

Contingency Evaluation of Performance of a Cabinet Solar Dryer Using Fresh Tomato *(Lycopersicum esculentum Mill.)*

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Abstract
The study designed, constructed and evaluated the performance of a solar dryer using fresh tomato (Lycopersicum esculentum Mill.) in Imo State, Nigeria. The paper became necessary due to the high cost of fresh tomato fruits during scarcity (lean season) as well as the need for appropriate preservation method for tomatoes during major season to curb scarcity in the study area. Data collected were analyzed using descriptive statistical tools, proximate analyses and One Way Analysis of Variance (ANOVA). A Cabinet /flat plate solar dryer with dimensions 1.36m, 0.9m and 0.79m of length, width and height respectively was used with softwood and hardwood during construction. Saws dust was used as an insulating material, finger glass as screen, mesh screen as air inlet and outlet vent, mild steel sheet as the solar energy collector. Weight losses and temperature of the test samples were recorded at intervals during drying. The highest temperature observed in the dryer was 720C while the ambient temperature was 470C. The initial weight of the solar dried sample was reduced from 490.56g to 6.87g in 70.00 hours while sun dried sample reduced from 490.56g to 6.67g in 71.00 hours. Estimated ANOVA revealed that significant differences (P<0.05) exist between solar dried, sun dried and fresh sample (control). The carbohydrate, crude fibre, ash, protein and fat content of all the dried samples increased at 95.00% confidence level (P<0.05) respectively. The vitamins, A and E increased while vitamin C, thiamin, niacin and riboflavin decreased significantly (P<0.05). The minerals, calcium, magnesium, phosphorus, sodium, and potassium increased significantly (P<0.05). The microbial load of the sun dried sample (4.20x105cfu/g) was higher than the solar dried sample (1.22x107cfu/g). Significant difference (P<0.05) also exist in the sensory evaluation of the appearance/colour, aroma, texture and general acceptability on the sun dried, solar dried and fresh tomato samples. Finding showed that solar drying is efficient, effective and most hygienic method. It was therefore recommended that a storage test be carried out on dried samples and also more durable glass should be used for the design and construction of a solar dryer for improved efficiency and performance. Government at all levels should intensify effort on the need for solar drying of fresh tomato samples as well as provision of fabrication materials/equipment for solar dryers as this would positively enhance the availability of fresh tomato fruit all year in the area and beyond.
Keywords: Fresh Tomatoes, Cabinet solar dryer, Design, Construction, Performance, Microbial, Mineral, Vitamins and Organoleptic Properties, ANOVA

INTRODUCTION

Fresh Tomato fruit (*Lycopersicum esculentum Mill.*) is grown in many parts of Nigeria both as wet and dry season crops (Adebayo *et al.,* 2012). Tomato is a prevalent vegetable use both in raw form as salad, for garnishing various food items and added for taste in various cooked items (Brindha *et. al.,* 2012). Tomato is also an important food component since it contains carotene, which is the precursor for vitamin A synthesis, extremely synthesis for vision. This increases the priority of safeguard its productivity and prevention from microbial spoilage (Khan *et. al.,* 2011).Tomato is highly prone to the spoilage of fungi especially *Aspergillus* species, *Penicillium* species and *Trichoderma* species (Ghosh, 2009). Among the wilt diseases, *Fusarium* wilt is most prevalent, particularly among the local varieties, which are very susceptible. Wilts of tomato are also prevalent and damaging to tomato in other countries (De-Cal *et al*., 2008). However, tomato fruit requires preservation for several reasons, such as to prevent spoilage, to maintain the availability throughout the year, to retain the nutritional value and to make value-added products (higher prices) (Ahmad *et al*., 2013). Vegetable spoilage or damage may occur during handling process due to the influence of physical, physiological, chemical or microbial damage. Chemical and microbial factors are the main causes of food spoilage. Several chemical and enzymatic reactions can occur during processing and storage of food. Vegetable preservation is usually done by preventing the growth of bacteria, fungi (e.g. yeast), and other microbes (although in some method, benign bacteria or fungi has been used to make certain foods, such as tempeh, oncom and tape), as well as retarding the oxidation of fats which cause rancidity (Mujumdar and Jangam, 2012 and Ahmad *et al*., 2013). Preservation of vegetables can also include inhibition of visual deterioration during food preparation, such as the enzymatic browning reaction in salaks, apples and potatoes after peeling (Diamante *et al.,* 2013).

Maintaining or creating nutritional value, texture and flavor are important aspects of vegetable preservation, although, historically, some methods drastically change the character of the vegetable which is preserved. In many cases, these changes have come to be seen as a desirable quality in carrots. To preserve vegetables, some methods are sometimes used together. Preserving fruit by turning into jam, for example, involves boiling (to reduce the water content of fruit and to kill microbes), the provision of sugar (to prevent their re-growth) and sealing in an airtight jar (to prevent recontamination) (Vivante, 2009). There are various ways to preserve vegetable especially carrots. The pre and/or post processing steps are critical to reduce the drying load as well as to make better quality product. The commonly methods used for pre-treatment are osmotic dehydration, blanching, salting and soaking. While post-processing such as coating, blending, frying, boiling, roasting, packaging, etc. are also important after drying of vegetables (Mujumdar and Jangam, 2012). Water content is a major cause of food spoilage, therefore the drying process is often done to reduce levels of water and extend the shelf life of food (Maria *et al.,* 2013). In the same vein solar dryers are structures having solar collector which trap the energy from the sun and dries the food materials quickly and neatly. The temperature generated in the chamber (solar dryer) can produce dried products with low final moisture contents compared to simple sun drying. This reduces the risk of spoilage during processing and subsequent storage. The solar dryer can be constructed from locally available materials. They enhance the insulation effect and contribute towards the generation of higher air temperatures and lower relative humidity. Particularly in the study area and in Nigeria at large, there are two seasons for tomatoes, the peak and lean season. At the peak

season, tomatoes are produced in large quantities resulting in post-harvest loss due to short storage life and poor of storage and processing facilities, while in lean season, tomatoes are scarce and expensive. Also a lot of studies (Bret *et al.,* 1996; Reynolds, 1998; David and Whitefield, 2000; Graw, 2007 and Eze, 2012) have only looked at the design and construction of solar dryer. However, little or no study have rigorously modeled the performance of solar dryer along with fresh tomato. The absence of this study has left a void in research and knowledge. The need for an appropriate preservation method for tomatoes during major season will reduce the excess cost of tomato during scarcity (lean season) and wastage during major season. Empirical evidence remains largely scanty, isolated and devoid of in-depth contingency evaluation of performance of solar dryer using tomato. Hence it becomes pertinent that the study was undertaken. Specifically, the study designed and constructed a solar dryer with locally available materials and skills; evaluated its performance by drying tomatoes sample with the solar dryer and compare with sun drying; assayed some microbial, mineral, vitamins and organoleptic properties of the solar dried tomatoes samples and compared with open sun dried samples.

MATERIALS AND METHODS

Study Area

The study was carried out in Imo State, Nigeria. Imo State is located in the eastern zone of Nigeria. It is delineated into 27 local government areas. The State lies between latitudes 50 481N and 60 081N of the equator and longitudes 60 141E and 70 021E of the Greenwich Meridian (Onubuogu and Esiobu*,* 2014). It occupies the area between the lower River Niger and the upper and middle Imo River. It is bounded on the east by Abia State, on the west by the River Niger and Delta State; and on the north by Anambra State, while Rivers State lies to the south. Imo State covers an area of about 5,067.20 km2, with a population of 3,934,899 (NPC, 2006and NBS, 2007) and population density of about 725km2 (Ministry of Lands and Survey Owerri, 1992).

