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POST-HARVEST DRYING KINETICS OF OKRA (*ABELMOSCHUS ESCULENTUS*) UNDER GREENHOUSE DRYING AND HEAT PUMP DRYING

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Abstract: *Drying is carried out to prolong the shelf life of food products to reduce post-harvest losses by reducing the moisture content present in it. Thin layer drying kinetics of okra (Abelmoschus esculentus) has been compared with open sun drying, heat pump drying and greenhouse drying with different glazing material such as UV Polyethylene sheet and drip lock sheet under passive and active modes. The experimental results showed that the reduction in moisture content of okra from 87.65 % to 10% was achieved in 16 hours under open sun drying (OSD), 14 hours using UV polyethylene sheet greenhouse dryer under passive mode (UVPM), 13 hours under drip lock sheet greenhouse dryer under passive mode (DLPM) and in UV polyethylene sheet greenhouse dryer under active mode (UVAM), 12 hours to achieve the moisture content of 9.3 % using drip lock sheet greenhouse dryer under active mode (DLAM) and 8 hours in heat pump drying (HPD). The highest dryer efficiency of 38.78% was achieved under HPD and 14.15% was achieved under DLAM greenhouse drying. Higher effective moisture diffusivity value of 2.09 x 10^{-10} m^2 /s was achieved in HPD compared to other modes and lower effective moisture diffusivity of 1.04 x 10^{-10} m^2 /s was achieved under open sun drying mode in drying okra. Heat Pump dryer had a higher Specific Moisture Extraction Rate (SMER) value of 2.60 kg/ kWh compared to other methods of drying. It was found that the products dried with minimum drying time in HPD compared to greenhouse drying but still in the economic point of view greenhouse drying has low cost.*

Keywords: *Active mode, Drying kinetics, Effective moisture diffusivity, Greenhouse dring, Heat pump drying, Passive mode*

1.INTRODUCTION

In order to utilize the medicinal and nutritional benefits of the food products throughout the year, processing is done. Food processing helps to increase the shelf life of the food product. The important parameters that influence the food loss are moisture content, pH value, physical structure of the product, temperature and relative humidity. Some of the food preservation methods are thermal processing, cold processing, radiation, drying, chemical processing and curing. The major methods followed in food processing industries are drying and cold storage. Drying is the main method followed due to abundant solar energy.Drying is the process of removing the moisture present in the product. The drying process is carried out by heating the air to reduce the relative humidity of air. Once the relative humidity of air is reduced, the air is now capable of absorbing the moisture in the product to be dried 1.. The main objective of drying is to increase the shelf life of the product. In olden days sun drying was carried out to dry the products. The sun drying was the cheapest and easily available source of energy but still it has some limitations like contamination of dried products and dust in the dried products. In traditional open sun drying the product to be dried was laid down in direct sun light for drying and the method followed is dependent on sunlight. The time consumption under open sun drying was also more. To overcome the demerits nowadays drying is carried out in a closed unit to protect the products from contamination and birds. This has paved the way for solar drying to dry the product safely and to maintain the quality of dried product.

