Variation of Temperature and Relative Humidity in the Drying Cabinet of a Mixed-mode MoringaOliefera Solar dryer

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Abstract **-This research explored diverse methodologies to conceive and fabricate a mixed-mode solar dryer. The primary objective is to monitor the variations in temperature and relative humidity within the dryer cabinet during the drying period. The constructed solar drier, with cabinet and collector areas of 1.6m^2 and 1.25m^2, respectively, was used to dry 10kg of MoringaOleifera vegetable leaves at SabonGari, Kano State, Nigeria. It took a minimum of 22 hours in the solar dryer to dry the moringa leaves from 10 - 0.9kg and obtain an equilibrium moisture level of 10-9%, compared to 96 hours in an open-air drier to dry the same moringa leaves from 10-1.3kg. The dryer achieved up to 39°C temperature in the cabinet with relative humidity (RH) decreasing from 84% to as low as 33% during the experiment. These optimum conditions in the cabinet result in a reduced drying period and help preserve the nutritional value of the MoringaOlifera leaves.**

Keywords– Drying, Temperature, MoringaOlifera,Relative humidity, Solar dryer

1. INTRODUCTION

The need to sun dry vegetables and other farm produce using solar dryers at a temperature and relative humidity that would not destroy the nutritious content of the produce has been investigated. All moisture-containing products experience relative humidity change as the surrounding air temperature changes. Drying is one of the oldest ways of food preservation and is still used today. Properly dried foods can be preserved for extended periods without degradation. According [1], food drying entails removing water from the food at a higher temperature. In most situations, drying involves vaporizing the water in the food, which requires the supply of latent heat of vaporization. This process involves the transfer of heat (temperature) to provide the necessary latent heat of vaporization and the movement of water vapor (decrease in relative humidity) through the food material and subsequently away from it to influence moisture content reduction. Drying is described by [2]as the process of reducing moisture content through simultaneous heat and mass transmission. Because mechanical dryers are expensive, unaffordable, and require fuel to run, sun drying has become popular in developing countries. Food drying is affected by a variety of meteorological factors. However, the report shows that the most crucial weather parameters are relative humidity, temperature, and wind speed for the evapotranspiration model [3]. The rate of evaporation is affected by temperature. As a result, the higher the temperature, the faster evaporation occurs. However, relative humidity has a massive effect on evaporation than temperature. These two parameters (temperature and relative humidity) are interrelated to a greater extent; when the temperature of the air rises, it absorbs more liquid, and thus the relative humidity falls. Lower relative humidity speeds up drying. Figure 1 shows that as the temperature of air increases, the amount of water required to saturate it increases exponentially.

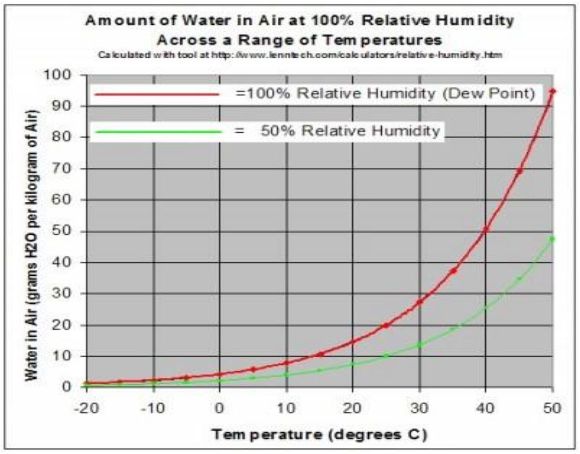

Figure 1. Amount of water in air at 100% Relative Humidity across Range of Temperatures [4]

Drying fresh vegetables, such as MoringaOliefera necessitates hygienic conditions and controlled temperature and relative humidity to preserve the nutritional and medicinal properties of the vegetable. One of the primary advantages of deploying solar energy is that it provides a sustainable free energy source for drying [5]. Research carried out by [6]shows that during solar drying, solar collectors heat up the air temperatures higher than the ambient temperatures, resulting in a more rapid drying process inside the dryer. Solar dryers can be classified into four types: direct, indirect, mixed-mode, and hybrid [7]. In direct sun dryers, the things to be dried are placed inside a clear plastic or glass enclosure and typically use black collectors to maximize heat absorption. In an indirect solar dryer, the produce undergoes indirect heating through hot air preheated in the collector by solar energy. The Mixed modes solar dryer combines direct and indirect drying techniques to achieve dryness. Aside from using the sun to dry, hybrid solar dryers use other technologies to create air flow in the dryers. Most small-scale farmers cannot purchase hybrid solar dryers due to their high initial cost [8].