Collection of Samples and Materials

Fresh tomato samples were purchased from Eke- Ukwu market, Douglas road, Owerri, Imo State. The materials needed for construction of the solar dryer was purchased from building materials market Naze, near Owerri. The materials include; wood, mild steel sheet, fibre glass (transparent), plastic wire mesh, abrasive paper, black paint, hinges/staples/nails. The dryer was constructed with the aid of a skilled carpenter and hand tools such as hammer, saw, measuring tape and chisel were used. Materials such as thermometers, knife, bowls, handkerchief (white), chlorine and others were also purchased in Eke-Ukwumarket, while weighing balance was obtained from food science and technology laboratory, Imo State University, Owerri.

Design and Construction of Solar Dryer

The solar dryer was a cabinet/flat plate mixed mode passive dryer. In designing this dryer, the height was sloped at a minimum of 45 degree for a good channel effect of air during drying. The slope was such that the inlet height is 0.58m while the outlet vent is 0.80m above the ground. Skeletal area of the chamber is 1.4m2. The solar dryer consist of the following; collector plate, made of mild steel, the inlet and outlet vents (0.14m x 0.86m), drying chamber (0.23m x 1.22m), insulating layer of two inches thick sawdust and a door 1.21m2 which allows loading and off loading of samples and two plastic sample trays (0.53m x 0.88m) and a plastic screen. The transparent screen formed the door and hinged to the chamber frame on one side and a lock put at the other side. The dryer was supported on four legs of which two are shortened (24cm long) and the other two are longer 32cm long both are made of hardwood, thus giving distance from ground level of 11cm and 18cm respectively, to provide differences in height between the inlet vent at bottom and outlet vent at the top thus creating a sloppy structure. The dryer chamber and collector plate are painted black in order to enhance absorption. The tray was made of softwood, the vents (inlet and outlet) were screened with plastic mesh to prevent interference by insects or rodents. Beneath the chamber was sealed with plywood, then packed with saw dust as an insulator to prevent heat loss. An air space of about 2 inches was created at the bottom of the drying trays to permit good air circulation and also prevent direct contact between food sample and the metal surface. The components were fastened together with nails.

Sample Preparation

The tomatoes were thoroughly washed with clean sterilized water after sorting and selecting the good and firm ones and adhering water removed with white handkerchief. The weighing balance surface was also cleaned and sterilised to prevent contamination of the tomatoes during weighing. The samples were weighed whole, cut into slices of 0.2cm thick and placed in a tray for sun and solar drying respectively. The samples were shared and labelled (X and Y) into two different portions. The portion ‘‘X’’ was dried in the solar dryer and ‘‘Y’’ was dried in ambient (sun) condition. This was done in triplicates.

Sample Preparation

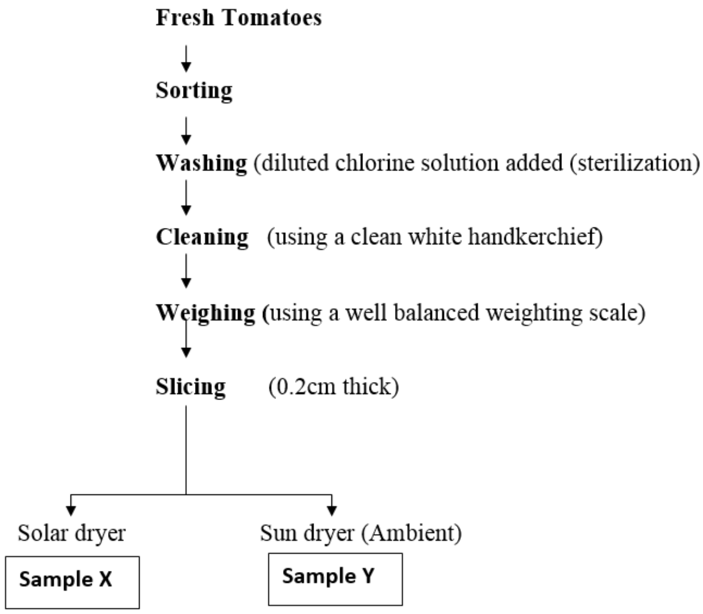

Figure 1: Flow diagram of Tomato sample preparation; Source: Field Survey Data, 2014

Solar Drying Operation

Before the sample was placed in the solar dryer, the dryer was cleaned with mild sterilant to disinfect it and kept aseptic. The cleaning and sterilization was carried out on the trays, the collector plate, the outlet and inlet vent and also the lid. The thermometers were also cleaned to prevent contamination. After cleaning, the samples were loaded on the trays and initial weight and temperature reading was taken at outlet vent, inlet vent, collector plate, tray and ambient making a total sum of five (5) locations. The dryer was securely closed to prevent interference by humans and animals. At intervals of one hour, sample weight and the various temperatures (inlet vent, outlet vent, collector plate, tray and ambient) were recorded. The daily relative humidity readings of the environment for the drying days were obtained from the meteorological centre of Imo State Agricultural Development Programme (ADP), Owerri, Nigeria.

Data Collection and Data Analysis

Data for the study on microbial, mineral, vitamins and organoleptic properties of the solar dried tomatoes samples were carefully collected and realized using descriptive statistical tools, proximate analyses, likert scale rating and One Way Analysis of Variance (ANOVA).

Result and Discussion

Design Parameter of the Solar Dryer

As complied in **Table 1,** the collector plate of the solar dryer was made of mild steel measuring 1.09m2 in area. Collector plate of a solar dryer is a highly conductive material coated black.

Table 1: design parameter of the solar dryer

Parameters	**Area(m^2)**
Collector plate	1.09
Door	1.29
Collector tray	0.59 (x2)
Inlet vent	0.12
Outlet vent	0.12

Source: Field Survey Data, 2014

The black coating makes it a good absorbing surface. It permits increase in absorbing and retaining heat. Inlet vent and Outlet vent are made equal (0.12m2) to allow free flow of air and good channeling effect and unhindered air circulation. They were screened with plastic mesh to allow air flow and to prevent insects from entering the chamber to contaminate the drying food material. The drying trays are two in number with equal measurement (0.59m2). Each holds the sample spread on it for drying in the chamber. They are placed above the collector plate in the dryer. It is also made with plastic mesh for free air circulation over the surface of the food. The door is wide enough measuring (1.12m2) to allow easy loading and off loading of samples and also to enable easy cleaning and sterilizing of the drying chamber.

Plate 1: Picture of a Constructed Solar Dryer; Source: Field Survey Data, 2014

No Load Temperature Profile of Dryer and Ambient

The No-load Temperature of the dryer and open-air (ambient) is presented in **Table 2 and Figure 2.** The observation from the result indicates variation in temperature with time of solar dryer and ambient. This is the period under study temperature of the dryer range from 45^0C – 84^0C while temperature of ambient ranges from 330C- 40^0C for the same period under study (9:00am to 17:00pm).

Table 2: No Load Temperature and Time Profile of Solar Dryer and Sun/Ambient

Time (Hrs)	T_A	T_B	T_C	T_D	T_E
9:00am	33	29	45	41	34
10:00am	34	30	52	47	35
11:00am	37	32	58	50	36
12:00pm	37.5	32	59	47	36
13:00pm	38	34	84	75	42
14:00pm	40	34.5	74	61	40
15:00pm	40	32	63	54	38
16:00pm	38	34	58	50	36
17:00pm	37	32	46	40	34

Source: Field Survey Data, 2014; Average solar drying chamber temperature =59.78^{0}C; Average ambient temperature = 37.06^{0}C;m Relative humidity =71.3%

Key:

$T_A{}^0C$ = Ambient temperature
$T_B{}^0C$ = Inlet vent temperature
$T_C{}^0C$ = Collector Plate temperature
$T_D{}^0C$ = Drying Tray temperature
$T_E{}^0C$ = Outlet vent temperature

The highest temperature of 84^{0}C for dryer was recorded about 13:00pm. At that time, the highest for the ambient was 400C. This show that the highest temperature reached by the solar dryer depends on the highest temperature of the ambient. The drying temperature with respect to time depends on the falling radiant energy from the sun which varies from time to time (Reynold, 1998). The temperature of the tray follows that of the collector plate (750C) and the exhausted gas 420C. The temperature of inlet air at the same time is 340C. It is closer to the ambient but, much lower than the chamber, the tray and the outlet air. The elevated temperature of the chamber subsequently the tray and outlet air can be attributed to the good thermal property of steel used as collector plate. The result is in agreement with Scanlin (1997) who opined that the solar dryer can elevate the temperature of drying above the ambient. This shows that the drying chamber (collector plate and tray) of the dryer had the highest temperature than ambient. The indication from this result, implies that higher and faster drying rate may be accomplished when using solar dryer than open air sun drying.

