and 7th – 17th 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

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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 1st Feb to 20th Feb 2011. Location 2 was at the Department of Mechanical Engineering, Federal University of Agriculture, Makurdi from 24th March 2011 to 30th April 2011. At each of the locations, cassava was peeled and grated and the mashed cassava 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 polyethene 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 (AOAC, 1984).

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 Analyzer model MB 36 Halogen before charging it into the dryer. Samples of dehydrated gari by local producers were collected at Nsukka from farmers and the moisture content analyzed using the moisture analyzer 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.

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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 equipments 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 efficiencies of equipment for okra drying. Table 8 shows the analysis of drying rates and equipments for pepper drying. Figure 1 shows the effects 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 Figure 2. The drying rate distribution pattern for the three farm produce in the two locations is expressed in Figures 3, 4 and 5.

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

Time (Hrs)	Mass b/4 drying (W) (g)	Mass after drying Ws (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)	Mass after drying Ws	M (%)	M_o-M (%)	ln (M_o - M)	Time (days)

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	(g)	(g)				
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

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120 **Table 3: Mean mass (moisture) profile of pepper sample in Makurdi Location (Control)**

Time (Hrs)	**Mass b/4 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	

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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	

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122 **Table 4: Mean mass (moisture) profile of Okro sample in Makurdi Location (Control)**

Time (Hrs)	Mass b/4 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

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Table 5: Analysis of drying rates and efficiencies of equipments for cassava drying (Makurdi Location)

ANOVA

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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 6: 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;					**α = 0.05**	
Ha: F> F crit						

Table 7: Analysis of drying rates and efficiencies of equipments for Pepper drying

ANOVA

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;					**α = 0.05**	
Ha: F> F crit						

Table 8: Analysis of drying rates and efficiencies of equipments for Okra drying

ANOVA

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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; **α = 0.05**

Ha: F> F crit

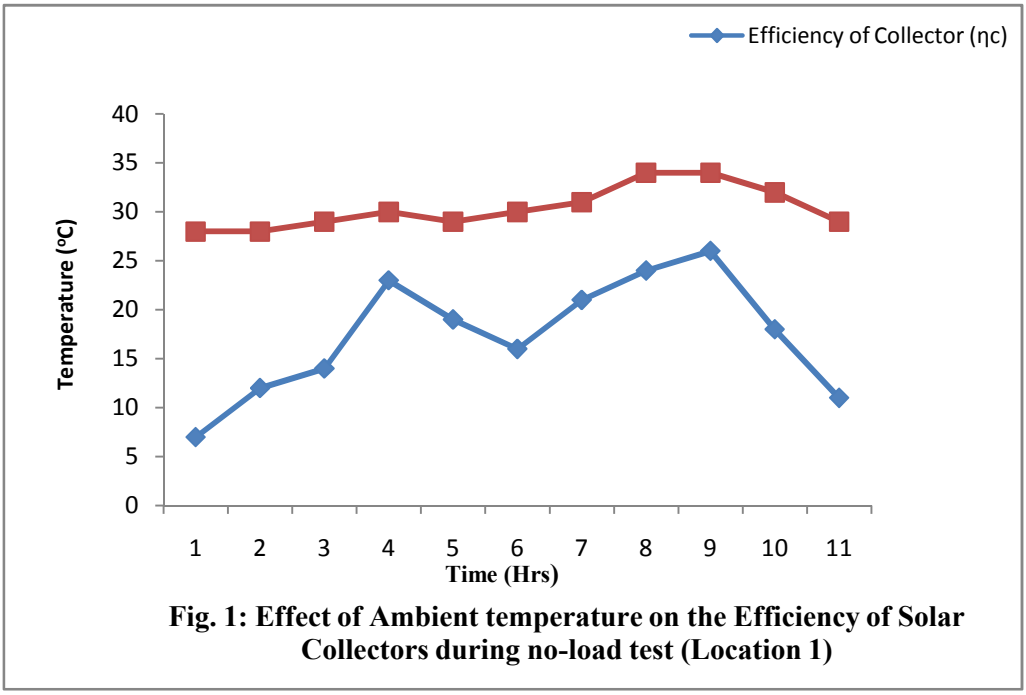

Fig. 1: Effect of Ambient temperature on the Efficiency of Solar Collectors during no-load test (Location 1)

The grated cassava was at initial moisture content of 69.8%. It took the solar dryer 12hrs 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 also to dehydrate the grated cassava moisture content of 47.56%.

