DESIGN, FABRICATION AND EVALUATION OF A SOLAR DRYER

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Abstract
This study presents the design, fabrication, and evaluation of a solar dryer as an advanced alternative to conventional sun drying methods. Focusing on enhancing product quality and minimizing nutrient loss, the research specifically investigates the drying characteristics of white ginger. Experimental evaluations involve drying 2.5 kg of white ginger slices at 3mm thickness, under varying blower operation cycles: 10 minutes on and 50 minutes off, 15 minutes on and 55 minutes off, and 20 minutes on and 1 hour off. Temperature, humidity, and weight measurements are collected at 2 hours intervals over the drying period. Results reveal that, 15-minute on and 55-minute off blower cycle emerges as optimal, yielding ginger with superior qualities. In-depth nutritional analyses demonstrate that dried ginger retains essential vitamins, minerals, and phytochemical compounds, rendering it suitable for food processing applications. During the three-day drying process, the ginger slices experienced the greatest weight reduction under the 15-minute on and 55-minute off blower cycle. The lowest moisture content achieved was 11.31%, while the final ginger weight was 0.51 kg. Proximate and phytochemical composition analyses revealed that this drying cycle resulted in ginger flour with reduced moisture, highest crude fiber (8.52%), crude protein (7.83%), and carbohydrate (66.20%) content. Moreover, the 15-minute on and 55-minute off blower cycle produced ginger flour with significantly higher levels of vitamins and phytochemical compounds. Based on the findings, it is recommended that subsequent solar dryer designs incorporate a blower operation cycle of 15 minutes on and 55 minutes off to achieve optimal drying outcomes for white ginger.

***Keywords**: Solar dryer, White ginger, Drying characteristics, Nutritional preservation, Blower operation cycle*

Introduction

The traditional "sun drying" approach simply entails placing the product on mats, roofs, or drying floors and leaving it in the sun to dry. The main drawbacks of this method include labor-intensiveness, loss of nutrients like vitamin A, loss of nutrients due to contamination by dust, birds, and insects, and the system's complete reliance on favorable weather conditions. A more sophisticated variation of traditional sun drying, solar drying (SD) exposes the goods to the sun while it is kept in a clear container.

The key distinction between SD and sun drying is that SD requires a solar collector, which can be equipped with a control system, whereas sun drying uses direct sunlight to dry things. Solar drying produces products of desired quality with little harm to the environment. Using this technique to dry agricultural products is efficient, affordable, and secure (Lyes, 2012). Drying is a typical way of food preservation that minimizes handling and packaging requirements (Oladele and Jimoh, 2017), however the quality of the finished product depends heavily on the method and the process factors (Oladosu-Ajayi et al., 2017). Through conductive and convective drying processes, the moisture content of food is decreased with an extended shelf life. Depending on the type of food material, the quantity and quality of an efficiently dried food product influence how long it can be stored. Historically, open sun drying has been the predominant method used in developing nations to preserve food. However, there are a number of drawbacks to this method, including its sensitivity to the weather, potential for contamination by foreign objects, lengthy processing times, variable product quality, and low output (Rhoda and Negimote, 2015; Oladele and Jimoh, 2017). In Nigeria, white ginger is grown all year round, but there is a particularly prolific time. It requires careful processing to protect the nutrients, especially the water-soluble vitamins, because it is highly perishable. The findings of this research would help to minimizes handling and packaging requirements, increase the shelf life of the product and also sensitize farmers on the best way to conserve the nutritional components and organoleptic properties of white ginger during drying.

A number of studies on the drying of moringa oleifeira, scent leaf and white ginger in a solar tray dryer and hot air cabinet dryer have been reported by various researchers from different regions of the world (Chinweuba et al., 2016: Oladele and Jimoh, 2017: Mirzaee et al., 2009). To the best of our knowledge, a comprehensive study on solar tray dryer having a variation in the operation of the inlet and outlet centrifugal blower cycle and the corresponding effect on nutritional and organoleptic property of the dried fruits and vegetables has not been reported yet. Therefore, the present research work describes the design and fabrication of a solar tray dryer, ascertains the drying characteristics on white ginger and also evaluates the effect of this drying method on the nutritional components of the dried products.