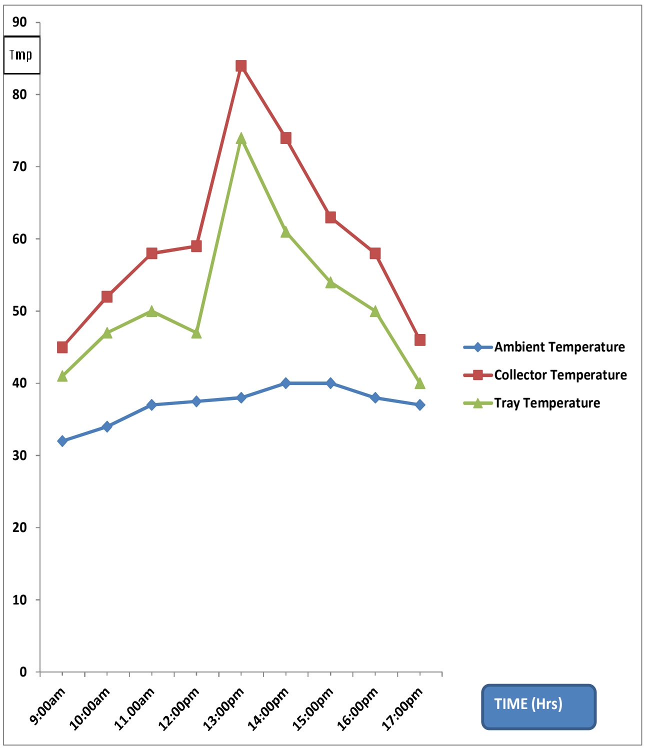

Figure 2: Shows that the collector temperature is above the ambient temperature throughout the period of time under study; Source; Field Survey Data (2014)

TEMPERATURE AGAINST TIME

Entries in **Table 3, Figure 3** and **4**, indicates the variations in temperature during drying of tomatoes under solar dryer and ambient. During four drying process, the collector plate, TC0 and drying tray, TD had the temperature range; 44-320C (day one), 45- 320C (day two), 52-330C (day three) and 50-400C (day four) and 42-340C (day one), 39-300C (day two), 40-310C (day three) and 38-350C (day four) respectively. The ambient temperature, TA range was 37-290C (day one), 34-290C (day two), 39-310C (day three) and 38-340C (day four). It was noted that the least temperature observed in each drying system was at 9:00am and 18:00pm respectively per day. The maximum temperature obtained was between 12:00pm and 13:00pm in each day. The increasing drying temperature observed in solar dryer could be attributed to the accumulation and storage of radiant energy from the solar that was absorbed through the transparent cover of the collector plate and tray. The radiant energy which falls on the drying surface area per unit time was not accumulated nor stored in open air sun drying (Frank and Jane, 1978). Comparing **Table 3** and **Table 4**, the No load temperature was higher than the Load temperature under load condition. This is because during no load, there was no product drying and this elevated the temperature. The drying materials absorb many or part of the heat during product drying. The drying chamber under load and no load have highest, followed by tray temperature and the least was ambient temperature. Scanlin (1997) earlier reported that solar dryers can be constructed from locally available material and that they enhance isolation effect and contribute towards generation of higher air temperature and lower relative humidity. The higher chamber temperature observed for No- load condition of the dryer and under load mean that the saw dust which is waste from woodwork was effectively insulated and the steel sheet was effective collector of heat from solar radiation.

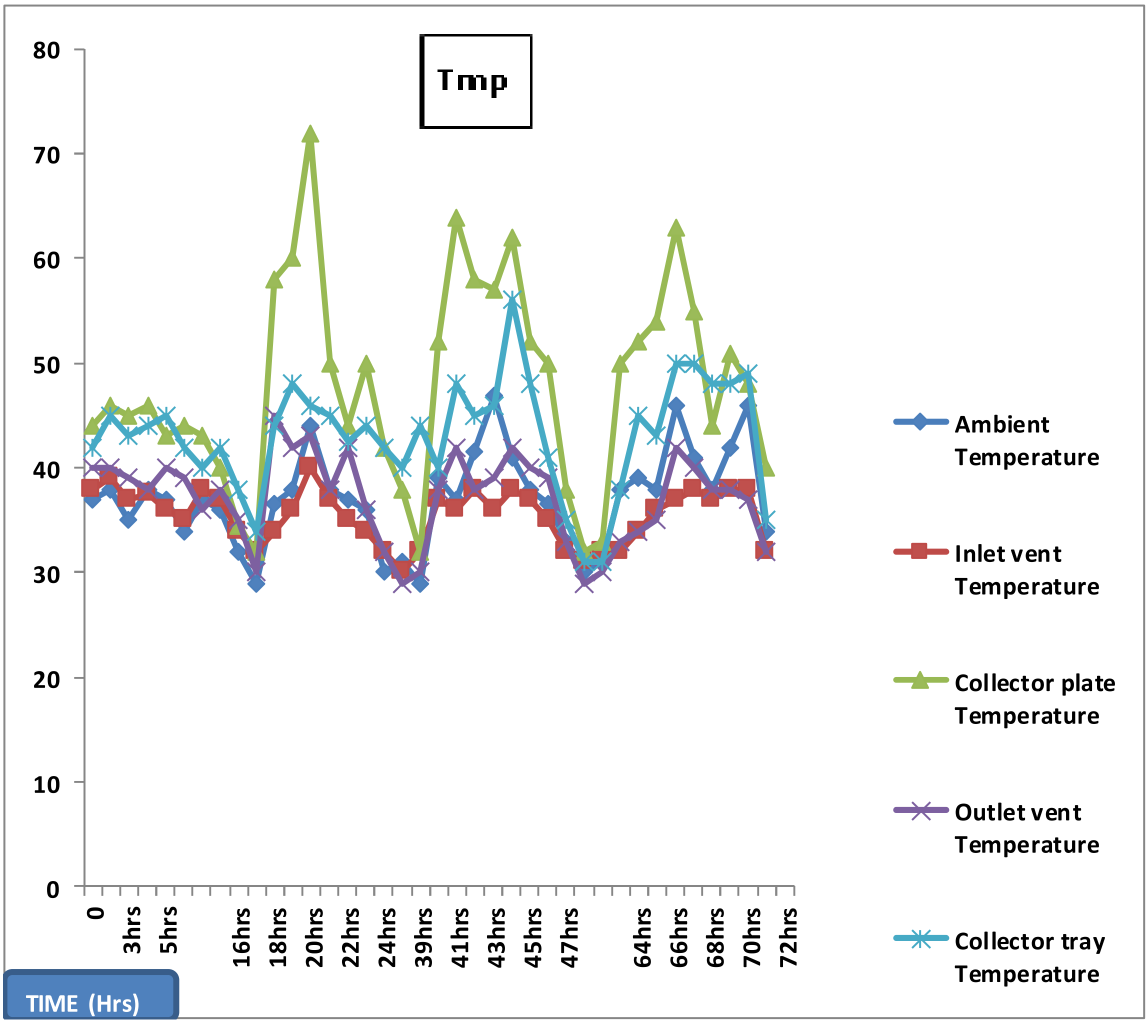

Figure 3: Temperature profile of dryer and ambient during Tomato drying Over Time (Hr); Source: Field Survey Data, 2014