An analytical study was conducted under open sun drying mode for drying apple, peaches and cherry during summer and winter season to predict the hourly variation of product temperature 2.. It was found that even though the temperature was high at 1 PM, but still the surface temperature of product was found maximum at 3 PM due to the heat storage capacity of the product. The duration of time taken to dry the products during summer was 34 hours and 24 hours in winter due to the high moisture content in air during winter. A low cost natural convection solar dryer was developed for drying plantain to overcome the difficulties like lack of electrical energy and inadequate refrigeration systems for preservation 3.. The cabinet was made up of mild steel and covered with glass. Both the cabinet and collector were coated with black paint to absorb heat energy for drying. The plantain cut in to pieces of 3 mm thickness and put it in the tray for drying inside the cabinet. The final moisture content of 15.75 % was achieved in 20 hours with drying rate of 0.184 kg/hr. The collector efficiency of the low cost developed dryer was 46.4 % and system efficiency was 78.73 %. This low cost natural convection dryer will be suitable for poor farmers with low initial cost. In greenhouse dryer the solar collector is replaced by a glazing material to absorb the heat from the sun and utilize the absorbed heat energy for drying. The glazing material was fixed along steel frames to prevent dust and other contaminations entering the dryer. A greenhouse dryer working on with a fan or blower for providing air movement inside the dryer is active mode greenhouse dryer and the other operating without a fan or blower is passive mode greenhouse dryer. In passive mode greenhouse dryer air movement is achieved due to the density difference of air inside the dryer. Two types of greenhouse dryers under passive and active mode were developed to analyze the performance under no load conditions4.. The experimental results showed that passive mode greenhouse dryer experiences a high relative humidity of 62.6% and active mode greenhouse dryer experiences 42.8% inside the dryer. This clearly indicates the lower drying rate under passive mode. The relative humidity inside the active mode greenhouse is controlled by the exhaust fan. There was a 2% increase in efficiency in active mode dryer than in passive mode dryer. The drying rate increased by 31% in active mode greenhouse due to lower relative humidity inside the dryer. A forced convection greenhouse dryer was developed for drying bitter gourd under three different air mass flow rates 5.. The experimental results showed that optimum drying efficiency was achieved in 0.0551 kg/s mass flow rate and the safe moisture content for preservation was achieved in 17h. The moisture content of bitter gourd was reduced from 96.8% to 12.2% by using polycarbonate sheet as glazing material under forced convection mode. The experimental results showed that the highest efficiency of 19.7% was achieved in 0.0551 kg/s mass flow rate. The payback period of developed greenhouse dryer was found to be 1.5 yrs. A study had been conducted to determine the potential factors favoring the usage of heat pump dryer in food drying 6.. The dryer efficiency up to 95% can be achieved in a heat pump dryer. The drying rate was increased and drying time considerably reduced in a HPD. The HPD was found to be eco-friendly. The maximum SMER value up to 4 kg/kW h can be achieved in a HPD.

The main objective of the present work are; (i) to study the drying characteristics of Okra in Open sun drying, Greenhouse drying and Heat pump drying and (ii) Comparison of drying characteristics between Open sun, Greenhouse drying and Heat pump drying.

2. MATERIALS AND METHODS

Experimental Setup

The drying of okra was carried out in open sun drying, greenhouse drying and in heat pump dryer till the safe moisture content of the product is achieved to increase the shelf life. Blanching was done at 50^0C to 60^0C for okra to enhance drying operation and to prevent enzyme activities after drying. Okra of uniform size of 2.5 mm thickness is cut in to pieces and used for drying. Experiments were conducted in the month of March from 9am to 4pm and the dried products were kept in air tight plastic sheets to prevent absorption of moisture from atmosphere during night time. Drying is carried out till the safe moisture content for preservation is achieved.

- *2.1.1 Open Sun Drying*

The product to be dried were kept in a steel mesh wire tray and the product to be dried are cut in to equal size and spread over the wire mesh tray for drying (Figure 3.1). The drying was carried out till the moisture content of the product reaches less than 10%. Generally moisture content with less than 10% will increase the shelf life of the dried product.

Fig. 1 Open sun drying

- *2.1.2 Greenhouse Dryer*

An even span roof type greenhouse dryer was designed and fabricated with 1.2 x 1.2 m^2 floor area and ceiling 1m height. The structural frame of the greenhouse dryer is covered by UV polyethylene sheet and drip lock sheet as glazing material of 0.10mm thickness, to trap the solar radiation under passive and active mode (Figure 3.2). For enhancing the air movement in greenhouse dryer, an air vent is provided at the roof of the passive greenhouse dryer and a fan or blower is used in active mode. Greenhouse dryer was placed in east west orientation to have maximum exposure of solar radiation. Samples of one kg of okra placed in trays in greenhouse drying under passive and active mode using UV polyethylene sheet and drip lock sheet as glazing material. The glazing material is the sheet used to cover the roof of the greenhouse dryer for absorbing the heat incident in it. Some of the factors considered in selection of glazing materials are transmission of radiation, life of the glazing material, aging factor, cost of the glazing material, maintenance cost and ease of availability of sheet. Most significant advantage of glazing material is it prevents loss of heat. The absorbed radiation cause the crop temperature to increase and at the same time the radiation energy after heating the product may try to escape which is prevented by the glazing material. Thus the temperature inside the dryer is maintained which enhances the drying rate of the product.

