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DEVELOPMENT OF AN INDIRECT SOLAR DRYER FOR THIN LAYER DRYING OF RED AND WHITE ONIONS

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Abstract: A solar dryer is intended to address the limits of natural sun drying, such as exposure to direct sunlight, risk of rodents and pest, lack of sufficient monitoring, and the increasing expense of the drier. The solar dryer is made up of an integrated solar collector and a drying chamber which is constrained by a rack of three cloth (net) trays. The solar dryer has the following dimensions: a stand that is 60 cm in height, a width of 30 cm, a length of 40 cm, and a height of 60 cm. Therefore, after drying the onion samples, the proximate analysis results show the difference between the fresh and dried samples for the two varieties of onion considered in this study.

Key words: *Solar dryer, Onions, Proximate, drying, moisture.*

INTRODUCTION

One of the most consumed vegetables worldwide is onion (*Allium cepa L.)* which is consumed either as fresh or dried product and has medicinal applications. It includes vitamin B as well as traces of calcium, iron, and vitamin C, [1,2].

Onions have a relatively high heat energy value compared to other fresh vegetables, a moderate level of protein, and are high in calcium and riboflavin [2].

Onions are largely used as a flavoring component in many nations [1]. They include a variety of healthy chemical constituents, including organic acids, vitamins, phenolic compounds, fiber, and other antioxidants [3].

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Gallic acid and quercetin are significant compounds that contains antioxidant, antiallergic, antimicrobial, anti-inflammatory, anti-hyperglycemic and anti-lipid peroxidative properties [4,5].
The average daily intake of phenolic compounds is around 1756 mg, which may be achieved in part by consuming onions [6]. Changes in temperature have a significant impact on phenolic compounds; Therefore, the right postharvest treatments and onion storage are required to preserve these chemicals. One post-harvest process for onions is drying; during this procedure, heat is used to eliminate any moisture content [,7]. Drying can lower the high moisture content of harvested onions, which is >80% [10], to 10% or less, extending their storage life. However, prolonged drying might reduce the phenolic compounds' stability and cause the antioxidant chemicals in onions to degrade [8]. Furthermore, the introduction of too much heat during drying might result in a reduction in vitamin C, color, and other components [9].

Dehydrating food products by drying entails removing moisture from the food to extend its shelf life by limiting bacterial development. Sun drying (putting the crops out in the sun to dry) is cheaper, but the finished product is of inferior quality because of dust, insects, birds, dogs, and rain contamination [10,11]. Additionally, direct exposure to UV radiation causes a loss of vitamins, minerals, and unattractive color changes, and it takes a longer time to dry [12,13] showed that when sun drying and solar dryers were compared, the former produced superior drying temperatures, lower product moisture content, lower relative humidity, and reduced spoilage. When compared to open-air drying, [14] have demonstrated that solar dryers produce dried commodities of higher quality and cut down on drying time by about 20%. According to [15,16,17], there are numerous variations in solar dryer sizes and designs, such as tunnel dryers, hybrid dryers, dryers that are oriented both horizontally and vertically, multi-pass dryers, and active and passive dryers.

Literatures affirm that solar dryers using forced convection are more effective than those with natural convection [11,18,19]. Additionally, forced convection solar dryers may dry products more quickly than natural convection solar dryers, and the finished goods produced by forced convection drying are of higher quality. In this Paper, a low-cost indirect mode solar dryer was designed and developed using environmentally friendly and locally accessible materials. The performance evaluation of the solar dryer was carried out to include proximate analysis, moisture removal rate and dryer efficiency for the red and white onions was carried out.

MATERIAL AND METHODS

Preparation of materials

The onions (red and white onions) were purchased at Ofa market in Ilorin, Nigeria. The samples brought to the lab preparation which include cleaning and washing to remove dirt and particles for the onions as seen in fig.1 below, to be weighed appropriately to know the accurate kilo weighed.

