Effect of Process Parameters of Infrared-Convective Drying on Osmosed Pineapple Slices

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***Abstract*: In osmotic dehydration, pineapple slices were immersed in the sugar syrup having concentration 70%, constant temperature 50ºC and immersion time 9 h. A laboratory scale infrared- convective dryer was used for drying osmosed pineapple slices. The drying was carried out at infrared power levels of 300, 400 and 500 W, drying air temperature of 30, 40 and 50ºC and air velocities of 1.0, 1.5 and 2.0 m/s. The infrared convective drying of osmosed pineapple slices exhibited drying having taken place in falling drying rate period. The drying rate was significantly influenced by infrared power, air temperature and air velocity. The drying time increased with increased in air velocity at all infrared power and air temperature. The average moisture diffusivity varied from 4.84 × 10^{-10} to 14.71 × 10^{-10} m^2/s and was also influenced significantly by infrared power, air temperature and air velocity.**

***Keywords*: Infrared, Convective, Effective moisture diffusivity, Colour, vitamin C.**

1. Introduction

Pineapple (*Ananas comosus)* is one of the choicest fruit all over the world because of its pleasant taste and flavor. The pineapple is one of the leading commercial fruit crops of the tropics. In terms of pineapple production India's has 6th in the world and leading pineapple growing states are West Bengal, Assam, Tripura, Karnataka, Bihar, Manipur, Meghalaya and Nagaland. Pineapple is the third most abundant tropical fruit in the world after banana and citrus. Pineapple is also a commercially important fruit crop of India with around 90,000 ha area under this crop, 15.27 lakh tonnes annual production and 15.3 tonnes/ha productivity.

The shelf life of peeled, sliced and polyethylene packed pineapple sold in market is 4-6 days, when stored at room temperature, whereas pineapple slices when kept at 8-10 ºC, do not stay more than 8-10 days. Therefore, many alternative approaches were followed for pineapple preservation. One of the techniques being widely studied is osmotic dehydration. It has been proven to improve the texture characteristics of thawed fruits and vegetables, decreases structural collapse and retain natural colour as well as volatile compounds during subsequent drying. The two most important advantages for its use as pretreatment in a complementary process are: quality improvement and energy saving. Osmo-air dehydration treatments are widely applied to fruits in order to prolong shelf –life, reduce packing and logistic costs and improve both sensory and nutritional quality of the end products. (Sinelli et al, 2011).

Infrared technology is a new word in the world of drying science and is based on the property of water to absorb infrared radiations. Far infrared (FIR) has recently much attention as a heat source to augment other drying techniques to enhance the overall process efficiency. The energy from infrared radiation penetrates through the material and is converted into heat. Hence, the material is heated rapidly and more uniformly. The infrared drying offers many advantages over conventional drying as the energy transferring to the product directly and allowing to reach the rapidly suitable temperature levels, which activates the fundamental drying mechanisms of the operation, high energy efficiency, high quality finished products, uniform temperature in the product while drying, and a reduced necessity for air flow across the product (G.P. Sharma, R.C. Verma, P. B. Pathare, 2005).

The objective of this research was to study the drying kinetics of osmosed pineapple slices using infrared-convective dryer, and to study the effects of operational variables such as infrared power, air temperature and air velocity on drying rate and quality of dried osmosed pineapple powder.

2. Materials and methods

A. *Osmosis of pineapple slices*

50 g pineapple slices were weighed and suspended in the vessel containing the sugar solution at the concentration of 70%, temperature 50ºC and 9 hours immersion time (Saputra, 2006). The samples were weight after each one hour.

B. *Experimental dryer*

A laboratory scale infrared-convective dryer was developed for the present study wherein infrared power, air temperature and air velocity could be varied within the range of 0–500 W, 30–50ºC and 1–2 m/s. Constructional details of the dryer are given elsewhere (Sharma, Verma, & Pathare, 2005). The infrared-convective dryer is comprised of two components i.e. a drying chamber having a tube type infrared heater and a hot air supply unit. Provision was made in the dryer so that the infrared radiation intensity as well as air temperature could be varied by regulating the voltage through a variac. The air velocity was regulated with the help of a damper placed in the air supply line to the drying chamber.