Materials and Methods

The research was conducted at the Agricultural and Bio Environmental Engineering Crop processing laboratory of The Federal Polytechnic Ilaro, Ogun state. The following materials were used for the fabrication of the mixed mode solar dryer:

Aluminum Sheet

Aluminum sheet of 2mm thickness was used because aluminum can serve as a heat absorber, it can also store heat energy to be used when there is no presence of solar radiation. This aluminum sheet was painted black because the colour black has the ability to store heat compared to other colors.

Ply wood

Plywood offers all the inherent advantages of the parent wood plus enhanced properties in its laminated structure, high impact resistance, surface dimension stability, high strength to weight ratio, panel shear, and it has resistance to bending, breaking, splitting, and warping which makes it good for the fabrication of this solar dryer.

Transparent glass sheet

A 4mm thick transparent glass sheet was used because it allows light or heat radiation to pass through it, dustproof and waterproof, aesthetically appealing, recyclable, UV stable, weather and rust resistant.

Inlet and Exhaust fan

The inlet ventilator fan is responsible for providing good air distribution and movement throughout the chamber. The exhaust fan is for ventilating the interior by sucking out air from the interior and expelling it outside. We decided to use exhaust fan at the outlet because it facilitates the remover of moisture and also gives room for fresh air to circulate within the drying chamber.

Drying trays

The drying trays were made from aluminum wire mesh which was framed with angle irons, the perforations within the wire mesh are to aid heat and mass transfer during drying.

Instrument and Apparatus

The following instrument and apparatus were used during the testing of the solar dryer: thermometer, humidity sensor, weighing balance, vernier caliper and alternating current timer.

Alternating current timer

The timer used is an alternating current timer which had ability to on and off the blowers attached to the solar dryer. The timer is of the following specification: KG316T Microcomputer timer switch, 30A, AC 220V.

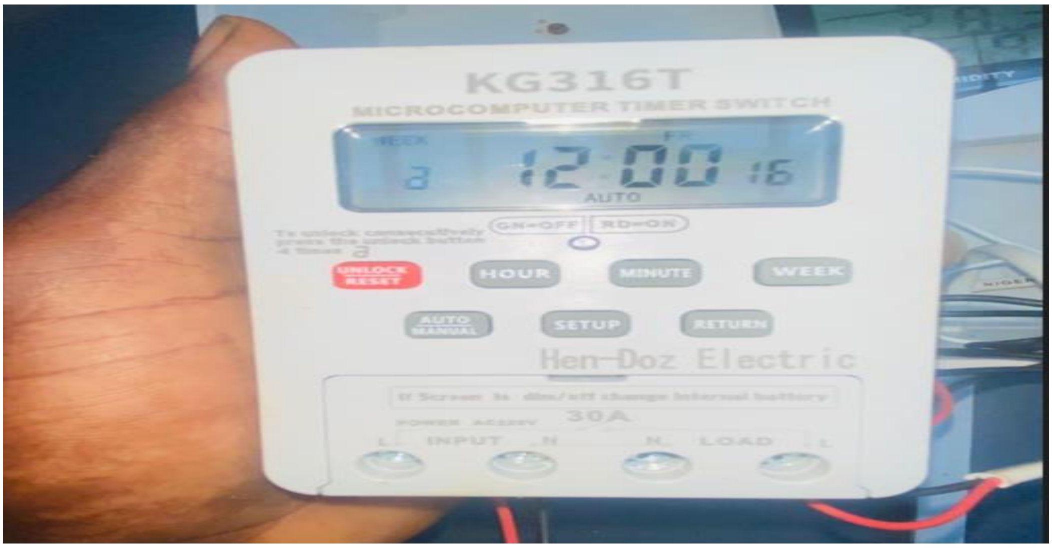

Plate 1.1: Alternating current timer

Plate 1 .2: Humidity and temperature sensor   Plate 1.3: Weighing balance with white ginger

2.2 Design analysis

To determine the total surface area and the volume of the Tray

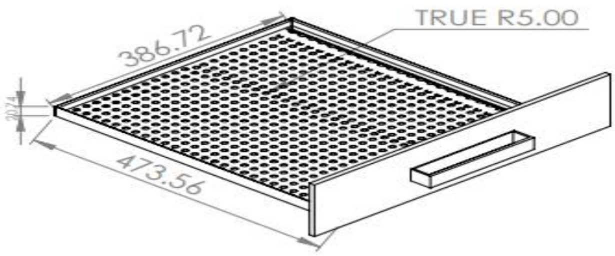

Fig. 1.1: Design analysis for the drying tray

Mathematically, the total surface area of the tray can be considered using the formula below:

$$2LH + 2LW + 2WH \quad (2.1)$$

Where: L is the length, H is the height and W is the width

2(473.56) (20.74) + 2 (473.56) (386.72) + 2 (386.72) (20.74)

