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DESIGN AND CONSTRUCTION OF A DESICCANT AIR DRYER FOR SEEDS AND VEGETABLES

The object of this research is the design of an affordable desiccant dryer for local farmers for seed and vegetable drying. The subsequent increase in food production has led to an accompanying need for easy, safe, and affordable preservation methods. This has led to a substantial increase in the number of driers, which are expensive for local farmers to acquire. Seeds and certain vegetables do not do well, under the high heat used in most dryers for drying as the drying process is often used as a final production step before packaging and selling agricultural products. Desiccant drying is hygienic, low energy, low cost, and safe method of drying agricultural products without degrading them or reducing their nutritional quality. A desiccant air dryer for seeds and vegetables was designed and constructed, and its performance was tested using bitter leaves (Vernonia amygdalina). Desiccant dryer materials were carefully sourced and selected based on the cost of the materials, availability, strength, lightness (weight), and resistance to rust. The desiccant dryer chamber has external dimensions of 43 cm by 30 cm and internal dimensions of 28 cm by 25 cm. The drying chamber is divided into five layers; each layer is 48 cm by 44 cm with a total surface area of 0.2112 m^2.

Results showed significant moisture loss in the dried sample in 26 hours from 167 g to 54.1 g when compared with ambient air drying values. Proximate analysis of the desiccant dried bitter leaf higher values across all parameters when compared with the sample dried using ambient air. From the results obtained, it was therefore concluded that the desiccant dryer dried the samples faster than the common air-drying method. It was recommended that seed and vegetables should be dried in a desiccant dryer in other to increase shelf life and reduce perishability.

Keywords: *preservation methods, desiccant dryer, drying agricultural products, shelf life, perishability, bitter leaf (Vernonia amygdalina).*

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1. Introduction

Drying is an excellent way to preserve food and air drying is an appropriate food preservation technology for sustainable development [1]. The drying process is often used as a final production step before packaging and selling of agricultural products. It is a suitable alternative for post-harvest management especially in developing countries where farmers will have to contend with poorly established, low temperature distribution and handling facilities [2]. Drying and dehydration of fresh fruits and vegetables is one of the most energy-intensive processes in the food industry and a promising method of reducing postharvest losses. Improving energy efficiency by only 1 % could result in as high as 10 % increase in profits.

Some seeds must dry down to minimum moisture content before they can germinate. Low seed moisture content is a prerequisite for long term storage, and it is the most important factor affecting longevity. Seed remains viable for a long time if seed moisture content and storage temperature are maintained [3]. Seeds lose viability and vigour during processing and storage [4] mainly because of high moisture content (seed moisture greater than 18 %). In general practice, seeds are dried at a temperature range of 50–60 °C but various studies showed that at this range of temperature, germination levels fall significantly. Various studies have also reported seed drying using dehumidified air [5].

The construction of a desiccant dryer will aid farmers who seek better ways of air drying their fragile crops such as vegetables and seeds as well as those who cannot afford to obtain or buy the costly dryers available in the market.

Thus, *the object of this research* is appropriate and efficient desiccant dryer materials. *The aim of this work* is the design and construction of a desiccant dryer for seeds and vegetables.

2. Research methodology

Dryer construction was carried out at Federal Ministry of Labor and Productivity/Skills Acquisition/Upgrading Training center and Trade testing office, Onireke Ibadan (Nigeria). Performance analysis was carried out within the premises of Federal College of Forestry, Jericho, Ibadan (Nigeria) which lies between Latitude 07°23' N and 7°28' N, and Longitude 03°15' N and 3°36' E. The area is tropically dominated by rainfall pattern from 1400–1500 mm; the average temperature is about 32 °C, average relative humidity of 80–85 %. The area experiences rainfall with two distinct seasons; dry season from November to March and rainy season from April to October [6].

2.1. Design considerations. *Material selection.* Materials used in the design of the desiccant dryer were carefully sourced and selected on the basis of properties such as the cost of the materials, availability, strength, lightness (weight) and resistance to rust.

Dryer dimensions. The dryer was designed to be small and lightweight enough to be transported easily while having enough volume to dry a sizeable amount of produce per time (Fig. 1). The external dimensions of the desiccant dryer are 90 cm by 50 cm and internal dimensions of 72 cm by 45 cm. The desiccant chamber has external dimension of 43 cm by 30 cm and internal dimensions of 28 cm by 25 cm.