Previous research on the effect of temperature and relative humidity on the drying process has been investigated in this paper. Kaya [9]explored the effects of drying air temperature, air flow rate, and air relative humidity on the drying kinetics of quince, apple, and pumpkin using convective dryer. Freshly harvested fruits have a high moisture content, making them prone to quick postharvest deterioration and losses ranging from 30% to 69% under the prevailing tropical conditions of high temperature and relative humidity, according to Samaila, Olotu, and Obiakor[10].As a result, during the peak of vegetable supply, veggies remained available at lower costs, only to be thrown. The shortage or unavailability of these crops throughout their off-seasons remained a recurring and unpleasant dilemma for disadvantaged farmers. Olajide[11]reported that food losses due to rotting and mishandling in developing countries were between 25% and 40%. It was discovered that increasing the temperature or velocity of the drying air reduces drying time and relative humidity [12]. Increased drying air temperature, on the other hand, reduced the equilibrium moisture content and overall drying time [13].Chen [14]emphasized the difficulty of maintaining quality standard for final items. The study revealed that closed-system drying techniques with regulated settings produced superior results to natural solar drying. This approach provided more control over the sun drying process in more hygienic and acceptable results.

In a related study, Vazquez [15]used a closed-loop drying device with a heat pump to dry grapes at varied airspeeds and temperatures. Despite the fact that grapes require around 40 days to dry naturally, the heat pump-assisted technology substantially decreased the drying period to 24 hours. Interestingly, the authors discovered that properties such as color and quality of raisins were unaltered, implying the efficacy of such a drying system for efficient use in industrial applications.Fatouh[16] reported that product type, loading quantity, drying air temperature, and air speed had an effect on the drying rates. The authors noted that small volume products had shorter drying time and less energy consumption. Unit water quantity displaced, initial product humidity rate, product geometry, and diffusion characteristics of product have an important role in drying performanceof a system.Drying cost is influence by the physical feature of a product, air flow,and by-pass evaporation rates.According to Hawlader and Jahangeer[17], there is a considerable need for low-cost, high-quality dry items. In the pursuit of producing enhanced and cost-effective dry products, it is imperative to optimize energy use. Using energy sources such as solar energy may significantly reduce drying costs. The fluctuation of temperature and relative humidity in the drying cabinet of a mixed-mode solar dryer used for drying MoringaOliefera, as well as its effect on the vegetable, were investigated in this study.

2. MATERIALS AND METHODS

The study was conducted from 09/06/2012 to 09/07/2012 in SabonGari, Kano State, Nigeria, with latitude 12.0046°N and longitude 8.2924°E. Wind speed, temperature, relative humidity, and sun radiation were measured using a hot-wire anemometer, hygrometer, and solarimeter. The averaged data presented in Table 2 used to fabricate the mixed-mode solar dryer. Data collection was done hourly for 8 hours daily, commencing at 9 a.m. and ending at 5 p.m.

Table A. Analyzed average data used for design (Measured Values)

S/N	Description	Average Value
1	Relative Humidity, η (Obtained experimentally)	64.4 ±0.1%
2.	Solar Radiation, G	419±0.1 W/m^2
3.	Ambient air temperature	31±1.0°C
4.	Wind speed	2.1±0.1 m /s
5.	Moisture content of 10 kg of moringa	7.32 ±0.01kg

2.1 Sample Preparation

The harvested MoringaOliefera (Miracle Vegetable) leaves with 73.2% moisture content would deteriorate after 2-3 days. To achieve the recommended moisture content of 9% on a dry basis, 10 kg of leaves were dried in a mixed-mode sun dryer.