(a) (b)

Fig. 2 Greenhouse dryers in (a) Passive mode (b) Active mode

- *2.1.3 Heat Pump Dryer*

The HPD used in the present work was a commercial based dryer manufactured by Ice Make Refrigeration system incorporated with a heat pump and dehumidifier. The main function of the heat pump is to add the latent heat and sensible heat. The heated air from the heat pump sent in to the drying chamber to absorb the moisture present in the vegetables to be dried. The hot air absorbs moisture from the product and converted in to cold humidified air and leaves the drying chamber. The HPD consists of two fans inside the drying chamber for circulation of heat uniformly. The refrigerant used in the heat pump dryer is R134. The dehumidification capacity is 2.5 (l/h) and maximum product capacity for drying in heat pump is 60 kg. The experimental set up of the heat pump dryer is shown in Fig. 3. The drying chamber consists of four racks with two trays in each rack (Fig. 4).

Fig. 3 Experimental set up of a heat pump dryer

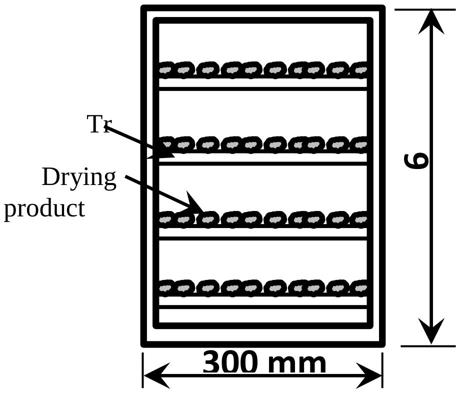

Fig. 4 Drying chamber

The number of trays can be decreased based on our requirement of the drying product. The drying chamber is of length 120 cm and width 55 cm. The maximum drying capacity of product can be placed in the drying chamber is 60 kg. The drying time and moisture content were found out for all the drying methods. Based on the moisture content and time taken for drying the drying rate and dryer efficiency was found out.

2.2 Instrumentation

A Halogen moisture Analyzer (Mettler Toledo) was been used to determine the initial moisture content of the product. A Solarimeter was used for measuring the solar radiation (range: 2000 W/m^2) with an accuracy of $\pm$5 W/m^2. A noncontact type infrared thermometer was used for measuring temperature up to 380°C with an accuracy of $\pm$1.5°C. An anemometer (Model: Benetech, range 0 to 30 m/s) was used to measure the wind speed.

2.3. Uncertainty Analysis

In the analysis of systems, there are some independent parameters. They were measured, like temperature, mass, time, etc. and some dependent parameters such as efficiency, power, etc. The uncertainty in the measured parameters was due to errors like sensitivity, calibration, reading, etc. (Table 1). Let x_1, x_2, $x_3 \ldots x_n$ are independent variables with uncertainty w_1, w_2, $w_3 \ldots w_n$ 7.. The result R is a dependent function of independent variables. The uncertainty in the result R is given by w_R in Equation (1).

$$\left[\left(\frac{\partial R}{\partial x_1} w_1\right)^2 + \left(\frac{\partial R}{\partial x_2} w_2\right)^2 + \left(\frac{\partial R}{\partial x_3} w_3\right)^2 + \ldots + \left(\frac{\partial R}{\partial x_n} w_n\right)^2\right]^{1/2} \quad (1)$$

Table 1 Uncertainty in the measured and calculated parameters

Parameters	Model/Measuring Instrument	Range	Uncertainty
Temperature (°C)	Noncontact type Infrared Thermometer	-50 to 380°C	$\pm$0.394°C
Solar radiation (W/m^2)	Solarimeter	2000 W/m^2	$\pm$0.714%
Wind velocity (m/s)	Benetech Digital Anemometer	0 to 30m/s	$\pm$0.2%
Mass of the products (kg)	HMS	5kg	$\pm$0.1%
Moisture ratio (%)	-	-	$\pm$1.09%
Drying rate (kg/h)	-	-	$\pm$1.24%