The onions were placed on a stainless-steel tray for slicing, before slicing the outside part of the onion was piled with a knife; the onions were sliced with a knife in diameter of 3mm and 5mm and the sliced onions were spread on the stainless-steel tray then load into the dryer.

a. Red Onion b. White Onion c. Slicing of onions d. Onions Slices

Figure 1. Image of Onion sample preparation

Design procedure

The design of the indirect solar dryer took into consideration different design criteria and parameters. These design parameters include environmental condition of experimental location, amount of moisture to be removed, drying temperature, heat energy requirement, sizing and orientation of the solar collector and determination of airflow requirement.

(a) Environmental condition of the experimental location

The solar dryer was fabricated and evaluated in Ilorin, Kwara State, Nigeria. Records gotten from the Meteorological Department of Ilorin International Airport (MDIIA) showed that the average solar irradiation for Ilorin was 340.8 W/m^2. The ambient temperature, T_a for the place of drying test was 25^{0}C with relative humidity of 67%.

(b) Amount of moisture to be removed

The quantity of onions sample to be dried is 4kg which is the volumetric capacity of the dryer. The formula to calculate the total amount of moisture removed M_w is given by [20,21] as in eq. 1 below:

$$M_w = \frac{W_{m}(M_i - M_f)}{I - M_f} \qquad \text{……………………….(1)}$$

Where,
M_w is the amount of moisture removed;
M_i is the initial moisture constant on wet basis;
M_f is the final moisture content on wet basis

(c) Drying temperature

ADOGA [20], recommended drying temperatures of fruits and vegetables to be between 40-45 ^{0}C. Higher temperature may cause browning of sugar of many fruit products when drying. Hence, for designing the dryer, average drying temperature, T_d of 45^{0}C was considered.

(d) Heat energy required to remove water

The heat required to remove water from a produce was calculated using the formula provided by [21]. This is given as seen in eq. 2 below:

$$Q_1 = M_w \times C_p \times D_T \qquad \text{…………………………………..(2)}$$

Where,
C_p is the specific heat capacity of the produce (in kg^0C) and
D_T = Td-Ta is temperature change (in ^0C).

Specific heat capacity of a food material can be determined using the following equation as seen in eq.3 below

$$C_p = M_c \times M_p \times M_f \times M_a \times M_i \qquad \text{……………………..……(3)}$$

Where,
M_c; M_p ; M_a; M_w; M_i is mass of fraction of carbohydrate, protein, ash, water, ice respectively.

The second stage is evaporating the moisture from the produce. As water start to evaporate after the produce is warmed up to the drying temperature, heat required to evaporate is giving by eq. 4 below

$$Q_2 = M_w \times L \qquad \text{…………………………..……(4)}$$

L = h_g – h_f, the latent heat of vaporization.

The values for h_g (enthalpy of a water vapour) and h_f (enthalpy of water as liquid) at the drying temperature were obtained from psychometric chart.

(e) Sizing the collector

The daily average isolation of Ilorin (where the experiment was carried out) is taken to be 15.48 MJ/m^2/day [22]. Struckman [23] presented the efficiency of a typical flat-plate collector be between 25-45%. The collector efficiency was influenced by factors such as temperature, airflow rate, type of transparent material, absorber plate and insulation used. To achieve an optimal design, average value of collector efficiency of 35% was considered as a design parameter. As a result, expected energy production by the collector was 10.84 MJ/m^2/day for two days, and the collector area was 0.82 m^2. Barki et al. [24] suggested that the length to width ratio of a solar collector to be 1: 2. Considering the ratio to be 1:2 for this design, the length and width of the collector were 130 cm and 60 cm, respectively.

(f) Orientation and tilt angle of solar collector

The flat plate solar collector was tilted and oriented in a way that it received maximum radiation. Optimal tilt angle varies according to the season. Generally, optimum angle of tilt is equal to the degree of latitude of the site [25]. In this design, the test location was in Ilorin (latitude $8^0 30^{'}$N), a collector tilt angle of 10^0 was considered.