= 401,954.6606 mm^2

While, the volume of the tray using the formula below:

$$V = LWH \quad (2.2)$$

= (473.56) (386.72) (20.74)

= 3,798,222.46 mm^3

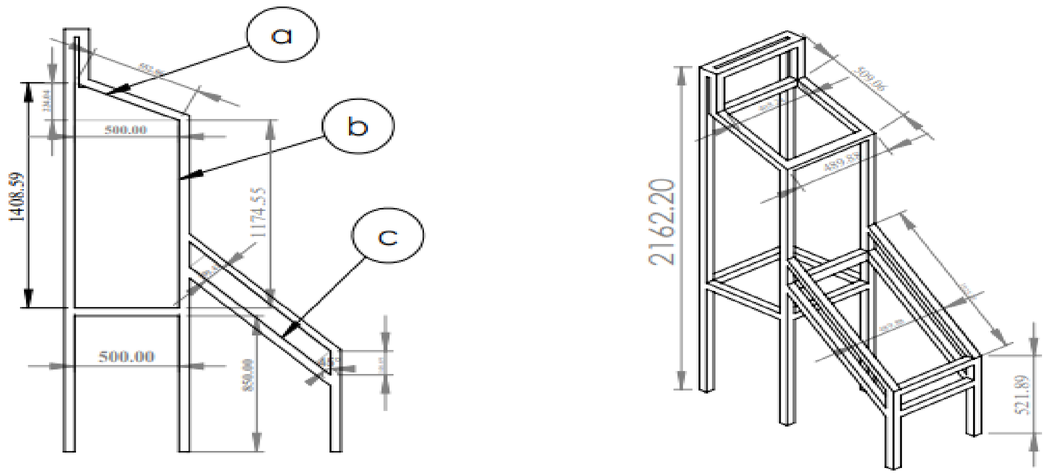

Fig. 1.2: Design of the frame (logging wood) for the solar dryer frame

Mathematically, the total surface area of the logging wood can be considered using the formula below, also the above shapes consist of triangle, rectangle and parallelogram shapes.

(a). ***Surface area of triangle***

Area of triangle = $^1/_2 \times b \times h$ (2.3)

$= {^1/_2} \times 500 \times 234.04$

$= 58{,}510 mm^2$

While, volume of a triangular prism is:

V = B H (2.4)

where B is $58{,}510 mm^2$

V = 58,510 × 408.24

V = 23,886,112.4 mm^3

(b). ***Surface area of rectangular prism***

2LH + 2LW + 2WH (2.5)

= 2(500) (1174.55) + 2 (500) (500) + 2 (500) (1174.55)

= 2,849,100 mm^2

Volume of the rectangular prism

V = L W H (2.6)

V = (500) (500) (1174.55)

V = 293,637,500 mm^3

(c) ***Surface area of parallelogram***

A = b h (2.7)

A = (500) (146.69)

A = 73,345

Volume of the parallelogram

V = (a × b) (c) (cos ø) (2.8)

Where;

a = 850.51mm, b = 500mm, c = 109.41mm, cos ø = 45^0

V = (a × b) (c) (cos ø)

V= 24,441,734.74 mm^3

2.2.1 Surface area and the volume of the glass

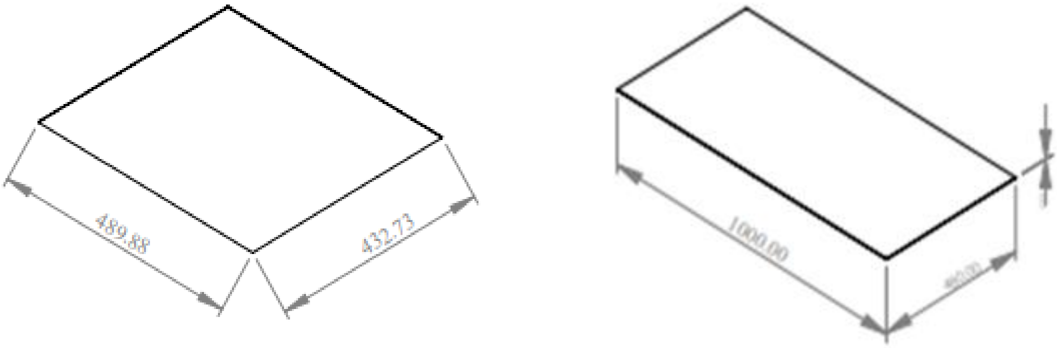

Fig. 1.3: Design of the glass used for solar collector

surface area of rectangular glass at the upper layer

Area = LB

= (489.88) (432.73)