Profile of the Solar Dryer and Ambient During Product Drying
Table 3: Time and Temperature for Four Days of Drying for Solar and Sun Drying

DAY 1	$T_A{}^0C$	$T_B{}^0C$	$T_C{}^0C$	$T_D{}^0C$	$T_E{}^0C$
Time (Hrs)	T_A	T_B	T_C	T_D	T_E
9:00	37	38	44	42	40
10:00	38	39	46	45	39
11:00	35	37	45	43	38
12:00	38	37.5	46	44	37
13:00	37	36	43	45	40
14.00	34	35	44	42	39
15:00	37	38	43	40	36
16:00	36	37	40	42	38
17:00	32	34	34.5	38	35
18.00	29	32	32	34	30
DAY 2					
Time (Hrs)	T_A	T_B	T_C	T_D	T_E
9:00	34	32	45	36	39
10:00	36.5	34	58	45	44
11:00	38	36	60	42	48
12:00	44	40	72	43	46
13:00	38	37	50	38	45
14.00	37	35	44	42.5	42
15:00	36	34	50	36	44
16:00	30	32	42	32	42
17:00	31	30	38	29	40
18.00	29	32	32	44	30
DAY 3					
Time (Hrs)	T_A	T_B	T_C	T_D	T_E
9:00	39	37	52	40	38
10:00	37	36	64	48	42
11:00	41.5	38	58	45	38
12:00	47	36	57	46	39
13:00	41	38	62	56	42
14.00	38	37	52	48	40
15:00	36.5	35	50	41	39
16:00	33	32	38	35	33
17:00	30	31	32	31	29
18.00	31	32	33	31	30
DAY 4					
Time (Hrs)	T_A	T_B	T_C	T_D	T_E
9:00	38	32	50	38	33
10:00	39	34	52	45	34
11:00	38	36	54	43	35
12:00	46	37	63	50	42
13:00	41	38	55	50	40
14.00	38	37	44	48	38
15:00	42	38	51	48	38
16:00	46	38	48	49	37
17:00	34	32	40	35	32

Source; Survey Data (2014); Average solar drying chamber temperature =48.44^{0}C; Average ambient temperature = 37.10^{0}C;
Relative humidity =74.54%
Key: TA0C = Ambient temperature
TB0C = inlet vent temperature
TC 0C = Collector Plate temperature
TD0C = Drying Tray temperature; TE0C = outlet vent temperature

From **Figure 3** and **4,** the graph indicates the drying temperature rate of tomatoes against cumulative drying time. The collector plate (TC) and tray (TD) of the solar dryer had the maximum temperature with collector being the highest. The tray temperature, TD is same as the drying product temperature. Therefore, the highest temperature, the tomato was exposed to during drying correspond to the highest tray temperature (560C) in **Table 4** and **Figure 4**. This highest product temperature of 56^0C is not capable of adverse product damage. It is mild enough and most of the nutrient can withstand it. Ambient temperature, TA was the least compared to solar dryer chamber. However, more heat was applied on the tomatoes in the solar dryer than under the sun/ambient.

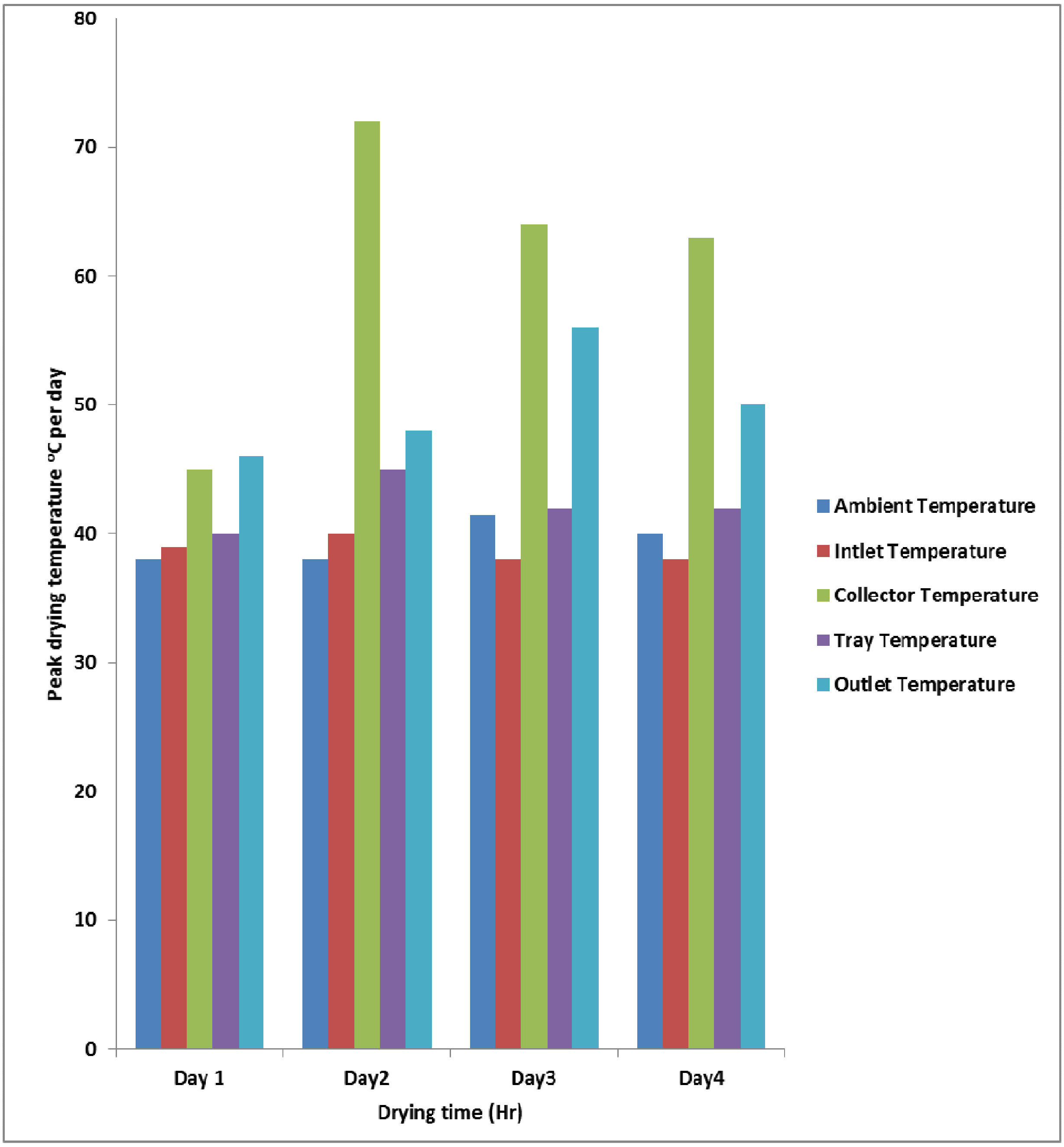

Figure 4: Histogram showing Peak temperature of different components of dryer during four days drying; Source: Field Survey Data, 2014

Weight Loss and Duration of Drying

Entries in **Table 4** show the weight loss and duration of drying for solar and sun dryer respectively. The weight loss of the drying sample over the total drying time can be taken to mean and the rate of drying. The total amount of moisture removed as represented by total weight loss can be taken as indicator of dryer efficiency in **Table 4** showed that 98.10% moisture was lost from the sample dried under solar dryer while 96.35% moisture was lost from the sample dried under ambient. This shows that the solar dryer removed more moisture than the ambient drying with the same duration (72.00hours) constant weight was achieved in 70.00hours with solar dryer and the average drying rate as calculated was 6.87 while in 71hours with sun drying and the average drying rate as calculated was 6.67 which indicate that solar dryer was faster than the ambient.