Air flow requirement in the drying chamber

Author et al. [26] recommended the range for air velocity to be between 0.51 m/s to 5.08 m/s. In addition, the depth of the air channel should be 1/15 to 1/20 of the length of collector.

Taking the average factor of the depth of the air channel (0.058) as recommended the depth of air channel was 7.54 cm. The vent area which was estimated as a product of the width of collector and air gap (6.18 m^2).

Determination of Proximate Composition of Onion Samples

Proximate Composition (Total Moisture Content, Crude Protein, Crude Fat, Crude Fiber, Ash Content,) of the two varieties of raw onions were determined by the following methods

Moisture content determination

Fresh onion samples of 30 g were placed in pre-weighed aluminum weighing dishes and according to the America Dehydration of Onions and Garlic Association [20] temperature of 70 ^{0}C for 6 hrs at 26.1 Hg vacuum in Thelco 29 vacuum oven (precision scientific, Chicago, IL). Moisture contents were estimated on dry basis using the following formula developed by Adoga [20] to obtain the initial moisture content as seen in eq. 5 below.

$$M_c(\%db) = \frac{w_{i-w_f \times 100}}{w_f} \qquad \text{..............................(5)}$$

Where,

W_i was the initial weight of the sample and

W_f was the final weight of the sample

Determination of Crude Protein

The onion sample was tested for crude protein content according to the Kjeldahl's method as described in AOAC [27], which involved protein digestion and distillation. About 2.0 g of the sample was weighed into an ash less filter paper and put into a 250 ml Kjeldahl flask. Then, 1 g of digestion mixture (as catalyst) and 15-20 ml of 98 % conc. Sulfuric acid were added. The whole mixture was subjected to heating in the digestion chamber until transparent residue contents were obtained. Then, it was allowed to cool. After cooling, the digest was transferred into a 100 ml volumetric flask and made up to the mark with distilled water and then distilled using Markham distillation apparatus. The digest in the condenser was steamed through until enough ammonium sulphate was collected. The solution in the receiving flask was titrated with 0.063 N hydrochloric acid up to a purple end point. After titration, the % nitrogen was calculated using the formula as seen in equation 6 below:

$$\%Nitrogren = (V_s - V_B) \times M\ acid \times 0.01401 \times 100W \qquad \text{................(6)}$$

Where,

Vs is the Volume (ml) of acid required to titrate sample;

VB is the Volume (ml) of acid required to titrate the blank;

M acid is the Molarity of acid;

W is the Weight of sample (g).

Then, percentage crude protein in the sample was calculated from the % Nitrogen as % crude protein = % N x F, where, F (conversion factor), is equivalent to 6.25, [28].

Determination of Crude Fat, Crude Fibre and Ash Content

The crude fat was estimated in the onion sample was determined using Soxhlet extraction for 24 hours.

The % fat in the sample was calculated using the formula as seen in equation 7.

$$Fat(\%) = \left(\frac{Weight\ of\ fat}{Weight\ of\ original\ sample}\right) \times 100 \qquad \text{.........................(7)}$$

The crude fibre was estimated using 2 g fat free sample of onion which was taken into a fiber flask and 100 ml of 0.255 N H_2SO_4 was added. The residue was washed with 50 ml of hot water twice on the sieve cloth before it was finally transferred in the pre-weighted crucible. The crucible with residue was oven dried at 105 ⁰C overnight to drive off moisture. The oven dried crucible containing the residue was cooled in a desiccator and latter weighted (W1) for ashing at 550 ⁰C for 4 hours [28]. The crucible containing white and grey ash (free of carbonaceous material) was cooled in a desiccator and weighted to obtain W2. The % of crude fiber was calculated as follows as shown in equation 8 while the % ash content in the onion sample was calculated as follows in seen equation 9

$$Fibre(\%) = \left[\left(\frac{W1-W2}{weight\ of\ sample}\right) \times 100\right] \qquad \text{...............................(8)}$$