3. PERFORMANCE ANALYSIS

3.1 Moisture Content

The initial moisture content of the product was calculated by halogen moisture analyser at a drying temperature of 130°C and the moisture content was found. The moisture content of samples was calculated for each day using Equation (2) 8..

$$M.C = \left(\frac{W_w - W_s}{W_i}\right) X\,100 \quad (2)$$

where,

Ww = Weight of wet sample (g)

Ws = Weight of dry sample (g)

Wi = Initial weight of sample (g)

M.C = Moisture content of ivy gourd (%)

3.2 Moisture Ratio

Moisture Ratio (MR) is an important parameter to analyze and compare the performance of solar dryers. Moisture ratio is the ratio between mass of water to mass of solid in a sample. It is given by Equation (3) 5..

$$MR = \frac{(M_{int} - M_{eq})}{(M_{in} - M_{eq})} \quad (3)$$

where,

Mint is instantaneous moisture content (%),

Min is initial moisture content (%) and

Meq is equilibrium moisture content (%).

3.3 Drying Rate

The drying rate is the ratio between the difference in moisture content and total hours taken for drying to reach the safe moisture content for preservation 5.. Drying rate is calculated by Equation (4).

$$Dr = \left(\frac{M_i - M_f}{\text{Total hours of drying}}\right) \quad (4)$$

where,

Dr =Drying Rate (g/h)

Mi = Initial moisture content

Mf = Final moisture content

3.4 Dryer Efficiency

It is the ratio of energy required to remove the moisture to the energy supplied to dryer 8.. The dryer efficiency is calculated from Equation (5).

$$\eta_d = \left(\frac{M_w L_v}{I_c A_c \ t}\right) \tag{5}$$

where,

M_w = Weight of Moisture removed (kg)

L_v= Latent heat of Vaporization (J/kg)

I_c = Average solar radiation incident during drying (W/m^2)

A_c = Area of the dryer (m^2)

t = Time taken for drying (s)

3.5 Effective Moisture Diffusivity

The rate of moisture moved from the interior surface of the product to the surface is denoted by effective moisture diffusivity. The effective moisture diffusivity depends on moisture content of the product, drying temperature and porosity of the product 9.. The effective moisture diffusivity (D_{eff}) of the vegetables under different modes has been calculated by Equation (6).

$$ln\frac{M_{int}}{M_i} = ln\frac{8}{\pi^2} - \left(\frac{\pi^2 D_{eff}\ t}{4L^2}\right) \tag{6}$$

where,

D_{eff} = Effective moisture diffusivity (m^2/s)

M_{int} = Moisture content at time t (%),

M_i = Initial Moisture content (%),

L = Half the thickness of the slab (m)

t = Time (s)

3.6 Specific Moisture Extraction Rate (SMER)

Specific Moisture Extraction Rate (SMER) The specific moisture extraction ratio is the ratio between the moisture evaporated from wet product to the energy input to drying system 5.. SMER was calculated from Equation (7).

$$\text{SMER} = \frac{\text{Moisture evaporated}}{\text{Input energy}} \tag{7}$$

4. RESULTS AND DISCUSSION

4.1. Moisture content

The moisture removal is higher during the initial drying period due to the evaporation of moisture from the free surface of the product. During the later stages of drying, part of heat energy is utilized for migration of moisture from the inner surface of the product. It is found that reduction in moisture content is faster in heat pump dryer due to uniform supply of hot air inside the dryer (Fig. 5).