Table 4: Weight Loss and Duration of Drying

Duration (Hrs)	Solar dryer sample weight (g)	Weight loss in solar dryer (g)	Ambient/Sun sample weight (g)	Weight loss in Ambient/Sun (g)
0	490.56	0.00	490.56	0.00
2	356.08	134.48	368.28	122.28
3	310.34	45.74	335.10	33.18
4	285.14	25.20	315.25	19.85
5	262.98	22.16	300.78	14.47
6	247.76	15.22	289.12	11.66
15	215.87	31.81	259.70	29.42
16	198.54	17.33	236.12	23.58
17	174.23	24.31	200.98	35.14
18	150.82	23.41	187.04	13.94
19	119.49	31.33	164.13	22.91
20	100.76	18.73	148.29	15.84
21	87.24	13.52	129.40	18.89
22	78.41	8.83	123.98	5.42
23	72.30	6.11	119.28	4.70
24	67.08	5.22	115.19	4.09
39	49.25	17.83	95.10	20.09
40	38.08	11.17	78.45	16.65
41	33.98	4.10	60.72	17.73
42	27.46	6.52	51.35	9.37
43	20.12	7.34	39.20	12.15
45	18.97	1.15	22.16	17.04
46	17.45	1.52	20.96	0.20
47	16.24	1.21	20.02	-0.06
48	15.95	0.29	21.87	-0.85
63	15.20	0.75	22.00	-0.13
64	14.97	0.23	20.34	1.66
65	14.01	0.93	19.97	0.37
66	13.82	0.19	19.15	0.82
67	12.45	1.37	18.73	0.42
68	11.87	0.58	18.01	0.72
69	10.25	1.62	17.42	0.59
70	09.87	0.38	16.89	0.53
71	09.87	0.00	16.89	0.00
72	09.87	0.00	16.89	0.00

Dry Rate Solar Dryer = 480.69/70 Sun Dryer =473.89/71 =6.87 =6.67; Source: Field Survey Data, 2014

Time duration in the falling rate period governs the total drying time. Reynolds (1998) stated that two principal mechanisms govern the migration of moisture during the falling rate period from the internal structure of the food to the surface. These are diffusion and capillary flow which are influenced by some factors such as; temperature of drying, particle size and initial moisture content of foodstuff. Since the initial moisture content and particle size are the same, therefore temperature is more important in this case. The difference in the level of drying obtained and the rate of drying can be said to be as the result of the higher temperature of the dryer. Again the weight loss per unit time is greater in the solar drying than sun drying as shown in **Table 5**. In both methods, this was greater during the initial hours and falls as drying progressed until they become zero in the last three hours in the case of solar drying and two hours in the case of sun drying **(Figure 5).**

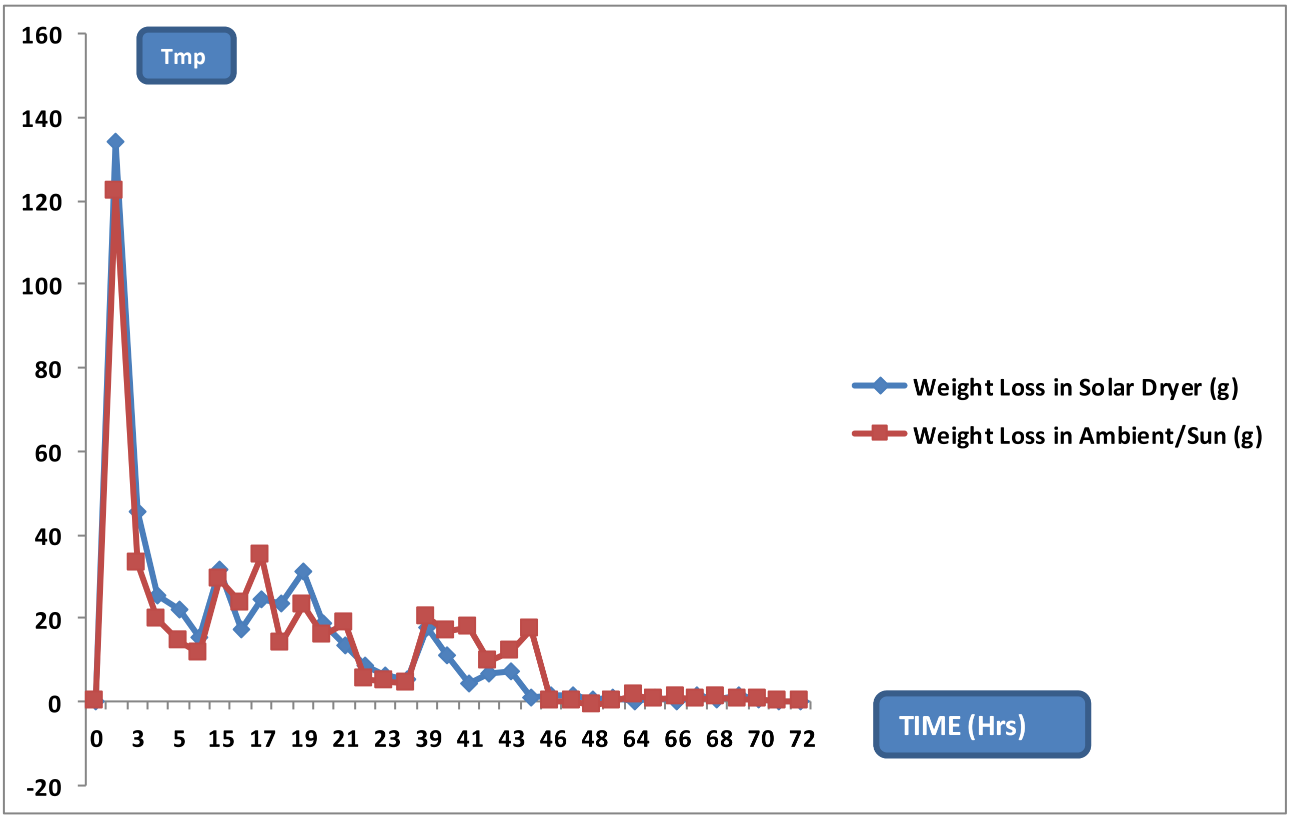

Figure 5: Graph showing weight loss (g) in Tomato during Solar and Ambient against time (Hr); Source: Field Survey
Data, 2014

Result in **Figure 5** displays the rate at which weight reduced was more in the solar dryer than the sun. After 41 hours, drying slowed down in the solar dryer. This is because free moisture in the tomatoes had been removed. What remains in the food at this point is bound moisture in the inside. They need to migrate to the surface before they can be removed. They continue to lose moisture more rapidly than solar until they both approached equilibrium moisture content. At 46-48 hours, there was gain in weight of the open-air sun dried samples. This was as result of bad weather. This change in weather increased the relative humidity in the air and brought about a decrease in temperature of the ambient. Increase in relative humidity had less effect on the solar dryer because the collector plate of the dryer was still hot compared to ambient. Decrease in drying rate for both sun and solar was as a result of moisture in the air (relative humidity). Drying continued on the fourth day for both systems (solar and sun) until a constant weight was reached then that there was no further reduction in weight.

Nutrient Retention of Dried Tomatoes
Proximate Composition of Dried Tomato and Control
Moisture Content
The final moisture content was 8.08% and 11.913% for solar dried and sun dried tomato. Samples respectively and that of the fresh tomato sample was 94.087%. The dryer reduced the moisture to as low as 8.08%. at this moisture level the tomato keep very well and falls below the safe storage level for bacteria, mould and fungi growth. The combined effect of elevated temperature and depressed relative humidity of air may be responsible for the achieved level of dry in the dryer. Statistical analysis showed that there exist significant difference at 95% confidence level ($P<0.05$) between the moisture content of the samples (**Table 5**). The Crude protein, fat, fibre, ash and carbohydrate content increased after drying with the following mean scores for fresh sample (A), sun dried sample (B) and solar dried sample (C) are: 0.587, 5.253 and 5.487 (protein), 0.040, 0.079 and 0.061(fat), 0.733, 6.0113 and 6.413 (crude fiber), 1.127,10.153 and 12.080 (ash), 3.180, 65.080 and 66.320 (carbohydrate).