= 211,985.772mm^2

While, volume of the rectangular glass

V = L W H (2.9)

V = (489.88) (432.73) (4)

V =423,971.54 mm^3

Surface area of rectangular glass at the lower layer

Area = LB = (1000) (432.73) = 432,730mm^2

While, volume of the rectangular glass: V = L W H

V = (1000) (432.73) (4)

V = 1,730,920mm^3

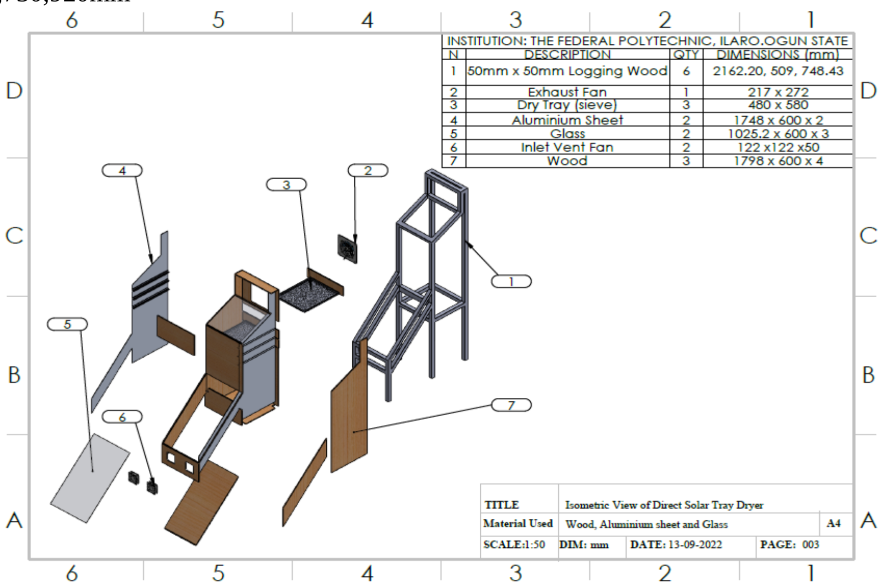

Fig. 1.4 Exploded view of the mixed mode solar dryer design

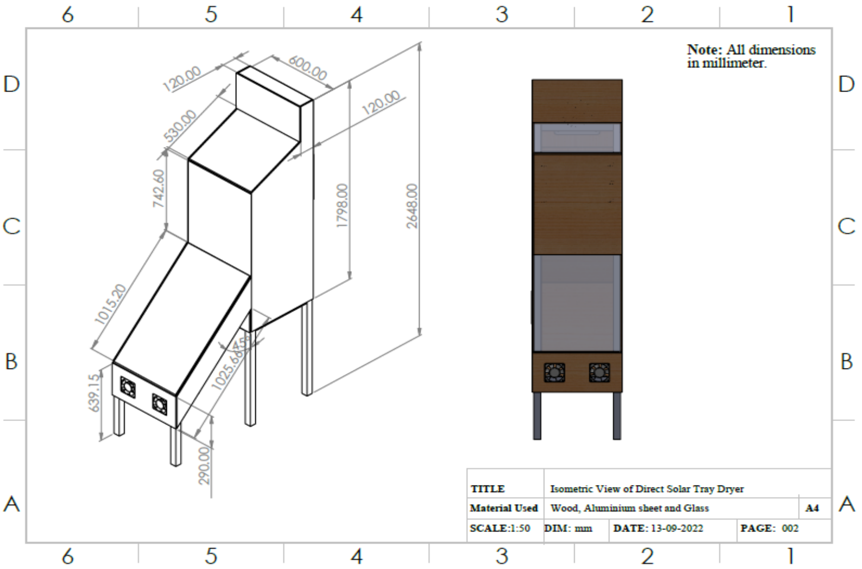

Fig. 1.5 Isometric view of the mixed mode solar dryer design

Evaluation and Experimentation Procedures

The moisture content of the materials to be used were determined immediately after purchase, the ginger was subsequently sliced to 3mm thickness size in order to facilitate the drying process. During the evaluation, 2.5kg of white ginger was dried at three different operating parameter of the mixed mode solar dryer. The duration in which the inlet and outlet blower functioned was varied at 10minutes on 50minutes off, 15minutes on 55minutes off and 20minutes on 1hr off respectively for each of the 2.5kg ginger that has been sliced to 3mm thickness size. The temperature of drying chamber and air leaving the chimney were measured and recorded at two hours' time interval, the mass of the product was also measured and recorded every two hours in order to determine the drying rate and to obtain a moisture profile for the drying process.

Plate 1.4: Ginger, 3mm thick sliced ginger and the compared drying procedure

Nutritional analysis of the dried ginger

The dried ginger from the solar dryer was milled and further subjected to laboratory analysis in order to determine the effect of the mode of drying and drying parameters on the nutritional content of the dried products.

Plate 1.5: Powdered ginger (dried with solar dryer)

Proximate composition