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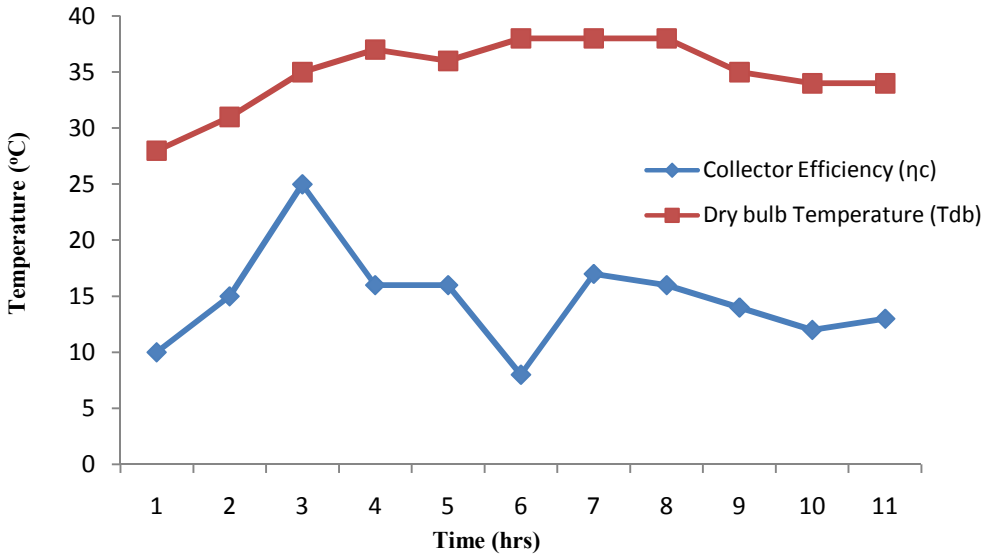

Fig. 2: Effect of Ambient temperature on the Efficiency of Solar Collectors during no-load test (Location 2)

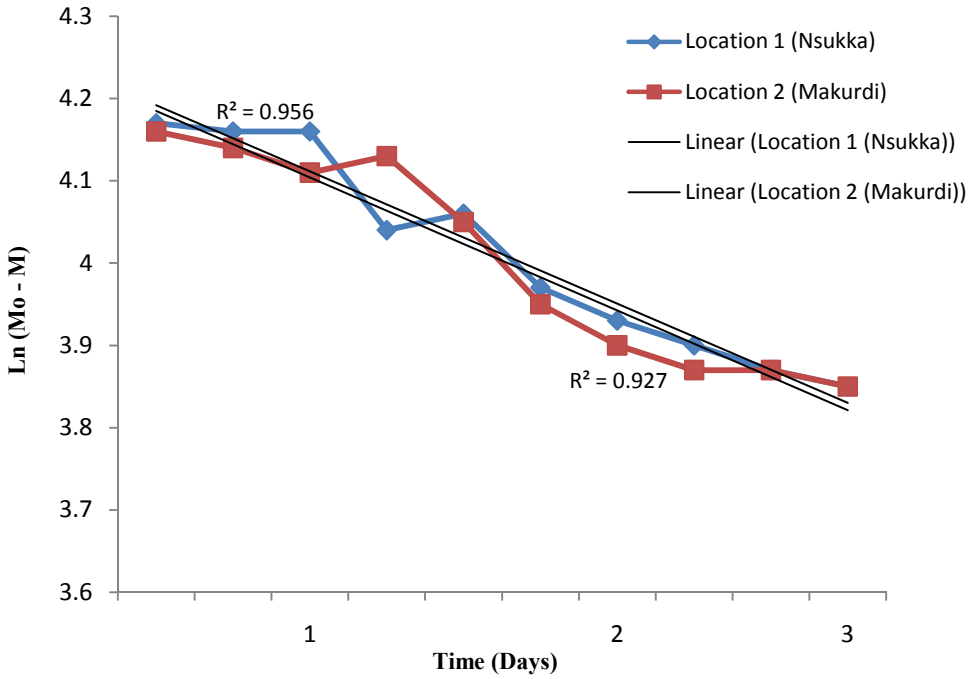

Fig. 3: Drying Rate of Open air sun drying for Nsukka and Makurdi (grated Cassava)