2.2 Solar Dryer

Figure 2 depicts the mixed-mode solar dryer fabricated from locally sourced materials. It comprises a solar collector responsible for heating the ambient air in the drying cabinet. The drying cabinet, where the product undergoes drying, features a transparent glass on the front side, enabling direct exposure to solar radiation. Additionally, a chimney facilitates the expulsion of moist air from the drying chamber. Within the chimney, a fan accelerates the removal of wet air, thereby enhancing the drying process. The solar radiation is transmitted into the solar dryer by the glass film. The glass film allows all the solar radiation outside to pass into the solar dryer and prevent re-radiation from the solar dryer to the outside, thereby helping to accumulate the heat inside the dryer. As a result, the temperature inside the solar dryer is higher than the ambient temperature. This help to remove the moisture content of the moringaoliefera inside the solar dryer, thereby facilitating drying.

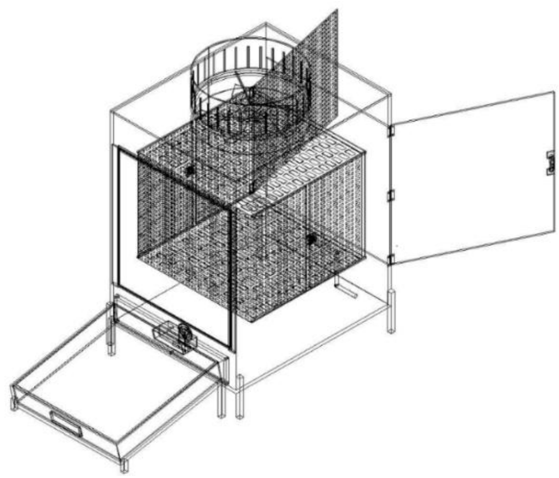

Figure 2. MoringaOliefera mixed-mode cabinet solar dryer

2.3MoringaOliefera vegetable drying Experiment

The experimental test to dry 10kg of moringaolifera was carried out in the College of Agriculture, Bayero University, Kano, Kano State, Nigeria, and lasted three (3) days. The experiment began and progressed simultaneously, with readings recorded from 31/01/2014 to 02/02/2014 to track the drying process within the dryer. Thermometers (wet and dry bulbs) installed at the inlet and exit solar dryer ports to record air temperatures. The study employed wind anemometer to measure the wind velocity.

As the drying process advances, the Moringa leaves in the dryer are flipped from time to time using the dryer's associated handle to ensure even air circulation. The ambient temperature, relative humidity, wind velocity, inlet and output temperatures of the dryer, temperature inside the chamber, and temperature of the chimney were all recorded hourly from 9.00 a.m. to 5.00 p.m. In addition, the weight of the Moringa leaves within and outside the drier was weighed hourly to record changes in moisture content until the product reached constant weight, i.e., equilibrium moisture content.

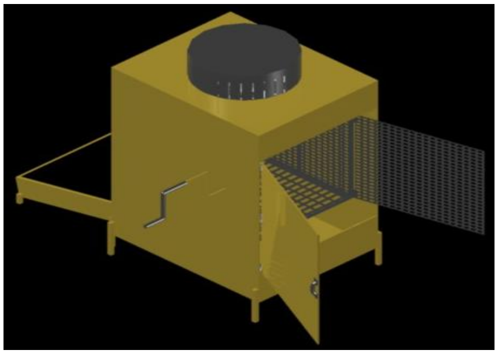

Figure 3. Schematic diagram of experimental set-up

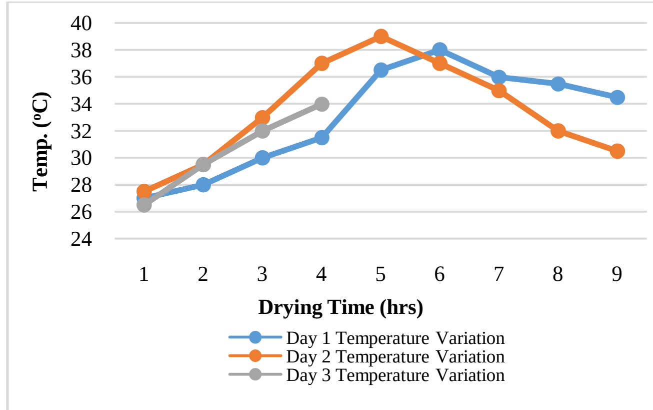

Figure 4. Variation of temperature within the drying chamber for three days

3. RESULTS AND DISCUSSION

For drying, heat is necessary to evaporate moisture from the Moringa leaves and a flow of air is needed to carry away the evaporated moisture. The drying process involve two fundamental mechanisms: first, the movement of moisture from the interior of the Moringa leaves to their surface, and second, the subsequent evaporation of this surface moisture to the surrounding ambient air.

