Investigation of the Drying Kinetics of Paw-Paw (Carica Papaya) Chips Using Locally Available Materials

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Abstract
The drying efficiency of paw-paw chips processed using open sun drying and a mixed-mode solar dryer is reported. Paw-Paw fruits were harvested and neatly peeled into chips and washed. The chips were measured into two equal quantities and then subjected to drying using open sun drying (OSD), and a mixed-mode solar dryer constructed using locally available materials. The total duration of the experiment was more than 2 weeks. The drying efficiency of the chips from the two methods were evaluated. The results indicate that the drying efficiency of the Paw-Paw chips done using the solar dryer was more promising. The mean drying period of the chips using the solar dryer was two weeks while that of the open sun drying lasted for three weeks. The drying rate of the paw-paw chips and system efficiency (mixed-mode solar dryer) were obtained to be 0.65 kg/h and 78.5% respectively.

1. Introduction

Food scarcity is one of the commonest scourge that is known to man. Although modern technology has attempted to solve most of the human needs, only a very small portion of the globe are privileged to have access in diverse areas of technology. In developing nations, technology is still rare in most field of human endeavour. In such nations, subsistence farming is mostly the economic mainstay. It is also pertinent to note that the dearth of technology also make food storage and drying to be done in a most primitive and illiterate manner. The implications of such scenario is that most of the farm produce are lost to wastages and decay, hence the commonest problem affecting farmers from such developing nations includes but not limited to; (i) lack of effective preservation of their farm products (ii) lack of storage facilities, (iii) lack of awareness of modern preservative and storage facilities. The consequences of this ugly trend include acute shortage and scarcity of food products in most developing nations. Paw paw (Carica papaya) is a member of the family Caricaceae and is not a perennial shrub but a tropical sparsely branched tree, usually with a single stem growing typically ≤ 10 m, with spirally arranged leaves confined to the top of the trunk [1-2]. The maturity period of Carica papaya is typically between 2-3 years depending on the species [3-4]. Paw paw is a common fruit in Nigeria, and it is also a seasonal crop in that it is always very scarce in some time of the year. Nigeria is naturally endowed with two seasons; wet season (from April to October), and dry season (April to March). Paw paw is commonly enjoyed during the dry seasons and very scarce during rainy seasons especially between
June to September in Nigeria. In the study area (Abakaliki in Ebonyi State, Nigeria), Carica papaya is among the staple fruits and plays different roles in solving human needs; ranging from ornamental, nutritional, and medicinal purposes. The medicinal and nutritional effect of Carica papaya has been widely established in the literature [5-15]. Other important derivatives and use of Carica papaya include; in curries, salads, and stews, contains a relatively high amount of pectin and hence used in making jellies, sweet and preserves, powdered meat tenderizers, and as a cure for malaria [8-16].

One of the major methods of moisture removal from agricultural products in most developing countries including Nigeria is by open sun drying. It is a common knowledge that this method is not only very primitive and barbaric but also exposes the products to dust, stains, rodents, birds and flies, such that the product becomes a potential vector for different ailments.

The major aim of this investigation is to develop an affordable and cost effective way of preserving Carica papaya chips through a modern and effective drying equipment in order to reduce the food waste and food contamination that is usually encountered by farmers in the under-developed countries. In order to ensure the success of this study, a mixed solar dryer that works on the principle of simultaneous crop drying was developed. The simultaneous drying of the Paw paw chips is made possible through tapping of the direct radiation from the transparent walls of the solar dryer and the cabinet roof, added with the heated air from the solar collector. The constructed solar dryer is mobile to ensure ease of moving the equipment close to the harvest points. The report presented, is a fundamental step toward exploring cheap effective pathways to combat food waste and poor food preservation techniques in developing nations.

2. Materials and Method

The mixed-mode solar dryer used for the investigation was constructed with cheap and locally available materials that were procured from local markets. Accordingly, the most significant parts of the constructed solar dryer include; the collector, drying cabinet, and drying trays. Further, the architectural design is relatively close to that reported in the literature [17-18] but differs in the dimensions and properties of the materials used as well as the orientation and location of the study area. It is generally understood that the best stationary orientation for solar dryers is to face it due south in the northern hemisphere and due north in southern hemisphere and with a tilt > the local latitude of the study area i.e Abakaliki, Ebonyi State, Nigeria.

2.1. Theoretical Considerations

Important parameters of interest in designing a solar collector includes; latitude (L), longitude, tilt angle (θ), declination (δ), Collector efficiency (η) etc. Different design equations exist in solar dryers configuration according to different research groups [17-19]. In this research, the optimum angle of inclination of the collector was 20° (local latitude + latitude of Abakaliki), determined using the relation [17-18];

$$\theta = L + 15$$  \hspace{1cm} (1)

where θ is the tilt angle and L is the local latitude of the study area.

The declination (δ) is the angle between the sun’s direction and the equatorial plane and is mathematically given as [19-20];

$$\delta = 23.45 \sin \left(0.9863 \left(284 + n \right) \right)$$  \hspace{1cm} (2)

In equation (2), (n) is the day in the year which varies from n = 1 to n = 365.

The collector efficiency is given by equation defined as [17];

$$\eta_C = \frac{\rho V C_p \Delta T}{A I C}$$  \hspace{1cm} (3)

In equation (3), \( \rho \) is the density of air (kg/m^3), (\( \Delta T \)) is the temperature elevation, (C_p) is the specific heat capacity of air at constant pressure (J/kg K), (V) is the volumetric flow rate (m^3/s), (A) is the effective area of the collector facing the sun (m^2), and (I) is the insolation received by the collector in watts per metre squared (W/m^2).