C. Experimental procedure

Locally available pineapples were used in the present study. The pineapples were cleaned, crowns removed and cut with a stainless steel knife into slices of thickness up to 8±0.12 mm. Three measurements were made on each slice for its thickness, using a vernier caliper and their average values were reported. The moisture content of the pineapple slices was measured by oven dry method (AOAC, 2010) and was expressed as g water/g dry matter. Sugar syrup of desired concentration was prepared by dissolving required amount of sugar in water. The initial moisture content in the raw pineapple was found to be 6.77 g water/g dry matter approximately. After osmotic dehydration, initial moisture content of pineapple slices was 1.14 g water/ g dry matter approximately. The dryer was run idle for about 0.5 h to achieve a steady state in respect of pre-set experimental drying conditions before each drying run.

Osmosed pineapple slices after weighing were uniformly spread on the tray. Preliminary trial of drying the osmosed pineapple slices, at infrared power of 600 W at 2.0 m/s air velocity browning the product. The drying experiments were, therefore carried out at infrared power 300, 400 and 500 W; drying air temperature 30, 40 and 50 ºC and lower air velocities of 1.0, 1.5 and 2.0 m/s. The mass of the osmosed pineapple slice was measured by a digital electronic balance throughout the drying experiment at an interval of 5 min for first one hour and 15 min subsequently thereafter. For measuring the mass of the sample at any time during experimentation, sample along with tray was taken out of the drying chamber and weighed on the digital top pan balance and placed back into the chamber. The digital top pan balance (2000±0.01 g) was kept near to the drying unit and weight measurement process took about 10 s time.

1) Effective moisture diffusivity

In drying, diffusivity is used to indicate the flow of moisture within the material. In the falling rate period of drying, moisture transfer occurs mainly by molecular diffusion. Moisture diffusivity of the foods is influenced mainly by moisture content and also by their temperature. Pineapple slices were considered as infinite slab. The moisture diffusivity for infinite slab was therefore calculated by the following solution (Eq. (1)) proposed by Crank (1975) mentioned here:

$$MR = \frac{M_t - M_e}{M_o - M_e} = \frac{8}{\pi^2} \exp\left(-\pi^2 \frac{D_{eff} t}{L^2}\right) \quad (1)$$

where D_{eff} is the effective diffusivity, m^2/s, L is the thickness (here half) of slab, M_e is the equilibrium moisture content, g water/g dry matter, M_o is the initial moisture content, g water/g dry matter, M_t is the average moisture content at time (t), g water/g dry matter and t is the time, s.

Eq. (1) is evaluated numerically for Fourier number, $F_o = \frac{D_{eff} t}{L^2}$, for diffusion and can be rewritten as

$$MR = \frac{8}{\pi^2} \exp(-\pi^2 F_o) \quad (2)$$

$$F_o = -0.101 \ln MR - 0.012 \quad (3)$$

The effective moisture diffusivity (D_{eff}) was calculated using Eq. (4) as

$$D_{eff} = \frac{F_o}{\left(\frac{t}{L^2}\right)} \quad (4)$$

D. Evaluation of color

The color of dried osmosed pineapple was measured by using spectrophotometer (Hunter Lab Colorimeter). The color values of sample were expressed in terms of L*(Lightness), a*(redness/greenness), and b* (yellowness/blueness) value.

E. Evaluation of vitamin C

Ascorbic acid is oxidized by colored dye 2,6-dichlorophenolindophenol to dehydroascorbic acid. At the same time dye is reduced to colourless compound so that end point is easily determined. Other compounds also oxidized by dye, to prevent this acid medium are used for the reaction AOAC (967.21).

F. Evaluation of Rehydration Ratio

Rehydration of dried fruits implies to restoration of water in them. Rehydration study was carried out by adding approximately 10g of dried pineapple slice in 100 ml of distilled water in a beaker at room temperature. After about 6 h, sample was taken out from distilled water surface moisture was absorbed carefully with tissue paper and then weighed.

3. Result and Discussion

The data collected on loss in the moisture content with elapsed time were analyzed to study the drying behavior of the product and also the effect of operational parameters on the drying characteristics was analyzed and presented here under.

A. Effect of air temperature

The drying curves of pineapple slices at air velocity of 1.0 m/s and infrared power 500 W, total drying time for pineapple slices at 30, 40, 50ºC are shown Fig. 1 and Table 1. The drying curves are typical to ones for food stuffs, i.e. moisture content of osmosed pineapple slices decreased exponentially with elapsed drying time. As the drying air temperature increased at any IR power (P), the drying curves exhibited a steeper slope indicating that drying become faster with increase in drying air temperature and this resulted into substantial decreased in drying time (t), when higher air temperature where used. Kumar et al. (2005) had also reported similar findings while drying onion under infrared and hot air drying conditions. The drying curves of pineapple slices at air velocity of 1.0 m/s and infrared power 500 W, total drying time for pineapple slices at 30, 40, 50ºC were about 4.5, 4, 3 h. respectively.