Moisture content, total ash, crude protein, crude fat, crude fibre and carbohydrate were determined using the procedure of AOAC (2005).

Result and Discussion

The following notations were used to denote the data collated: T_1°C is temperature inside the dryer, T_2°C is temperature of the air exiting the dryer, R_1% is relative humidity inside the dryer, R_2% is relative humidity of the exhaust air, and Kg is weight of ginger.

Table 1: Evaluation of the solar dryer at 10 minutes on and 50 minutes off.

1 Day:

Time	[kg] weight	T1°C	R1%	T2°C	R2%
10:56 am	2.5kg	32.6°c	33.1%	33.7°c	32%
12:56 pm	2.02kg	35.1°c	27%	38.0°c	27 %
2:56 pm	1.64kg	35.3°c	26%	36.7°c	26%
4:56 pm	1.3kg	36.0°c	26%	34.8°c	27%

2 Day:

Time	[kg] weight	T1°C	R1%	T2°C	R2%
10:56 am	1.3kg	29.8°c	40%	29.4°c	40%
12:56 pm	1.1kg	38.0°c	28%	39.4°c	28%
2:56 pm	0.89kg	37.8°c	27%	40.5°c	26%
4:56 pm	0.74kg	39.9°c	25%	42.1°c	24 %

3 Day:

Time	[kg] weight	T1°C	R1%	T2°C	R2%
10:56 am	0.74kg	32.2°c	39%	32.0°c	40%

12:56 pm	0.64kg	39.2°c	28%	41.1°c	26%
2:56 pm	0.59kg	40.4°c	26%	43.3°c	26%
4:56 pm	0.57kg	24.9°c	41%	28.0°c	37%

4 Day:

Time	[kg] weight	T1°C	R1%	T2°C	R2%
10:56 am	0.57kg	30.7°c	44%	31.3°c	43%
12:56 pm	0.52kg	31.0°c	35%	33.8°c	34%
2:56 pm	0.52kg	33.6°c	32%	35.9°c	30%

Table 2: Evaluation of the solar dryer at 15 minutes on and 55 minutes off

1 Day:

Time	[kg] Weight	T1°C	R1%	T2°C	R2%
10:56am	2.5kg	28.7°c	51%	29.3°c	51%
12:56pm	2.05kg	33.3°c	34%	36.1°c	30%
2:56pm	1.66kg	32.5°c	32%	34.8°c	30%
4:56pm	1.34kg	34.0°c	30%	35.1°c	30%

2 Day:

Time	[kg] weight	T1°C	R1%	T2°C	R2%
10:56am	1.34kg	31.8°c	40%	31.9°c	40%
12:56pm	1.1kg	35.0°c	30%	38.1°c	29%
2:56pm	0.89kg	42.4°c	25%	43.9°c	26%
4:56pm	0.76kg	46.2°c	28%	44.5°c	24%

3 Day

Time	[kg] weight	T1°c	R1%	T2°C	R2%
10:56am	0.76kg	31.4°c	38%	31.9°c	39%
12:56pm	0.54kg	36.4°c	29%	39.4°c	28%
2:56pm	0.51kg	42.6°c	26%	44.9°c	25%
4:56pm	0.51kg	41.4°c	24%	40.3°c	26%