2.2. Dryer Efficiency (\( \eta_D \))

According to the literature [18], the dry efficiency can be expressed as;

$$\eta_D = \frac{\Delta M L}{A I D t}$$  \hspace{1cm} (4)

where \( \Delta M \) is the change in the mass of the crop, (L) is the latent heat of vaporization of water, (M), (t) is the time of drying, (I_D) is the insolation received by the dryer and (A) is the effective area of the dryer. Accordingly, the minimum quantity of heat needed for crop drying is given by the relation;

$$Q_{\min} = M_w L = \rho C_p V \left(T_{\text{amb}} - T_{\text{dryer}} \right)$$  \hspace{1cm} (5)

where \(L = \) latent heat of vaporization of water, \(M_w = \) mass of crop before drying, \(\rho = \) density of water, \(T_{\text{amb}} = \) ambient temperature, \(T_{\text{dryer}} = \) dryer temperature.

The moisture content from the crop is calculated using the formula given in [17-18] as;

$$MC (\%) = \left[ \frac{M_i - M_f}{M_i} \right] x 100\%$$  \hspace{1cm} (6)

where \(M_i = \) mass of sample before drying and \(M_f = \) mass of sample after drying.
2.3. Analysis of Energy Flow

It is a common knowledge that the three major modes of heat energy transfer are radiation, convection and conduction. The sum of these and other processes taking place in the system is necessary to evaluate the energy balance of the solar dryer. The energy balance of the absorber can be adequately approximated to the heat equations by assuming that the total heat energy lost by the solar collector = the total heat energy gained, represented mathematically as;

\[ I_C A_C = Q_A + Q_C + Q_V + Q_R + Q_{RR} \]  

(7)

where \( I_C \) and \( A_C \) retains their usual meanings, \( Q_A \) in watts (W), is the rate of useful heat collected by air, \( Q_C \) in watts (W), gives the rate of heat loss from the absorber due to conduction, \( Q_V \) in watts (W), is the rate of heat loss from the absorber due to convection, \( Q_R \) in watts (W), gives the heat loss from the absorber due to re-radiation of long wavelengths, and \( Q_{RR} \) in watts (W) is the heat loss from the absorber due to reflection losses. The energy loss due to conduction, convection and radiation can be summed up in a compact form as;

\[ Q_L = Q_C + Q_V + Q_R \]  

(8)

3. Results and Discussion

Figure 1. Change in temperature with time of the day.

The change of the temperature and the time of the day throughout the duration of the experiment is shown on Figure 1. Some important parameters such as; temperatures, relative humidity of the dryer and ambient conditions were monitored with thermometers and a relative humidity sensor. The chips were carefully sliced into uniform dimensions of 1.25 cm² by surface area, and 150 g of the sliced paw paw chips was measured out after washing. The paw paw chips were then filled in the tray. The same quantity and size of paw paw chips that was included in the tray, were spread outside under open sun drying to serve as control. The findings indicate that a maximum temperature range of 50°C to 75°C was recorded in the collector between 13.30 pm to 14.30 pm. A possible explanation to this observation is that the collector retains the heat sensibly. This will give room for longer effective drying, thus indicating the effectiveness of the constructed dryer. The difference between the ambient temperature and the dryer is very wide (25°C), which the advantage of the dryer over the open sun drying method.

Figure 2. Change in mass loss with the day number.

Figure 2 gives the plot for the comparative picture of the mass loss in kilograms for the methods used for the drying the paw paw chips. As indicated in Figure 2, the mass loss was more pronounced for the solar dryer compared to the open sun drying method. The paw paw chips dried faster, resulting in earlier zero mass loss while the paw paw chips subjected to the OSD technique exhibited zero mass later as shown on Figure 2. This observation also points to the fact that the drying done using the solar dryer is more efficient, less time consuming, less energy demanding and more cost effective compared to the open sun drying method.

The change in the moisture content with the time of the day is shown on Figure 3. The drop in moisture content was computed on daily basis through the period of the study. The results show that the Carica papaya chips dried from an initial moisture content of 88% to an average storage moisture content of 12.5% in 5 days of the drying process, using the solar dryer. For the open sun drying method, the process lasted for about 7 days for the potato chips to attain a moisture content of 15.5% from the same initial moisture content. Another important observation for the paw paw chips dried using the solar dryer, was that the colour did not change as the experiment progressed. A colour change from milky to milky-brown was observed in the open sun drying case. The observation was explained on the basis that some dust particles and debris that it picked up during the drying process used the color change. Another significant disadvantage of the OSD was that paw paw chips gave sign of contamination and rotten odour. This show that the paw paw chips are gradually attaining stages of spoilage and decay. The exposure to the environment makes the Carica papaya chips to be prone to contamination by flies and other vectors/rodents that perch on them.
The change of the relative humidity with time of the day is shown on Figure 4. The relative humidity is usually least at noon as the atmosphere is clearest at noon. This observation has been reported by other research groups [21-22]. It is pertinent to note that the values observed for the solar dryer is relatively higher compared to that obtained for the open sun drying. This behaviour is due to the difference in the atmospheric conditions of the open environment compared to the solar dryer. Changes induced by related variables have been reported to affect the physicochemical and functional characteristics, proximate composition and morphology of Carica papaya products [21-25].

4. Conclusion

An alternative pathway that is geared toward alleviating the farmers from third world countries from loss of farm produce arising from poor preservation and primitive drying method of farm products has been explored in this study. The result show that the drying of the Carica papaya chips done using the constructed solar dryer, gives faster drying process, yields high quality products and is also more time saving compared to the Carica papaya chips dried with open air sun drying approach. The possible commercialization of the constructed solar dryer will help in no small measure to combat food wastages thereby increasing food availability for all.

References