Air flow and power source. Ambient air blown by the fan placed at the desiccant compartment passes through the silica gel for de-humification. The de-humidified air then flows through the drying chamber, passing through the trays and around the farm produce to absorb moisture. Moisture laden air exits through the outlets at the top of the chamber. Dehumidified air serves as the drying medium; it extracts and conveys moisture from the produce to the atmosphere through the air vents. The dryer was designed to be powered both by electricity and a small 12 V battery in the event of power failure.

Drying chamber volume and capacity. The drying chamber is divided into five layers; each layer is 48 cm by 44 cm with a total surface area of 0.2112 m^2. The layers give room for five trays to be put into the drying chamber where the produce to be dried is placed.

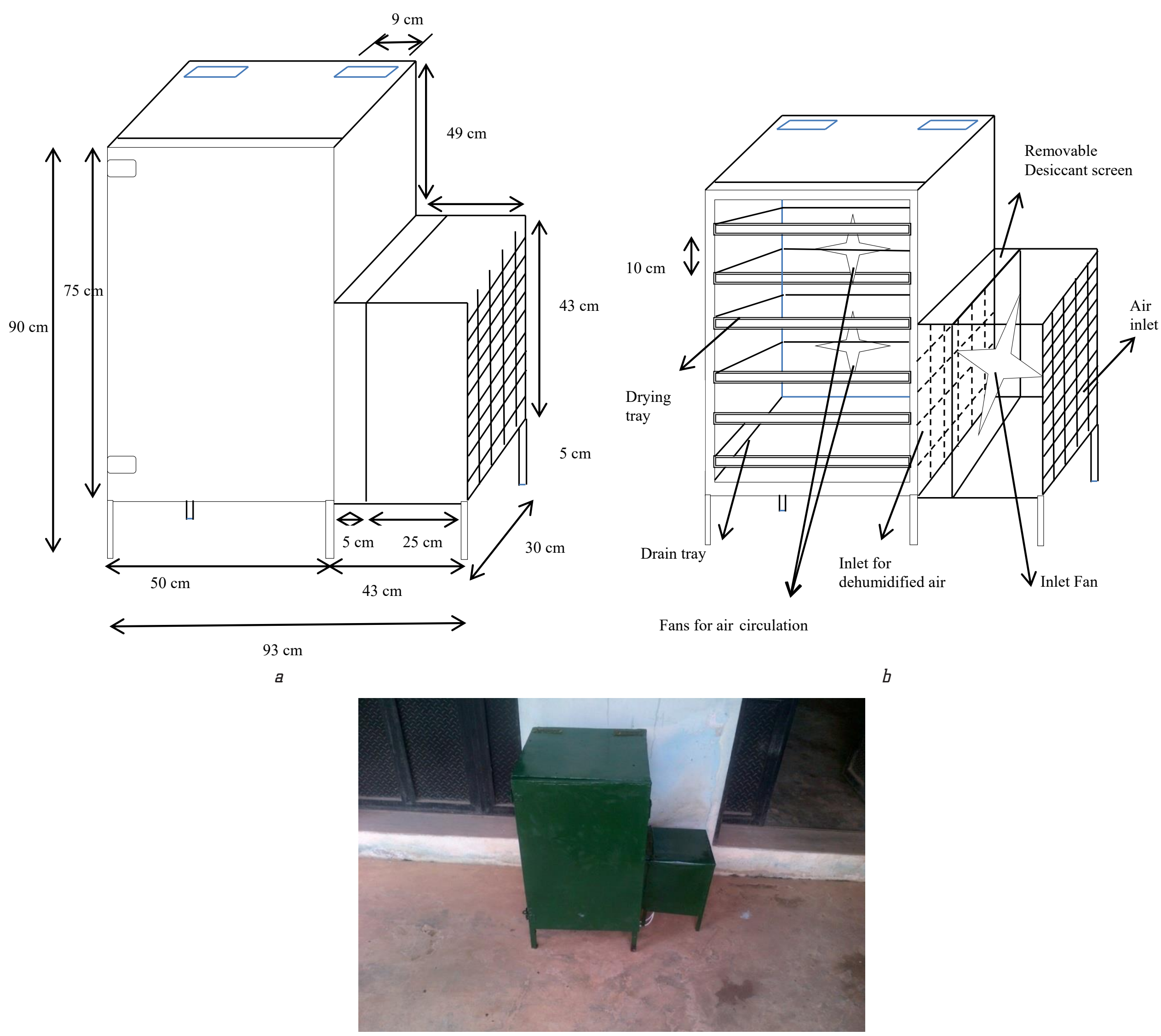

Fig. 1. Desiccant dryer: *a* – external dimensions; *b* – internal dimensions; *c* – exterior view

Using the formula:

$$V = A Ŧ,$$

where A – tray area (0.2112 m^2); $Ŧ$ – average leaf breadth of bitter leaf *Vernonia amygdalina* (0.06), $V=1.27\cdot10^{-2}$ m^3 and dryer capacity (using bulk density values of *Vernonia amygdalina*; 330 kg/m^3) [7] was calculated as 20.9 kg/load.