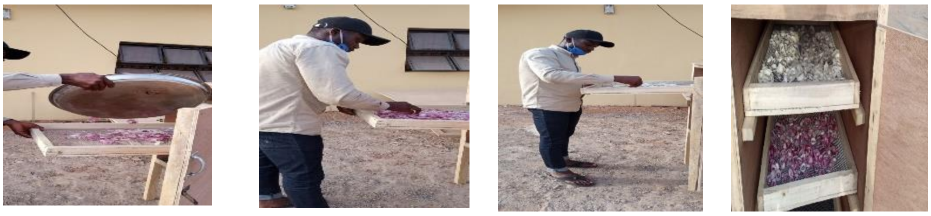
$$Ash(\%) = \left(\frac{weight\ of\ ash}{weight\ of\ sample\ taken}\right) \times 100 \qquad \text{....................................(9)}$$

Side view of the dryer | Front view of the dryer | Top view of the dryer | Inner view of the dryer

Figure 2. Pictorial representation of the dryer

Drying of Onion Samples

Prior to drying, the onions were weighed at 1.7 kg and chopped into 3 and 5 mm diameters. After the proximate analysis test was completed, the sliced onions were taken to the dryer's location. The drying chamber door was opened, and the sliced onions on the stainless-steel tray were moved to the mesh plate inside the drying chamber. The sliced onions on the mesh try were evenly distributed, as shown in figure 3. The door to the drying chamber was closed once the Red and White sliced onions had been arranged on the mesh tray within.



Pouring of onions in trays | Arranging of red onions | Arranging of white onions | Drying

Figure 3. Drying procedure

RESULTS AND DISCUSSION

Results of the proximate composition in studied sample materials are shown in Table 1. The proximate analysis of the two varieties of *Allium cepa* L. revealed that the moisture contents, dries from 84 % to 14.13% in the red onion, while for White onion it dries from 85 % to 14.54%. There was a substantial difference in the fat, Ash, fibre, protein contents of both varieties, with the white Onion variety having a higher value compared to the red onion. The interaction effect of variety and moisture content was significant as shown in the proximate analysis result. The change increased with an increase in drying temperature, but the increase was significantly different among onion varieties.

Table 1. Proximate composition of two varieties of onions

Parameter	Sample			
	Red Onion		White Onion	
	Fresh	Dried	Fresh	Dried
Moisture content	84%	14.13%	85%	14.54%
Fat	0.6%	1.02%	0.5%	1.10%
Ash	0.7%	1.51%	0.8%	1.60%
Fibre	1.4%	1.95%	1.3%	2.10%
Protein	0.8%	1.54%	0.9%	1.62%

The white variety of Allium cepa L. has the highest moisture content (14.54%) of the two varieties examined in proximate analysis. Given their susceptibility to deterioration, the high moisture content of both *Allium cepa* L. types indicates that proper care is required for their preservation. Their susceptibility to microbial infections is increased. The body benefits from the high water content as it doesn't have to expend as much of its own water to digest them. This indicates that the body can assimilate all the nutrients much faster and with fewer energy and resources throughout the digestion process. Therefore, the digestive tract is under less pressure [29]. The level of protein in the two varieties of *Allium cepa* L. was not too high; however, the protein content of the white onion variety (1.62 %) was higher than that of the red onion variety (1.54 %). The higher protein contents of white onion studied, indicates that its intake can contribute to the formation of hormones which controls a variety of body functions such as growth, repair, and maintenance (replacement of wear and tear of tissues) foody. In addition, it may be useful as a preferred option to animal proteins for diabetics as the later tend to be high in saturated fats. This confirms that onion is an energy giving food.