The present study investigates the variation of temperature and relative humidity and how this variation affects the drying of moringa leaves in the mixed mode solar cabinet dryer. Figure 4 presents the performance results of the solar dryer measured from 9 am to 5 pm daily for three days. The graph shows that temperatures varied from 27-38 for Day1, 27.5-39 for Day 2, and 26.5-34 for Day 3. From the graph, the temperature has higher values in the dryer cabinet within 12noon to 2pm due to sun intensity at these peak hours. Interestingly, the dryer completed the process within the first four hours of Day 3 after achieving repeated 0.9kg of the leaves and attaining the recommended 9% moisture content.

Figure 5 depicts the hourly changes in relative humidity within the drying chamber, with values ranging from 84 to 46% on Day 1, 66 to 37.5% on Day 2, and 47 to 37.5% on Day 3, showing a decreasing trend in relative humidity as a result of increased air temperature, which consequently improves the drying process within the cabinet. Figure 6 compares relative humidity and temperature fluctuations in the dryer cabinet. The results demonstrate that when the temperature rises from 27 to 38°C, the relative humidity falls from 84 to 46%, which, when combined with air velocity in the dryer's cabinet, dramatically lowers the moisture content of the product from 10 to 2.45kg on Day 1 of the study. Another notable feature from the results is the higher values of temperature measured at 1pm to 3pm when the relative humidity recorded low values, thereby enhancing the drying process at that period. Thus, the lower the amount of water vapor in the air (relative humidity) within the dryer chamber, the more the rate of water vapor transported away from the surface of the leaves, the better the drying process.

Figures 7 and 8 show the temperature and relative humidity variations for Day 2 and Day 3. Day 2 has 27.5 to 39℃ for temperature and 69 to 37.5% for humidity variations, while Day 3 recorded a 26.5 to 34℃ increase in temperature and a 47 to 37.5% decrease in relative humidity. Figure 8 distinguishes itself by collecting data for the first four hours of the Day 3 experiment. This is because there were no longer any variations in the mass of the leaves in the drying chamber, indicating no change in moisture content, signaling the end of the drying process.

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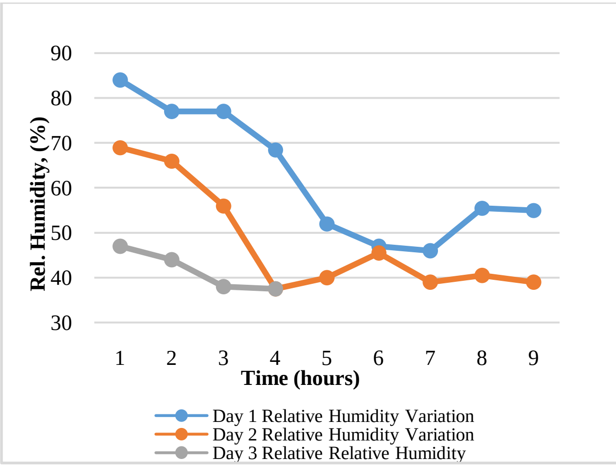

Figure 5. Variation of Relative Humidity within the drying Chamber for three days

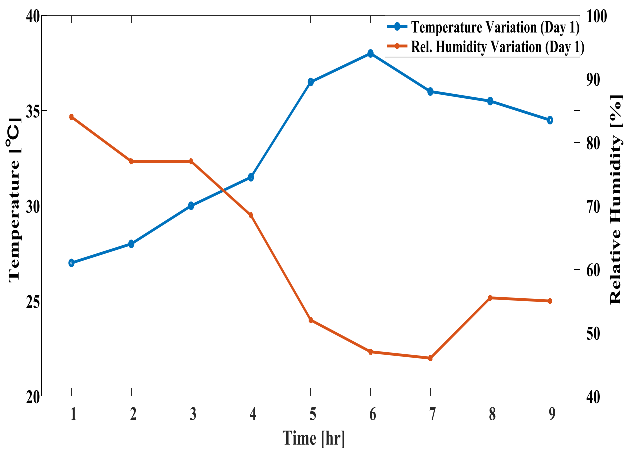

Figure 6. Variation of Temperature and Relative Humidity for day 1 in the drying chamber