Choice of desiccant. Silica gel was chosen as the desiccant for use in the dryer based on its successful use in literature and its relatively cheaper price when compared to standard dehumidifiers used in most commercial desiccant dryers [5, 8].

2.2. Performance evaluation. The following were carried out in the performance evaluation of the desiccant dryer:

1. *No load test:* to determine the adsorption rate and regeneration rate of the silica gel, using:

$$R_c = M_{ra}.(w_2 - w_1),$$

where R_c – regeneration/adsorption rate of the silica gel screen, kg water/h; M_{ra} – mass flow rate of air, kg/s; w_2 – inlet air moisture ratio/humidity ratio, kg water/kg dry air (read from psychrometric chart), $w_2=0.017$; w_1 – outlet air moisture ratio/ humidity ratio, kg water/kg dry air (read from psychrometric chart) $w_1=0.0175$.

$$M_{ra} = \rho.v.A_x, \text{ i. e., } 1.34 \text{ kg/s [8]},$$

where ρ – density of air, kg/m^3, $\rho=1.1443$ kg/m^3 [9]; A_x – area of inlet screen, from calculation: $A_x=27\cdot26$ cm$=0.27\cdot0.26=0.07$ m^2; v – velocity of air, m/s (converted from inlet fan with rating of 2450 rev/min), using:

$$v = r\cdot2\cdot\pi\cdot(2450)/60,$$

where v – linear velocity, m/s; $\pi=3.142$; revolutions per minute RPM$=2450$; r – fan radius, $r=7.5$ cm.

$$R_c = 1.1443\cdot(0.0178-0.0175) =$$

$$= 0.00034 \text{ kg water/h} = 3.4\cdot10^{-4} \text{ kg water/h}.$$

2. *Load test:*

The dryer's performance was evaluated using fresh bitter leaves (*Vernonia amygdalina*). Washed and chopped bitter leaves of 2 kg were spread evenly on the 5 dryer trays and dried. The same weight of bitter leaf was also air dried as control. The following parameters were assessed:

– relative humidity: inlet, screen outlet, vent, and dryer chamber humidity values were taken with a hygrometer;

– temperature: ambient, Inlet and dryer temperature values were taken at intervals to monitor the drying process;

– weight: the change in the weight of the bitter leaf was determined every two hours. This was carried out for the produce in the desiccant dryer and for the sample dried under ambient air. The percentage moisture content (wet basis) was calculated using the formula:

$$M_c = \frac{M_w - M_d}{M_w}\cdot100\ \%,$$

where M_c – moisture content, %; M_w – mass of wet sample; M_d – mass of dry sample;

– dryer efficiency: dryer efficiency was calculated with the formula:

$$\eta_d = (M_w/M_t)\cdot100,$$

where η_d – efficiency of drying chamber, %; M_w – mass of water evaporated, g; M_t – total/initial mass of sample, g.

2.3. Proximate analysis. Proximate analysis was carried out on bitter leaf samples after drying with ambient air and in the desiccant dryer.

3. Research results and discussion

Desiccant dryer performance evaluation. No load test (Table 1). Load test (Table 2).

Table 1

Humidity and temperature values for no load test

Parameters	Initial readings	Final readings
RH_{is} (%)	88	87
RH_{os} (%)	88	86
T_{is} (°C)	24.8	24.9
T_{os} (°C)	25.3	24.6
W_{sg} (g)	33.4	66.1

Notes: RH_{is} – relative humidity of air at silica screen inlet, %; RH_{os} – relative humidity of air at silica gel outlet, % (i. e. relative humidity at drying chamber inlet); T_{is} – temperature of air at silica screen inlet, °C; T_{os} – temperature of air at silica gel outlet, °C; W_{sg} – weight of silica gel

Table 2

Average relative humidity values during the test period

Parameters	Day 1	Day 2	Day 3	Day 4	Day 5
RH_a (%)	89.25	89.75	87.25	87.6	90
RH_{os} (%)	85.25	87.75	86.75	84.67	89
RH_{id} (%)	86.25	88.5	83.75	86	86

Notes: RH_a – ambient relative humidity; RH_{os} – relative humidity at desiccant screen outlet; RH_{id} – relative humidity inside drying chamber

Table 2 shows the average relative humidity values during the test period of Bitter leaf. Ambient relative humidity values were consistently higher than humidity values at the desiccant screen outlet and inside the dryer. This was expected as the air at the screen outlet had lost some moisture resulting in lower values. Humidity values inside the drying chamber were lower than the ambient values but slightly higher than the values at the screen outlet, except for days three and five. This was due to inconsistent power supply on days three and five.