Table 3: Evaluation of the solar dryer at 20 minutes on and 60 minutes off

1 Day:

Time	[kg] weight	T1°C	R1%	T2°C	R2%
10:56am	2.5kg	22.2°c	63%	23.8°c	61%
12:56pm	2.08kg	28.7°c	40%	32.1°c	36%
2:56pm	1.72kg	26.7°c	41%	30.0°c	37%
4:56pm	1.46kg	24.2°c	52%	26.3°c	49%

2 Day:

Time	[kg] weight	T1°C	R1%	T2°C	R2%
10:56am	1.46kg	26.9°c	51%	29.0°c	47%
12:56pm	1.27kg	30.0°c	39%	33.5°c	36%
2:56pm	1.07kg	28.3°c	42%	32.4°c	36%
4:56pm	0.97kg	28.9°c	75%	31.0°c	65%

3 Day:

Time	[kg] Weight	T1°C	R1%	T2°C	R2%
10:56am	0.97kg	23.3°c	61%	26.9°c	51%

12:56pm	0.83kg	28..2°c	50%	30.9°c	45%
2:56pm	0.73kg	32.9°c	34%	35.8°c	32%
4:56pm	0.66kg	28.5°c	42%	31.3°c	38%

4 Day:

Time	[kg] Weight	T1°C	R1%	T2°C	R2%
10:56pm	0.66kg	28.3°c	50%	30.5°c	45%
12:56pm	0.59kg	31.9°c	37%	35.0°c	34%
2:56pm	0.56kg	42.1°c	28%	44.4°c	26%
4:56pm	0.56kg	39.7°c	29%	39.2°c	29%

Table 4: Proximate and phytochemical composition of flour

SAMPLE	MOISTURE CONTENT (%)	CRUDE FAT (%)	TOTAL ASH (%)	CRUDE FIBRE (%)	CRUDE PROTEIN (%)	CHO (%)	TANNIN (%)	SAPONIN (%)	PHYTATE (%)	TRYPSIN INHIBITOR (%)	TOTAL PHENOL (%)
20mins on 1hr off	17.37 ± 0.06^{f}	2.79 ± 0.04^{a}	3.11 ± 0.02^{a}	8.15 ± 0.02^{a}	7.32 ± 0.02^{a}	61.28 ± 0.04^{a}	0.22 ± 0.00^{e}	1.10 ± 0.00^{d}	0.60 ± 0.00^{d}	0.40 ± 0.01^{a}	1.67 ± 0.01^{a}
10mins on 50min off	12.12 ± 0.06^{e}	3.05 ± 0.04^{b}	3.25 ± 0.02^{c}	8.44 ± 0.04^{b}	7.67 ± 0.01^{b}	65.48 ± 0.06^{b}	0.26 ± 0.00^{f}	1.12 ± 0.00^{e}	0.63 ± 0.00^{e}	0.46 ± 0.01^{c}	1.94 ± 0.01^{c}
15mins on 55minutes off	11.31 ± 0.10^{d}	2.97 ± 0.02^{b}	3.18 ± 0.02^{b}	8.52 ± 0.01^{bc}	7.83 ± 0.01^{c}	66.20 ± 0.03^{c}	0.23 ± 0.00^{e}	1.11 ± 0.00^{e}	0.61 ± 0.00^{d}	0.42 ± 0.00^{b}	1.74 ± 0.00^{b}

Mean values with different superscripts within the same column are significantly different ($p < 0.05$); CHO: CARBOHYDRATE

Table 5: Vitamin composition of flour

SAMPLE	VIT. A µg/100g	VIT. E mg/100g	VIT. D µg/100g	VIT. K µg/100g	VIT. C mg/100g	VIT. B_6 mg/100g	VIT. B_{12} µg/100g	THIAMINE mg/100g	RIBOFLAVIN mg/100g	NIACIN mg/100g
20mins on 1hr off	0.08±0.00e	0.24 ± 0.00^{d}	0.06 ± 0.00^{d}	0.14 ± 0.00^{d}	6.03 ± 0.00^{d}	0.14 ± 0.00^{d}	0.02 ± 0.00^{b}	0.05 ± 0.00^{c}	0.01 ± 0.00^{c}	0.80 ± 0.00^{d}
10mins on 50min off	0.09±0.00d	0.28 ± 0.00^{f}	0.07 ± 0.00^{e}	0.18 ± 0.00^{e}	6.79 ± 0.00^{f}	0.17 ± 0.00^{f}	0.04 ± 0.00^{e}	0.06 ± 0.00^{d}	0.02 ± 0.00^{e}	0.84 ± 0.00^{f}
15mins on 55minutes off	0.09 ± 0.00^{d}	0.26 ± 0.00^{e}	0.06 ± 0.00^{d}	0.14 ± 0.00^{d}	6.41 ± 0.01^{e}	0.15 ± 0.00^{e}	0.03 ± 0.00^{d}	0.05 ± 0.00^{c}	0.01 ± 0.00^{c}	0.81 ± 0.00^{e}