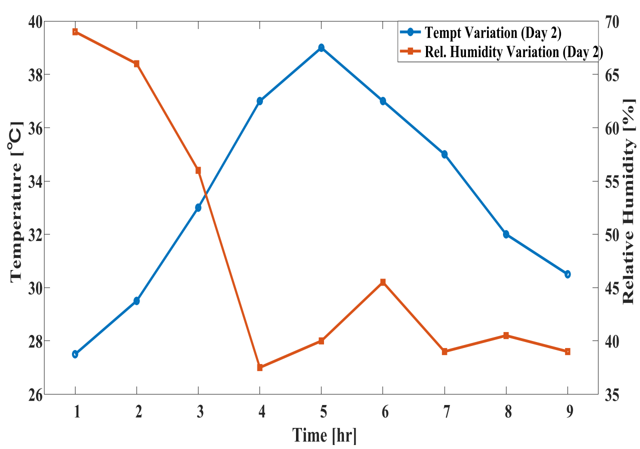

Figure 7. Variation of Temperature and Relative Humidity for day 2 in the drying chamber

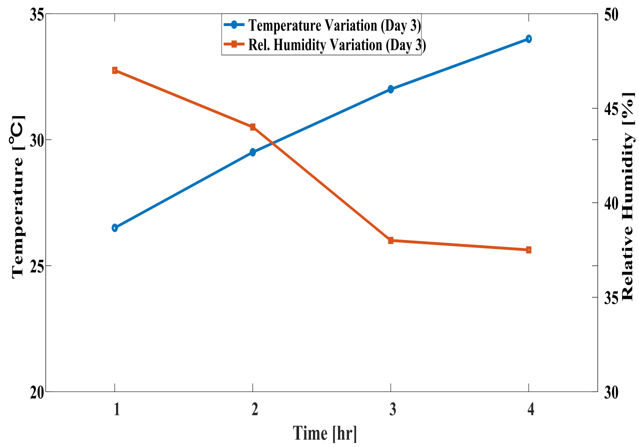

Figure 8. Variation of Temperature and Relative Humidity for day 3 in the drying chamber

Figure 9 delineates the variations in the mass of MoringaOleifera leaves over the three-day period. The findings reveal a substantial reduction in leaf mass, with a notable decrease from 10 kg to 2.45 kg on Day 1. Day 2 exhibits a further decline from 2.15 kg to 0.98 kg, reflecting the diminishing moisture content. On Day 3, a marginal decrease from 0.94 kg to 0.90 kg was observed. Intriguingly, the subsequent hour showed no notable change in mass, indicative of the conclusion of the drying process.

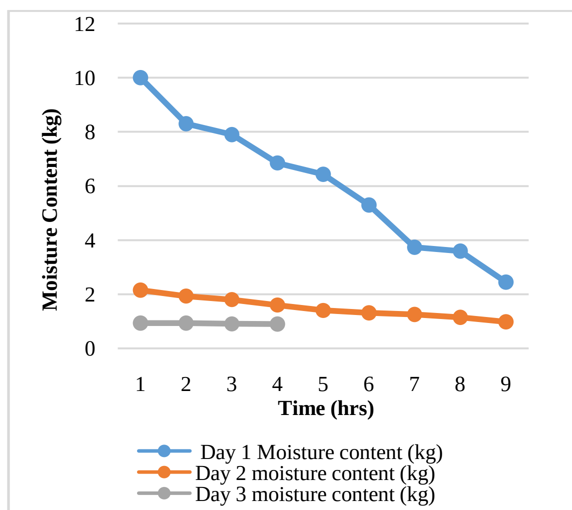

Figure 9. Variation of moisture content in the solar dryer for 3 days drying

In evaluating the performance of the mixed-mode solar dryer, findings were compared to results from an open-air drying method for the same 10 kg mass of

MoringaOleifera leaves conducted as a control experiment. The comparison revealed that it took five days (96 hours) to reduce the leaf mass from 10 kg to 1.3 kg, while the constructed mixed-mode solar dryer achieved a reduction from 10 kg to 0.9 kg mass of the MoringaOleifera leaves within a significantly shorter duration of two days (22 hours). Another significant advantage of this product is that it uses renewable energy and has insignificant greenhouse emissions effects on our environment. Furthermore, as shown in Table A-F of the Appendix, the temperature outlet of the collector and temperature inside the drying chamber is much higher than the ambient temperature because of the enhanced migration of moisture from the inside of the leaves to surface, then to the surrounding due to the present heat inside the dryer.