Table 5: Effects of Drying on Proximate Composition of Dried Tomatoes

Tomato Samples	Moisture content (g)	Protein (g)	Fat(g)	Crude fibre (g)	Ash (g)	Carbohydrate (g)
A	4.087^{a} ± 0.277	0.587^{b} ± 0.982	0.040^{b} ± 0.301	0.733^{b} ± 0.231	1.127^{c} ±0.416	3.180^{b} ±0.269
B	11.913^{b} ±0.306	5.253^{a} ± 0.216	0.079^{a} ±0.346	6.013^{a} ± 0.291	10.153^{b} ±0.18	65.088^{a} ±3.77
C	8.080^{c} ± 0.400	5.487^{a} ± 0.982	0.061^{a} ±0.400	6.413^{a} ±0.306	12.100^{c} ± 0.60	66.32^{c} ± 0.889

Keys; A= Fresh tomato sample; B= Sun dried sample and C = Solar dried sample; Mean of triplicate analysis ± standard deviation. Mean score with different superscript in a row are significantly different at 95% level of confidence (P < 0.05); Source: Field Survey Data, 2014

The increase observed can be attributed to concentration effect which occurs after removing water. This effect was more in the solar dried sample. This can be explained by the fact that more water was removed in the solar dried sample (C) than in the sun dried sample (B). Statistical analysis show that significant difference exist between the fresh sample (A) and the dried samples (solar and sun dried) in protein, crude fibre, fat and carbohydrate at 95% confidence level (P<0.05). but the sun dried and solar dried samples do not differ significantly at the same confidence level. But the ash content differ significantly for fresh sample (A), sun dried sample (B) and solar dried sample (C) at 95% confidence level (P<0.05).

Vitamin Contents of Dried Tomatoes

Vitamin A (Retinol)

Table 6 shows the effect of drying on vitamin A content on solar and sun dried Tomatoes. Mean value of the fresh tomato (sample A) was 465.950 IU. However, increase in the vitamin A content was observed in the dried samples with mean values of 686.667IU and 744.820IU for sun dried sample (B) and solar dried sample (C), respectively.

Table 6: Effects of Drying on Vitamin Contents of Dried Tomatoes

Tomato Samples	*Vitamin A (I U)	*Vitamin C (mg/100g)	*Vitamin E (mg/100g)	*Thiamin (B_1) (mg/100g)	*Riboflavin(B_2) (mg/100g)	*Niacin (B_3) (mg/100g)
A	465.950c ±0.173	25.23^{a}±1.016	361.96^{b}± 0.13	0.110^{a}±0.003	0.036^{a} ±0.06	0.651^{a}±0.005
B	686.667^{b} ±0.173	14.61^{b} ±1.062	66.957^{a}±0.702	0.045^{b}±0.030	0.016^{b}+0.005	0.289^{b}±0.024
C	744.820^{a}±0.437	11.71 ^{b}±1986	667.633^{a}±0.739	0.017^{b}±0.003	0.00^{c}± 0.000	0.098^{c}±0.063

Keys; A= Fresh tomato sample; B= Sun dried sample and C = Solar dried sample; Mean of triplicate analysis ± standard deviation. Mean score with different superscript in a column are significantly different at (P<0.05); Key: A = Fresh sample (control); B = Sundried sample; C = Solar dried sample; Source: Field Survey Data, 2014

The vitamin A content reduced in sun dried sample (B) while it was retained most in solar dried sample (C). Thus, significant differences exist among all the samples at 95% confidence level (P < 0.05). This result agrees with the result as recorded for vitamin A retention on dried tomatoes by Mulokozi and Svanberg, (2003).

Vitamin C (Ascorbic acid)

Table 6 presents vitamin C content of the fresh tomatoes (sample A) 25.227mg/100g, and those of sun dried sample (B) and solar dried sample (C) 14.613mg/100g and 11.707mg/100g respectively. After drying, the mean values for vitamin C content decreased to 14.613mg/100g and 11.707mg/100g for both sun dried sample (B) and solar dried sample (C). The results show that there was loss in vitamin C value for the dried samples. Vitamin C is a water soluble vitamin and it is rapidly destroyed by heat (Onwuka, 2005). Heat treatment such as cooking and drying leads to adverse loss of vitamin C. Sun dried sample (B) and solar dried sample (C) differ significantly from fresh sample (A) but no significant different exist between sun dried sample (B) and solar dried sample (C) at 95% confidence level (P< 0.05).

Vitamin E (Tocopherol)

Vitamin E content for fresh tomatoes (sample A) was 361.963mg/100g and 660.95mg/100g for sun dried sample (B) and 667.633mg/100g for solar dried sample (C). There was a sharp increase in vitamin E content after drying the tomatoes with mean values for sun dried sample (B) and solar dried sample (C). This result shows that vitamin E was not decreased by heat treatment. Vitamin E is susceptible to light and air. Sun dried sample had lower vitamin E mean value than solar dried sample because of exposure to light and air. Vitamin E is an antioxidant. It prevents oxidation from taking place by getting oxidized instead of the food material. Thus, the use of solar dryers for drying tomatoes increased the concentration of the fat soluble vitamins than sun drying.

Vitamin E content for sun dried sample (B) and solar dried sample (C) is significantly different from fresh sample (A) but sun dried sample (B) does not significantly different from solar dried sample (C) at 95% confidence level (P< 0.05) (Table 6).

Thiamine content (Vitamin B2)
Table 6, shows the mean values for thiamine content for fresh tomatoes (sample A), thiamine value was 0.110mg/100g. for sun dried sample (B), 0.045mg/100g and solar dried sample (C), 0.017mg/100g. This show that thiamine decreased significantly in the dried samples with solar dried sample (C) having the least value. This loss could be due to light, heat effect. Therefore, dried sample differ significantly from fresh sample (A) at 95% confidence level (P<0.05). But sun dried sample (B) and solar dried sample (C) does not differ significantly at the same confidence level.

Riboflavin content (Vitamin B2)
As represented in **Table 6**, the mean value for riboflavin content for fresh tomatoes was 0.036mg/100g, for sun dried sample (B) 0.016mg/100g and solar dried sample (C) 0.000mg/100g. From this result, there was decrease in riboflavin content of the solar and sun dried tomato samples, and it was completely lost in solar dried sample (C). This could be as a result of light and ultra violet rays and not heat, this is because riboflavin is heat stable and the temperature of the solar dryer cannot destroy it. Solar dried tomato therefore is not a dietary source of riboflavin. Fresh sample (A) had the highest riboflavin value; this indicates that the two drying methods affected the riboflavin retention in the dried tomatoes. Significant differences exist among all the fresh samples (A), sun dried sample (B) and solar dried sample (C) at 95% confidence level (P<0.05).

Niacin content (Vitamin B3)
From **Table 6**, the niacin content for fresh tomatoes (sample A) was 0.651mg/100g but 0.289 mg /100g for sun dried sample (B) and 0.098mg/100g for solar dried sample (C). Niacin decreased significantly in the dried samples with much decrease on solar dried sample (C) than sun dried sample (B). This is because of the amount of heat in the solar dryer. Fresh sample (A) had higher niacin content because it was not subjected to heat. Thus, sun dried sample (B) and solar dried sample (C) differ significantly from fresh sample (A), but sun dried sample (B) and solar dried sample (C) are not significantly different at 95% confidence level (P< 0.05).

Mineral Contents of Dried Tomatoes
Table 7 shows the amount of mineral content retained in the dried and fresh tomatoes samples. Mineral content is a measure of the amount of specific in-organic components present in a food. Minerals are not destroyed by heat and they have a low volatility compared to other food components.