Table 3 shows the average temperature readings during the test period. Temperature values ranged from 24.4 to 26.7 °C during the test period. Ambient temperature readings were consistently lower than temperature readings at the screen outlet, inside the drying chamber and at the outlet vents. Air temperature at screen outlet was consistently higher than that inside the dryer except for days 2 and 5.

Moisture content analysis (Table 4).

Ambient air drying showed the lowest value in the percentage of water lost (64.3 %) followed by tray 4. This shows that ambient air drying is not as effective as desiccant drying. The control showed the lowest percentage shrinkage in bitter leaf during the five days of drying. This also shows that ambient air drying is not as effective as desiccant drying.

Average drying rate (Table 5).

Table 3

Average temperature readings during the test period

Parameters	Day 1	Day 2	Day 3	Day 4	Day 5
T_a (°C)	25.0	24.8	25.1	24.4	25.1
T_d (°C)	25.3	26.7	25.5	25.1	25.8
T_{os} (°C)	25.9	26.0	25.6	25.3	25.5
T_{od} (°C)	26.0	25.9	25.7	25.2	25.4

Notes: T_a – ambient temperature readings/temperature readings at screen inlet; T_d – temperature inside the drying chamber; T_{os} – temperature at desiccant screen outlet; T_{od} – temperature at dryer outlet vents

Table 4

Final weight readings of bitter leaf

Initial (g)	T_0 (g)	T_1 (g)	T_2 (g)	T_3 (g)	T_4 (g)	T_5 (g)
33.4	11.9	10.5	10.8	10.9	11.2	10.7
Moisture content (%)	68.5	67.6	67.3	66.4	67.9	64.3
Shrinkage (%)	25.5	25.3	25.2	25.0	25.4	24.4

Notes: T_0 – Control; T_1 – Tray 1; T_2 – Tray 2; T_3 – Tray 3; T_4 – Tray 4; T_5 – Tray 5

Table 5

Average drying rate (ADR) of bitter leaf samples

Parameters	Dryer (all 5 trays)	Control
Initial weight	167 g	33.4 g
Final weight	54.1 g	11.9 g
ADR for 26 hours	0.0043 kg/h	0.0083 kg/h

The average rate of dryer of the desiccant is five times more than the drying rate of ambient air drying. This shows that the desiccant dryer is five times faster than traditional air drying.

Efficiency of the dryer, using $\eta_d=(M_w/M_t)\cdot 100$. Dryer efficiency was calculated as 67.6 %.

Proximate analysis results (Table 6).

Table 6

Proximate results of the dried bitterleaf (Dry matter basis)

Parameters	Ash (%)	Crude protein (%)	Crude fibre (%)	Fat (%)	Carbohydrate CHO (%)
Desiccant dryer sample	15.82	16.50	17.06	5.05	45.57
Control sample	14.10	14.70	15.20	4.50	40.60
Fresh bitter leaf values [10]	16.22	21.70	18.30	5.30	38.46

Proximate results showed that the desiccant dryer sample had higher values than those of the control, while both samples had lower values in all the parameters except Carbohydrate content, when compared with fresh results. This shows that drying vegetables in the desiccant dryer will preserve their nutritive content, when compared to ambient air drying.

It should be noted that our findings are limited only to the use of silica gel as a desiccant and bitter leaf (*Vernonia amygdalina)* as a test crop. Further research can be carried out on other hygroscopic/desiccant materials and on other heat sensitive test crops. Research should also be carried out on methods to increase the dryer efficiency.

4. Conclusions

Results showed that desiccant dryer is an effective means of drying when compared to regular air drying methods. Proximate analysis results showed that the desiccant dryer sample had higher values (15.82 %, 16.5 %, 17.06 %, 5.05 %, and 45.57 %) than those of the control (14.10 %, 14.70 %, 15.2 %, 4.5 %, 40.6 %) for ash, protein, fibre, fat, and carbohydrate contents respectively. This shows that drying vegetables in the desiccant dryer will preserve their nutritive content, when compared to ambient air drying.

Based on the results derived from this experiment, it is therefore recommended that heat-sensitive seeds, fruits and vegetables should be dried in a desiccant dryer. There should also be provision for an alternative source of energy (e. g., battery or solar panels) in case there is a shortage of electricity in order to enhance and improve the dryer efficiency.

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