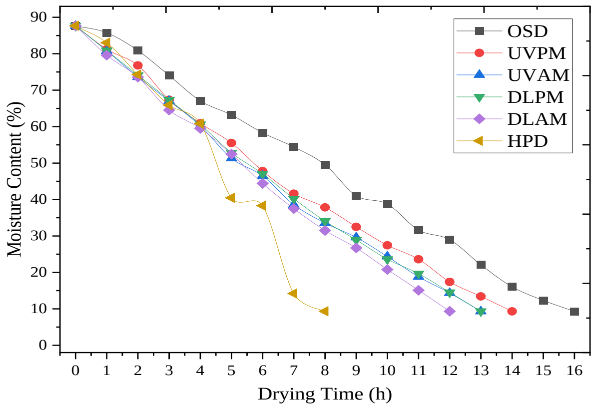

Fig. 5 Variations of moisture content of okra under different modes of drying

In greenhouse dryer drip lock sheet under active mode had high moisture removal rate because of more amount of heat transfer achieved by the air movement. The reduction in moisture content of okra from 87.65 % to 10% was achieved in 16 hours under OSD, 14 hours using UVPM, 13 hours under DLPM and in UVAM, 12 hours to achieve the moisture content of 9.3 % using DLAM and 8 hours with HPD.

4.2 Moisture Ratio

The final moisture ratio of around 0.1 had been achieved in 11 hours in DLAM, 12 hours in UVAM and in DLPM.Whereas, UVPM and OSD took 16 hours and 14 hours respectively to reach moisture ratio of 0.1. Final moisture ratio of 0.1 was achieved in 8 hours in HPD (Fig. 6).

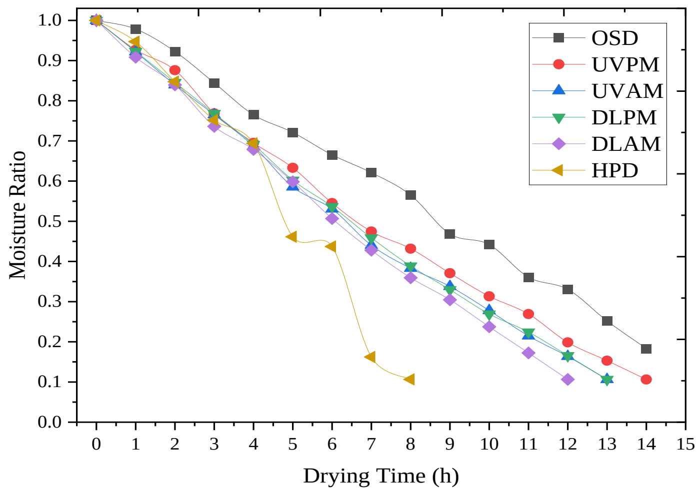

Fig. 6 Variations of moisture ratio under different modes in drying of okra

4.3. Drying Rate

Drying rate mainly depends on the glazing material used and the air temperature inside the drier. Higher the heat transfer higher will be the drying rate. From the experimental results it is found that the drying rate of 4.95 g/h is achieved in Heat Pump Dryer (HPD). The drying rate is found to be higher in drip lock greenhouse active mode dryer compared to OSD, UVPM,UVAM and DLPM because of the more amount of heat transfer enhanced by the air movement by fan and due to increase in temperature inside the greenhouse dryer by the glazing material used.

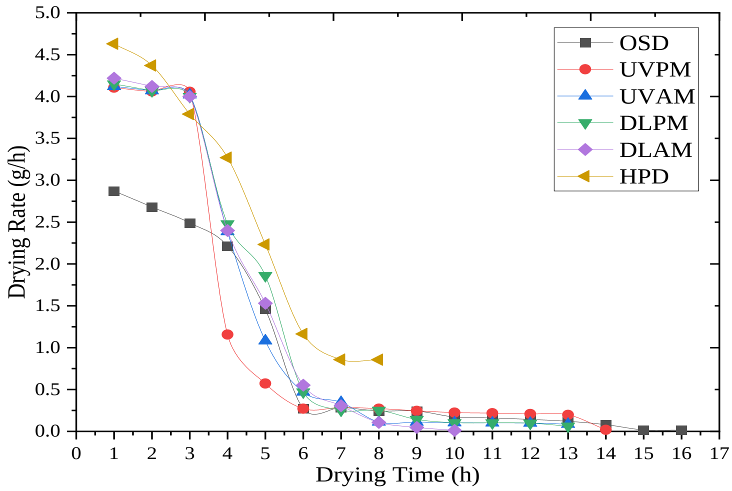

Fig. 7 Variations of drying rate under different modes in drying of okra

It is also seen that drying rate decreases continuously with time. All the drying process follow falling rate period. Diffusion of water in the solid governs the falling rate period during drying. The variations of drying rates for each day for different modes of drying of turkey berry are shown in Fig. 7.