Mean values with different superscripts within the same column are significantly different ($p < 0.05$); VIT: VITA

Discussion

Evaluation of the solar dryer at varying conditions

Tables 1 which shows the observation of the solar dryer at 10minutes and 50minutes blower timed on and off respectively. The following parameters were recorded: highest T_1°C recorded is 40.4°c and lowest R_1% is 26%, lowest T_1°C recorded is 24.9°C and the highest R_1% is 41%. The highest T_2°c recorded is 43.3°C and lowest R_2% is 24%, lowest T_2°C recorded is 28°c and highest R_2% is 43%.
Table 2 describes the evaluation of the solar dryer at 15 minutes on and 55 minutes off for the inlet and exhaust blower. The following parameters were recorded for the highest and lowest temperature and relative humidity: Highest T_1°C recorded is 46.2°C and lowest R_1% is 24%, lowest T_1°c recorded is 28.7°C and highest R_1% is 51%, highest T_2°C recorded is 44.9°C and lowest R_2% is 24%. The lowest T_2°C recorded is 29.3°C and highest R_2% is 51%.
Table 3, talks about the evaluation of the solar dryer at 20 minutes on and 60 minutes off variation of the functioning period of the blower, the following peak results were observed: highest T_1°c recorded is 42.1°C and lowest R_1% is 28%, lowest T_1°C recorded is 22.2°C and highest R_1% is 75%, highest T_1°C recorded is 44.4°C and lowest R_2% is 26%, lowest T_2°C recorded is 23.8°C and highest R_2% is 65%.

Proximate and phytochemical composition of flour

During the 15minutes on-55minutes off evaluation process, the drying period was observed to be shortest, three days drying period of 10:56am to 4:56pm per day was examined for the drying process. The highest reduction in weight was recorded to be 0.51kg for the product which was initially at 2.5kg before drying. Under this same evaluation parameter, ginger flour with the highest crude fibre, crude protein, carbohydrate of 8.52%, 7.83% and 66.20% were recorded respectively while the lowest moisture content of 11.31% db was also recorded.
However, operating the dryer under 10 minutes on - 50minutes off working condition of the inlet and outlet blower, the ginger flour produced under this condition has the highest toxicity. The following percentage of Tannin, Saponin, Phytate, Trypsin inhibitor and Phenol (0.26%, 1.12%, 0.63%, 0.46% and 1.94%) were recorded respectively. On the other hand, the ginger flour produced via this operating parameter, has the highest vitamin content, followed by that of 15min on -55min off operating condition.
Moreover, there is no significant colour variation of the ginger flour dried using the solar dryer, but it generally has bright colour and it also gives good taste and aroma when consumed in soups.

Conclusion

The mixed mode solar dryer exhibited commendable performance by preserving the natural attributes of ginger and enhancing its quality for various applications. The findings highlight the significance of solar drying in retaining nutritional value and sensory attributes in dried produce. This research underscores the potential of the mixed mode solar dryer as an efficient and environmentally friendly solution for small and medium-scale agricultural and food processing enterprises.

Recommendation

Based on the evaluation outcomes of the mixed mode solar dryer, several recommendations are proposed:

1. The mixed mode solar dryer is suitable for adoption by small and medium-scale farmers, as well as agricultural crop processing businesses, to enhance post-harvest processing efficiency.
2. The dryer can be effectively deployed in regions with fluctuating solar radiation, thereby increasing its adaptability and usability.
3. This solar dryer is particularly advantageous for drying crops intended for spice production, as it helps retain color, taste, aroma, and nutritional content.
4. Optimal utilization of the solar dryer should be during the dry season when solar radiation is high and rainfall is minimal, ensuring maximum efficiency and output.
5. Given its capacity to preserve heat-sensitive vitamins, the mixed mode solar dryer is recommended for crops with delicate nutritional profiles, underscoring its significance in promoting food security and quality.

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