Optimization analysis discloses that the drying chamber attains an optimal condition with a maximum temperature of 39°C and a minimum relative humidity of 33%. This is particularly noteworthy, considering the medicinal properties inherent in MoringaOleifera leaves. The efficiency of the solar dryer is evident in the significantly reduced drying duration compared to open solar drying methods, establishing it as an efficient, hygienic, and expeditious approach for drying MoringaOleifera vegetables. This performance owes to the observed increase in the drying cabinet's temperature and concurrent decrease in relative humidity.

Table B. Moisture Content of an Open Air drying of Moringa

Date	Days	Mass (kg)
31/01/14	1	10.0
01/02/14	2	6.6
02/02/14	3	2.7
03/02/14	4	1.3
04/02/14	5	1.3

4. CONCLUSIONS

This study created a mixed-mode solar drier focusing on temperature and relative humidity variations in the drying chamber, achieving reduced drying time while ensuring the Moringa vegetable preserves its nutritious content. It took a minimum of 22 hours in the solar dryer to dry the moringa leaves from 10 - 0.9kg and obtain an equilibrium moisture level of 10-9%, compared to 96 hours in an open-air drier to dry the same moringa leaves from 10-1.3kg. The significant difference in drying time measured is due to the higher temperatures and lower relative humidity conditions achieved inside the dryer. The solar dryer can as well be used to dry other things that do not require direct sunlight because it protects the produce from direct ultraviolet rays of the sun, which could harm some of the nutrients in the food. The solar dryer was built to research the variation of temperature and relative humidity in the dryer's drying cabinet, which has the advantages of easy construction, minimal maintenance, and weather protection of the produce, thus minimizing damage from harsh showers and flying dirt.

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6. APPENDIX

Table A. Experimental Data for mixed-mode solar dryer (Day 1)

Date	Time (hrs)	Amb. Temp $T_i(^oc) \pm 1.0$	Exit temp $T_e(^oc) \pm 1.0$	Chamber Temperatures		Mean Tempt .$T(^oC)$ ± 1.0	Moisture Content ,(m kg) ± 0.05	Wind Speed, V(m/s)±0	direction
				$T_1(^oC) \pm 1.0$	$T_2(^oC) \pm 1.0$				
31/01/14	09 00	25.0	26.0	27.0	28.0	27.5	10.00	4.6	SW
	10 00	27.0	28.5	28.5	30.0	29.0	8.30	3.2	SW
	11 00	28.0	29.5	30.0	30.5	30.0	7.90	3.7	SW
	12 00	30.5	32.0	31.5	34.0	33.0	6.85	2.1	SW
	13 00	35.0	36.0	36.5	37.0	37.0	6.43	1.1	NE
	14 00	35.0	37.0	38.0	38.5	38.0	5.30	1.6	SW
	15 00	34.0	36.5	36.0	38.5	37.0	3.74	0.9	SW
	16 00	33.0	35.0	35.5	36.0	36.0	3.60	1.3	SW
	17 00	31.0	33.0	34.5	35.5	35.0	2.45	0.8	SW

Table B. Experimental data for mixed-mode solar dryer (Day 2)

Date	Time (hrs)	Amb. Temp $T_i(^oc)$ ± 1.0	Exit temp $T_e(^oc) \pm 1.$	Chamber Temperatures		Mean Tempt. $T(^oC)$ ± 1.0	Moisture Content, M(kg) ± 0.05	Wind Spe V(m/s) ±	direction
				$T1(^oC) \pm 1.0$	$T2(^oC)$ ± 1.0				
01/02/14	09 00	26.0	27.0	27.5	28.5	28.0	2.15	3.2	SW
	10 00	27.0	28.0	29.5	30.0	30.0	1.93	2.2	SW
	11 00	30.0	32.0	33.0	34.5	34.0	1.80	1.2	SW
	12 00	35.0	36.5	37.0	39.0	38.0	1.60	4.2	SW
	13 00	33.0	37.0	38.5	41.0	40.0	1.40	2.6	SW
	14 00	31.5	35.0	36.5	39.0	38.0	1.31	1.1	SW
	15 00	30.0	31.0	35.0	37.5	36.0	1.25	0.8	SW
	16 00	29.0	31.5	32.0	34.0	33.0	1.15	1.0	SW
	17 00	31.0	33.0	34.5	35.5	35.0	0.98	0.7	SW