4.4. Dryer Efficiency

The efficiencies of the dryer under different drying modes were calculated. For Okra, the dryer efficiency is 12.12 % in UVPM, 14.15% in DLAM, 13.06% in UVAM and DLPM. Whereas 38.78% of dryer efficiency was achieved in heat pump dryer. The increase in dryer efficiency in heat pump dryer was due to the increase in heat transfer inside the dryer and also due to retention of heat inside the dryer Fig. 8 presents the dryer efficiency of okra dried under different modes of drying.

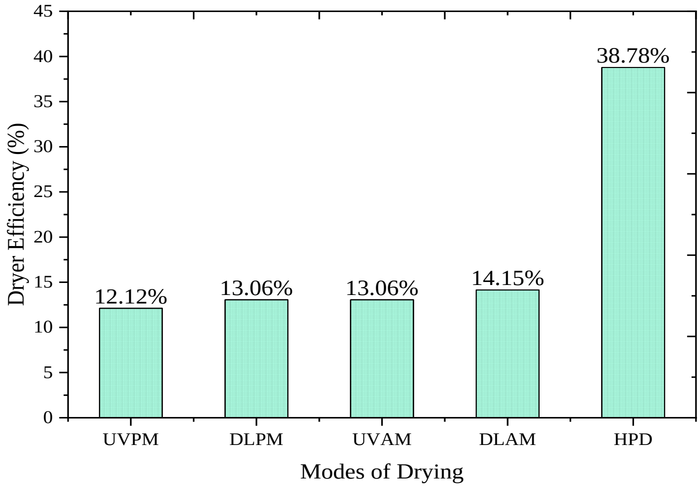

Fig. 8 Dryer efficiency under different modes in drying of okra

4.5. Effective Moisture Diffusivity

In okra higher effective moisture diffusivity value of 2.09 x 10^{-10} m^2 /s was achieved in HPD compared to other modes and lower effective moisture diffusivity of 1.04 x 10^{-10} m^2 /s was achieved under open sun drying mode in drying okra. Higher temperature and air velocity inside the HPD increased more heat and mass transfer to get higher effective moisture diffusivity. For all the other modes effective moisture diffusivity lie within the range of 10^{-2} to 10^{-12} m^2/s of food products 10..

4.6. Specific Moisture Extraction Rate (SMER)

A higher SMER 2.60 kg/ kWh were achieved under heat pump dryer in drying okra. It was found that Heat Pump dryer and active mode greenhouse dryer gave higher SMER values compared to passive mode because of increased mass flow rate. The other drying methods UVPM, UVAM, DLPM and DLAM gave 0.1877 kg/ kWh, 0.2021 kg/ kWh, 0.2021 kg/ kWh and 0.219 kg/ kWh respectively.

5. CONCLUSION

The post- harvest drying kinetics of okra was carried out and the following conclusions were drawn from the experimental results:

- Considerable amount of drying time was saved in drying to reach safe moisture content under Heat Pump Dryer (HPD) compared to greenhouse drying. The okra took 8 hours in HPD to reach safe moisture content.
- The maximum dryer efficiency of 38.78 was achieved in Heat Pump Dryer (HPD) in drying okra.
- A higher SMER of 2.60 kg/ kWh were achieved under heat pump dryer in drying okra. In green house dryer SMER of less than 0.57 kg/kWh were achieved in all modes of drying.
- The effective moisture diffusivity values under Heat Pump Dryer (HPD) were 2.09 $x10^{-10}$ for okra. For all the other modes effective moisture diffusivity was within range of 10^{-2} to 10^{-12} of food products.
- It was found that the products dried with minimum drying time in HPD compared to greenhouse drying but still in the economic point of view greenhouse drying has low cost.

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