The presence of crude fiber in the diet is necessary for digestion and for elimination of wastes. The contraction of muscular walls of the digestive tract is stimulated by fiber, thus counteracting constipation [30]. In addition, it decreases the absorption of cholesterol from the gut in addition to delaying the digestion and conversion of starch to simple sugars, an important factor in the management of diabetes. It may reduce cerium cholesterol levels too. Crude fiber also functions in the protection against cardiovascular disease, colorectal cancer, and obesity. Thus, the high percentage fiber contents in the White variety of onion (2.10 %) makes it more effective and useful than the red one (1.95 %) in the management of diabetes mellitus, colorectal cancers, and weight reduction in obsessed individuals, and this is the most significant finding in this present study. The study of ash content is very important to the extent that it provides an insight into the nutritionally important inorganic mineral elements, which are presented in Table 1. It was reported that the ash content of a food sample gives an idea of the mineral elements present in the food sample [31]. In the present study, both the varieties exhibited low level of ash content. Yet, white variety of *Allium cepa* L. could be promising sources of essential or non – essential mineral elements as it holds higher level of ash content (1.60%) than that of red onion (1.51 %). The effect of excess intake of crude fat has some well-established health implications especially for the overweight. The consumption of excess amounts of fats has been recognized as the most important dietary factor aiding increased level of cholesterol. Besides the cholesterol implications due to high fat intake, obesity is a factor in the causation of disease [31]. In this regard, red variety of *Allium cepa* L. could be said to be better preferred as it may reduce the risk of coronary heart disease and lower the risk of hypertension due to its lower crude fat content of about 1.51%

Table 2. Drying Properties

Properties	Value
Heat energy required to remove water	
M_i	0.84 kg
W_m	4 kg
M_f	0.14 kg
M_w	3.26 kg
C_p	11.97 KJ/kg^{0}C
D_T	20^{0}C
Q_1	957.56 KJ
h_g	2583 KJ/Kg
h_f	188 KJ/Kg
L	2395 KJ/Kg
Q_2	7807.7 KJ
Q	8765.3 KJ
Airflow requirement in the drying chamber	
Volume flow rate	0.02331 m^3/s
Mass Flow rate	0.02080 kg/s

This mass flow rate value lies between the ranges of 0.02-0.9 kg/s, as recommended by [33] for natural convection dryers. The results from the table 2 indicate that drying has significant effect on the quality of two varieties of onion, namely, red onion and White onion. Generally drying is simply defined as the removal of moisture content from food.

Moisture content after drying is one of the important parameters used to estimate the performance of the solar dryer. The moisture content of the red and white onion decreases after drying while the fat, ash, fibre, and protein of the red and white onion increase after drying. The drying time for red onion was 12 hours and the drying time of white onion was 12 hours 45 minutes. The dried red onion and white onion was placed in a glass cylinder for packaging.

CONCLUSIONS

The moisture content reduced from 84% to 14.13%, while in fresh white onion, the moisture content reduced from 85% to 14.45% after drying. The fat in the red onion increased from 0.6% to 1.2% after drying, the fat in white onion increased from 0.5% to 1.10% after drying. The ash in red onion increased from 0.7% to 1.51% after drying, the ash in white onion increased from 0.8% to 1.6o% after drying. The fibre in the red onion increased from 1.4% to 1.95% after drying, the fibre in white onion increased from 1.3% to 2.10% after drying. The protein in the red onion increases from 0.8% to 1.54% after drying, the protein in white onion increased from 0.9% to 1.62% after drying. The moisture content of the red and white onions decreases after drying while the fat, ash, fibre, and protein all decreases after drying.

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RAZVOJ INDIREKTNE SOLARNE SUŠARE ZA SUŠENJE CRVENOG I BELOG LUKA U TANKIM SLOJEVIMA

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Solarna sušara se sastoji od integrisanog solarnog kolektora i komore za sušenje koja je ograničena stalkom od tri platnene (mrežaste) posude. Solarna sušara ima dimenzije: postolje visine 60 cm, širine 30 cm, dužine 40 cm i visine 60 cm.
Zato, nakon sušenja tankih uzoraka luka, rezultati neposredne analize, pokazuju razliku između svežih i sušenih uzoraka za dve sorte luka koje se razmatraju u ovoj studiji.

Ključne reči: *Solarna sušara, luk, neposredno, sušenje, vlaga.*

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