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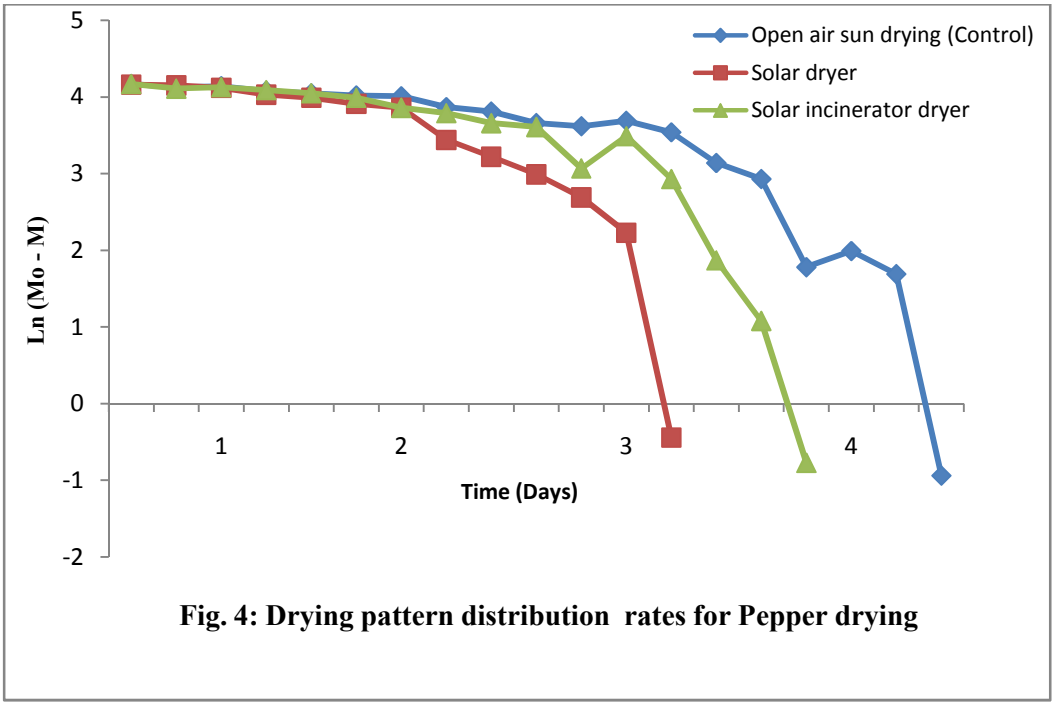

Fig. 4: Drying pattern distribution rates for Pepper drying

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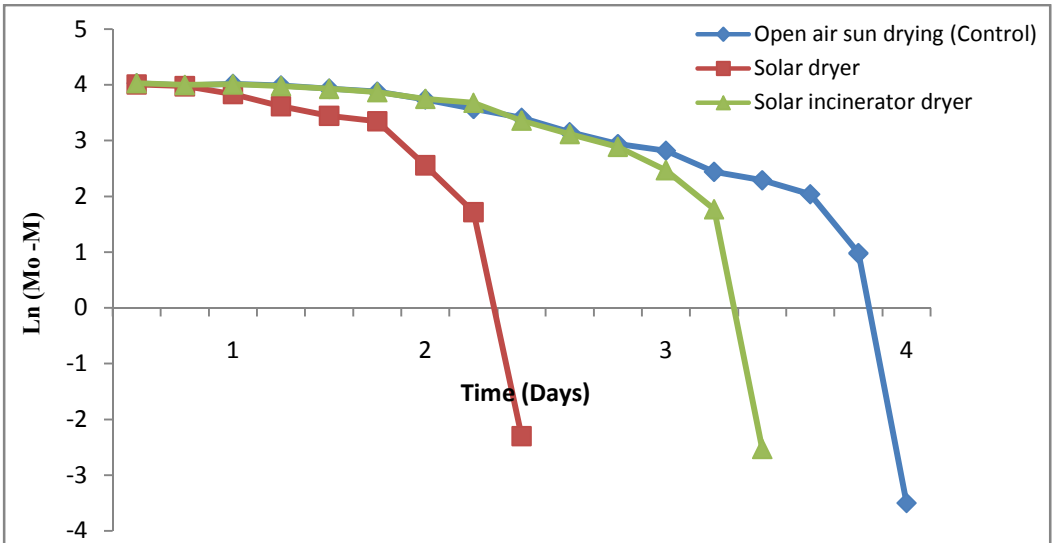

Fig.5: Drying pattern distribution rates for Okra drying

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148 This showed a significant reduction in time in the order solar dryer, solar - incinerator dryer and
149 incinerator dryer with solar, dryer having the highest time reduction and incinerator the lowest
150 time reduction. More so, the sample dried in the dryer were clean and of high quality with no
151 contamination through dust or insects and did not change colour while those under open air sun

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dry showed change in colour indicating signs of deterioration in quality. No colour change was observed for solar samples dehydrated in the dryer.

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 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. Drying rates and efficiencies of equipment for okro 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 equipments for pepper 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 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.

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CONCLUSION AND RECOMMENDATIONS

The following conclusions were obtained within the limits of the study conditions.

1. The mean efficiency of the collector was 0.17.
2. The dryer efficiency for solar dryer, solar-incinerator dryer are 0.29 and 0.23 respectively.
3. Location 1 and location 2 do not significantly affect the dryer performance.
4. The solar dryer has the most efficient drying rate.
5. The dryer can be used efficiently during dull, raining and bright weather conditions and at nights.
6. The project can be commercialized if improved upon.
7. The dryer can be used to substitute the gari dehydration means in rural areas for improved quality of gari.

The solar dryer has a better performance when compared with the research work of Anyanwu and Okonkwo (2006) 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 chilly pepper whereas this efficient dryer took 3 days. It is hereby recommended that further study be undertaken to include a D.C pump to improve the system performance. Further research on chemical analysis of gari 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.

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