Calcium Content
Calcium content of the fresh sample (sample A) in Table 7 was 10.687mg/100g. After drying, the values increased to 25.367mg/100g and 29.390mg/100g in sun dried sample (B) and solar dried sample (C). The calcium content for solar dried sample (C) was higher than that of sun dried sample (B) and fresh sample (A). Fresh sample (A) differ significantly from sun dried sample (B) and solar dried sample (C) at 95% confidence level (P<0.05). But sun dried sample (B) and solar dried sample (C) does not differ significantly at same confidence level.

Table 7: Effects of Drying on Mineral Content of Dried Tomatoes Sample

Tomato Sample	Calcium (mg/100g)	Magnesium (mg/100g)	Phosphorus (mg/100g)	Sodium (mg/100g)	Potassium (mg/100g)
A	$10.687^{b} \pm 2.309$	$7.333^{b} \pm 0.231$	$26.000^{c} \pm 0.260$	$30.933^{b} \pm 0.115$	$58.933^{c} \pm 0.231$
B	$25.387^{a} \pm 2.315$	$20.00^{a} \pm 1.386$	$33.617^{b} \pm 0.491$	$38.133^{a} \pm 0.306$	$116.533^{b} \pm 0.611$
C	$29.390^{a} \pm 4.625$	$20.800^{a} \pm 1.386$	$36.467^{a} \pm 0.633$	$39.333^{a} \pm 0.231$	$119.467^{a} \pm 1.222$

Keys; A= Fresh tomato sample; B= Sun dried sample and C = Solar dried sample; Mean of triplicate analysis ± standard deviation. Mean score with different superscript in a column are significantly different at 95% confidence level (P<0.05); Source: Field Survey Data, 2014

Magnesium content
The magnesium content of the fresh tomato sample (A) in **Table 7** was 7.333mg/100g while that of the dried samples were 20.000mg/100g and 20.800mg/100g for both sun dried sample (B) and solar dried sample (C) respectively. More magnesium was in solar dried sample (C) than sun dried sample (B) and fresh sample (A) had the least magnesium content. The difference in magnesium content of solar dried sample (C) is slightly higher than sun dried sample (B). Thus, sun dried sample (B) and solar dried sample (C) differ significantly from fresh

sample (A) at 95% confidence level (P< 0.05) but sun dried sample (B) and solar dried sample (C) does not differ significantly at same confidence level.

Phosphorous content

For fresh sample (A) in Table 8, the phosphorus content was 26.000mg/100g 33.617mg/100g for sun dried sample (B) and 36.467mg/100g for solar dried sample (C). This shows that dried tomatoes retained more phosphorus than fresh sample (A). There was more increase in phosphorous content of solar dried sample (C), followed by sun dried sample (B) and the least was fresh sample (A). This shows that the solar dryer was able to retain the phosphorus content in the tomatoes than sun. Statistical analysis shows that significant difference exists among fresh sample (A), sun dried sample (B) and solar dried sample (C) at 95% confidence level (P< 0.05).

Sodium content

Sodium content of the fresh tomatoes (sample A) in Table 7 was 30.933mg/100g. After drying the sodium content increased to 38.133mg/100g for sun dried sample (B) and 39.333mg/100g for solar dried sample (C). The sodium content was higher in the solar dried sample (C) was higher than that of sun dried sample (B) and fresh sample (A). Solar dried sample (C) and sun dried sample (B) differ significantly from fresh sample (A) but solar dried sample (C) does not differ significantly from sun dried sample (B) at 95% confidence level (P<0.05).

Potassium content

The potassium content for the fresh tomatoes (sample A) in Table 7 was 58.933mg/100g and 116.533mg/100g and 119.467mg/100g for sun dried sample (B) and solar dried sample (C) respectively. The potassium content was higher in solar dried sample (C) than sun dried sample (B) and fresh sample (A). Significant difference exist among fresh sample (A), sun dried sample (B) and solar dried sample (C) at 95% confidence level (P< 0.05).

Sensory Evaluation of Dried Tomatoes

Colour/Appearance

The panelists mean scores of sensory attributes are shown in **Table 8** for the appearance of the samples. the panelists ranked fresh sample (C) highest with mean score of 7.72 which corresponds to like very much on the 9-points hedonic scale. This was followed by solar dried sample (B) with mean score of 6.88 which corresponds to like moderately on the 9-points hedonic scale. Sun dried sample (A) was scored least with mean score 6.56 which correspond to like slightly on the 9-points hedonic scale. Statistical analysis shows that significant difference exist between fresh sample (C) and other two samples; sun dried(A) and solar dried sample (B) at 95% confidence level (P<0.05). But no significant difference exists between sun dried sample (A) and solar dried sample (B) at the same confidence level. The colour of food contributes to its acceptance. The presence of contaminants and other factors affects the appearance of food. The colour of fresh tomatoes is due to the presence of lycopene and other pigments (Nguyen and Schwartz, 1999).

Plate 2: Picture of Solar Dried Tomato Sample; Source: Field Survey Data, 2014

Texture

The panelist mean score of the sensory attributes are shown in **Table 8** for the texture of the samples. The panelist ranked fresh sample (C) least with mean score of 6.32 which corresponds to like slightly on the 9-points hedonic scale. This was followed by sun dried sample (A) with mean score of 7.17 which corresponds to like moderately on the 9-points hedonic scale and solar dried sample (B) was ranked highest with mean score of 7.92 which corresponds to like very much on the 9-points hedonic scale. The texture of solar dried sample (B) was crispier than sun dried sample (A). Statistical analysis shows that significant difference exist between the dried samples and fresh sample at 95% confidence level (P<0.05). Solar dried sample (B) is not significantly different from sun dried sample (A) at the same confidence level (P<0.05).

Table 8: Mean Score of Sensory Attributes of Dried Tomatoes Samples

Tomato Samples	Appearance/Colour	Aroma	Texture	General Acceptability
A	6.56^b	7.28^a	7.17^a	7.36^a
B	6.88^b	7.00^a	7.92^a	7.80^a
C	7.72^a	7.32^a	6.32^b	6.80^b

Keys; A= Fresh tomato sample; B= Sun dried sample and C = Solar dried sample; Mean score with different superscript in a column are significantly different at 95% confidence level (P<0.05); Source: Field Survey Data, 2014

Aroma

The panelist mean scores of the sensory attributes are shown in **Table 8** for aroma of the samples. The panelists ranked the fresh sample (C) highest with mean score of 7.32 which corresponds to like moderately on the 9-point hedonic scale. This was followed by sun dried sample (A) with mean score of 7.28 which corresponds to like moderately on the 9-point hedonic scale and the least was solar dried sample (B) with mean score of 7.00 which corresponds to like moderately on the 9-point hedonic scale. Flavonoid are responsible for aroma of foods and could be lost when exposed to heat. Statistical analysis show that significant difference does not exist among the fresh sample(C), sun dried sample (A) and solar dried sample (B) at 95% confidence level (P<0.05).

General acceptability

The panelist mean scores of the sensory attributes are shown in **Table 8** for general acceptability of the samples. The panelist ranked solar dried sample (B) highest with mean score of 7.80 which corresponds to like very much on the 9-points hedonic scale. This was followed by sun dried sample (A) with mean score of 7.36 which corresponds to like moderately on the 9-points hedonic scale and the least was the fresh sample (C) with mean score of 6.80 which corresponds to like slightly on the 9-points hedonic scale. The solar dried sample (B) was more accepted than sun dried sample (A) and fresh sample(C). Statistical analysis shows significant difference exist between the dried samples and fresh sample, but no significant difference exist between solar dried sample(B) and sun dried sample (A) at 95% confidence level (P<0.05).