Table C. Experimental data for mixed-mode solar dryer (Day 3)

Date	Time (hrs)	Amb. Temp $T_i(^oc)$ ± 1.0	Exit temp $T_e(^oc) \pm 1.0$	Chamber Temperatures		Mean Tempt. $T(^oC)$ ± 1.0	Content, M(kg) ± 0.05	Wind Spe V(m/s) ±	direction
				$T1(^oC) \pm 1.0$	$T2(^oC) \pm 1.$				
02/01/14	09 00	25.0	26.0	26.5	27.0	27.0	0.94	3.6	SW
	10 00	27.0	28.0	29.5	30.0	30.0	0.91	2.9	SW
	11 00	29.5	31.0	32.0	33.0	32.5	0.90	1.7	SW
	12 00	31.0	33.5	34.0	35.5	35.0	0.80	1.1	SW

Table D. Temperatures and Relative Humidity for solar dryer(Day1)

Outside the dryer (Ambient Air)						Inside the Dryer			
Date	Time(hrs)	T_d (°c) ±1.0	T_w(°c) ±1.0	Depr. (°c)	Rel.Hum. (%)	T_d (°c) ±1.0	T_w (°c) ±1.0	Depr. (°c)	Rel.Hum. (%)
31/01/14	09 00	25.0	22.0	2.0	84.0	27.0	24.0	3.0	77.0
	10 00	27.0	24.0	3.0	77.0	28.0	26.0	2.0	85.0
	11 00	28.0	25.0	3.0	77.0	30.0	26.0	4.0	72.0
	12 00	30.5	25.0	4.5	68.5	31.5	27.0	4.5	69.5
	13 00	35.0	26.0	8.0	52.0	36.5	28.0	8.5	50.5
	14 00	35.0	26.0	9.0	47.0	38.0	29.0	9.0	50.0
	15 00	34.0	28.0	9.0	46.0	36.0	27.0	9.0	48.0
	16 00	33.0	26.0	7.0	55.5	35.5	27.0	8.5	49.5
	17 00	31.0	26.5	7.0	55.0	34.5	26.0	9.5	43.5

Table E. Temperatures and Relative Humidity for solar dryer (Day 2)

Outside the dryer (Ambient Air)						Inside the Dryer			
Date	Time(hrs)	T_d (°c) ±1.0	T_w(°c) ±1.0	Depr. (°c)	Rel.Hum. (%)	T_d (°c) ±1.0	T_w (°c) ±1.0	Depr. (°c)	Rel.Hum. (%)
01/02/14	09 00	26.0	22.0	4.0	69.0	27.5	18.0	9.5	35.5
	10 00	27.0	22.5	4.5	66.0	29.5	20.0	9.5	45.5
	11 00	30.0	23.5	6.5	56.0	33.0	24.0	9.0	45.0
	12 00	35.0	24.0	11.0	37.5	37.0	25.0	12.0	35.0
	13 00	33.0	23.0	10.0	40.0	39.0	26.0	13.0	33.0
	14 00	31.5	22.0	8.5	45.5	37.0	25.0	12.0	35.0
	15 00	30.0	20.5	9.5	39.0	35.0	23.0	12.0	33.0
	16 00	29.0	20.0	9.0	40.5	32.0	22.0	10.0	39.0
	17 00	28.0	19.0	9.0	39.0	30.5	20.5	10.0	37.0

Table F. Temperatures and Relative Humidity for solar dryer (Day 3)

Outside the dryer (Ambient Air)						Inside the Dryer			
Date	Time(hrs)	T_d (°c) ±1.0	T_w(°c) ±1.0	Depr. (°c)	Rel.Hum. (%)	T_d (°c) ±1.0	T_w (°c) ±1.0	Depr. (°c)	Rel.Hum. (%)
02/02/14	09 00	25.0	18.0	7.0	47.0	26.5	19.0	7.5	46.0
	10 00	27.0	19.0	8.0	44.0	29.5	20.0	9.5	38.0
	11 00	29.5	20.0	9.5	38.0	32.0	21.0	11.0	34.0
	12 00	31.0	21.0	10.0	37.5	34.0	22.0	12.0	32.0