Table 9: Microbiological Evaluation of Dried Tomato (*Lycopersicum esculentum Mill.*)

Tomato Samples	Total plate aerobic count (Cfu/g)	LSD
Sun dried sample(F_1J_1)	$4.020^a \pm 0.000$	0.0041
Solar dried sample (F_1J_2)	$1.225^b \pm 0.007$	0.0043

LSD; Least Significance Difference; Mean of Triplicate Analysis ± Standard deviation. Mean Score with different Superscript Column are significantly different at 95% confidence level (P< 0.05); Key: Cfu/g = Colony forming unit/gram Source: Field Survey Data, 2014

The results of the microbial load (cfu/g) for the dried tomatoes using the two drying methods are presented in Table 9. The microbial load counts obtained from the fresh sample prior to drying were 6.3 x 105 cfu/g and 4.2 x 103cfu/g for bacteria and fungi respectively. This load generally reduced to 5.44 x 104cfu/g and 3.60 x 103cfu/g for bacteria and fungi after drying. This could be due to the exhaustion of moisture on which these microbes thrive (Adebayo and Shopeju, 1993). The result in **Table 9** shows the mean values for the total plate aerobic count (in cfu/g) of the samples. Sun dried tomato sample (F_IJ_1) and solar dried tomato sample (FIJ 2) were 4.20 x 105 cfu/g and 1.22 x 107 cfu/g. This shows that there was more microbial load in sun dried sample (FIJ 1) than solar dried sample (F_IJ_2). This load could be due to contamination by flies, insects and other air resident organisms that could have in one way or the other contaminated the food. Contamination by man could have resulted by not taking adequate preventive measures during the drying, for example; by talking, coughing and sneezing. Lack of proper washing and sterilization of the hands and equipment used can also contaminate the sample. Solar dried sample (FIJ 2) was also contaminated but in lesser quantity. This contamination could be due to preliminary operations carried out prior to drying such as; improper sterilisation of fresh tomatoes, knife, trays and weighing balance used. Micro-organisms are ubiquitous in nature and cannot be seen with an unaided eye only but with the aid of a microscope. The above reasons could have led to the microbial proliferation by bacteria and fungi. Also, the moisture content of sun dried sample (F_IJ_1) can probe the growth of microbes compared to solar dried sample (F_IJ_2). Thus solar dried sample (FIJ 2) is significantly different from sun dried sample (FIJ 1) at 95% confidence level (P<0.05). The result however, showed that the bacterial load counts of the sun dried samples (FIJ 1) and solar dried (FIJ 2) were within the safe limit (<10,000 cfu/g) as revealed by Obuekwe and Ogbimi,(1989) for tomatoes and other vegetables.

Bacteria Isolate of Tomato (*Lycopersicum esculentum Mill.*)

Table 10: Identification of Bacteria Isolated from the Dried Tomato (*Lycopersicum esculentum Mill.*)

Sample Code	Total viable Bacteria count	Probable microorganisms isolated
Sun dried sample(F_1J_1)	4.2×10^5 cfu/g	*Bacteria spp., Actinomyces Spp.*
Solar dried sample(F_1J_2)	1.22×10^7 cfu/g	*Bacillus spp.*

Key: Cfu/g = Colony forming unit/gram; Source: Field Survekeey Data, 2014

Micro-Organisms Associated with Tomato (*Lycopersicum esculentum Mill.*)

Bacteria Isolates

Identification of the microbial isolation test revealed that the micro-organisms (bacteria) associated with tomatoes includes species of *Staphylococcus*, *Bacillus, Escherichia* and *Enterobacter*. The presence of *Staphylococcus aureus* and *Bacilllus cereus* (a mesophile) have been implicated in food poisoning (Obuekwe and Ogbimi, 1989). They also reported that 80% *Staphylococcus aureus* is being harboured by man as a normal floral and can be an indication of contamination to food. The occurrence of *Bacillus* species in **Table 11**, can be said to be as a result of prevalence of their spores in the environment (Obuekwe and Ogbimi, 1989). Some bacteria associated with bacterial cultures of Nigeria are; *Bacillus subtilis, Bacillus cereus* and some other gram positive bacteria. *Bacillus* species are spore formers whose spores could survive high temperature of processing even drying. Also, presence of *Enterobacter,* organisms resident in the air was found in the samples analysed. Its occurrence can be attributed to bad habit of handlers such as sneezing and coughing without covering their mouth during processing and handling (Hobbs and Gilbert, 2007). *Escherichia coli* have also been implicated in the tomato samples analysed. Its occurrence can be attributed to the environment on which the tomato was planted and treatment given to the tomato during its growing period.

Fungi Isolates

Table 12 Identification of Fungi Isolate from the Dried Tomato (*Lycopersicum esculentum Mill.*)

Isolate Code	Colonial morphology	Microscopic Appearance	Micro-organism Identification
F_1	Greenish dark surfaces, dark reverse velvety or cottony in appearance	Septate hyphae with branched conidiosphores beaming vesicles that produce chains of conidial	*Aspergillus spp.*
F_2	Light grey surfaces, non-pigmented white reverse	Non- septate hyphae, long branches sporangiosphores bearing sporangia, Rhizoid absent	*Mucor spp.*

Key: F1 and F2 represent Fungi isolate; Source: Field Survey Data, 2014

Fungi Isolates

The fungi associated with the tomatoes *Lycopersicum esculentum mill.* in **Table 12**, include species of *Aspergillus, Mucor* and *Fusarium*. A number of fungi can colonise the compost or decay of the tomatoes during drying. Presence of *Aspergillus* species (*Aspergillus flavus)* in the tomatoes analysed can be attributed to the prevalence of their species in the atmosphere. This organism is easily trapped during then handling of tomatoes. Since most fungi spores are found in the air. The spores must have contaminated the tomatoes during growth, harvesting, processing and handling. The liberated spore can easily settle on the food and ceilings of room and then germinate. The studies of Dogo and Ayodele, (1997) and Okhouya and Ayanlola (2002) have shown that *Aspergillus* occurred higher in the number of colonies identified from air spore of some localities.

CONCLUSION AND RECOMMENDATIONS

The study focused on the design, construction and evaluation of the performance of a solar dryer using tomato (*Lycopersicum esculentum Mill.*) in Imo State, Nigeria. The paper became necessary due to the high cost of tomato fruits during scarcity (lean season) as well as the need for appropriate preservation method for tomatoes during major season to curb scarcity in the study area. Data collected were analyzed using descriptive statistical tools, proximate analyses and One Way Analysis of Variance (ANOVA). In the study, the two drying techniques used (solar drying and sun drying) where capable of preserving the nutrients in the food crop (tomato) without total loss except for riboflavin which was completely lost in the solar dried sample. Solar drying was observed to be more hygienic as indicated by less microbial load of the solar dried tomato sample to that of sun dried tomato sample. Analysis done indicated that solar dried tomato sample was rated high in sensory properties (colour/appearance, texture, aroma and general acceptability) than the sun dried tomato sample after drying. Proximate analysis on fat, protein, crude fibre, ash, carbohydrate increased after drying but drying effectively reduced the moisture content for sun and solar dried samples. Solar drying was more efficient and effective than sundrying, in removing moisture content in this study, suggesting a higher capacity to prevent microbial growth and decay in dried samples during storage. Vitamins A and E increased in the dried samples while Vitamin C, thiamin, niacin and riboflavin decreased. The minerals: calcium, magnesium, phosphorus, sodium, and potassium increased in the dried samples. The bacterial load of the sun dried sample was higher than the solar dried sample. The saw dust used was effective in insulating the solar dryer and the collector steel sheet was an effective collector of heat from solar radiation as indicated by higher dryer temperature throughout the duration. It was recommended based on the major findings of the study that storage test be carried out on the dried tomato samples. Apparently, the reduced moisture content will improve shelf life of the tomato. It is also important that more durable glass should be used for the design of any solar dryer for its efficiency and performance. All year round availability of tomato could also be enhanced by solar drying. Packaging and marketing of dried tomato in small quantities could be a lucrative enterprise for young entrepreneur. Ultimately, government at all levels should intensify effort on the need for solar drying of fresh tomato samples as well as provision of fabrication materials/equipment for solar dryers as this would positively enhance the availability of fresh tomato fruit all year in the area and beyond.

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