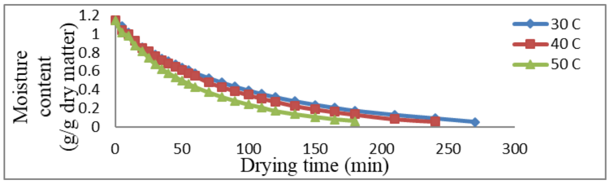

Fig. 1. Drying curves for osmosed pineapple slices at various air temperatures (ºC) at air velocity 1.0 m/s, infrared power of 500 W

B. *Effect of infrared power*

Drying curves at air velocity of 1.0 m/s, air temperature of 30 ºC as a function of infrared power are shown in Fig 2 and Table 1. The drying time to reduce the moisture content of osmosed pineapple slice to about 0.06 g water/g dry matter at infrared power of 300, 400 and 500 W was about 6, 5.5 and 4.5 h. respectively. The drying time reduced dramatically with increase in infrared power. The increase in infrared power caused a rapid increase in the product temperature of the product, which increases the vapors pressure inside the product resulting in faster drying. A similar trend was observed at other air velocity of 1.5 m/s and 2 m/s and at air temperature of 35ºC and 40ºC when IR power was increase from 400 W to 500 W.

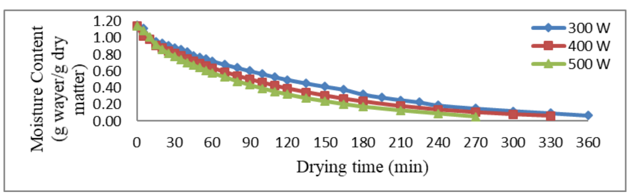

Fig. 2. Drying curve for pineapple slices at various IR power under infrared convective drying at velocity of 1 m/s and air temperature 30 ºC

C. *Effect of air velocity*

The air velocity also influenced the drying time of the osmosed pineapple slices as shown in Fig. 3 and Table 1. At a given air temperature and infrared power, an increase in air velocity increased the drying time i.e. decreased the moisture removal rate. The drying time for the pineapple slices at air velocity 1.0 m/s was about 5 hours at infrared power 300W and air temperature of 50ºC, which increased to about 6.5 hours when air velocity was 2.0 m/s, the other parameters being unchanged. They observed that in increased drying time of pineapple slices at all infrared convective drying conditions when air velocity was increased. The increase in air velocity accelerated the cooling effect, reducing the temperature at the surface of product thus the water vapor pressure or the moisture driving force. ANOVA carried out to see the effect of process variables on the drying time of osmosed pineapple slices revealed that air velocity (v), air temperature (T) and infrared power level (P) had a significant effect on the drying time at 1% level.

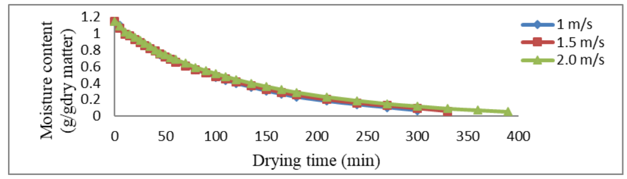

Fig. 3. Drying curves for osmosed pineapple slices at various air velocities (m/s) at temperature of 50ºC infrared power of 300 W

Table 1
Effect of process variables on drying time

Drying air conditions		300 W	400 W	500 W
Air velocity (m/s)	Air temperature (ºC)	Drying Time (min)		
1	30	360	330	270
	40	330	300	240
	50	300	210	180
1.5	30	390	360	330
	40	360	330	270
	50	330	270	210
2	30	450	390	360
	40	420	390	300
	50	390	300	270

D. *Effect of process variables on effective moisture diffusivity*

The variation in moisture diffusivity with moisture content is a complex and system specific function. In the first stage of drying, liquid diffusion of moisture could be the main mechanism of moisture transport. As drying progressed further, vapour diffusion could have been the dominant mode of moisture diffusion in the latter part of drying.

The effective moisture diffusivity(D_{eff}), for osmosed pineapple slices under various drying conditions was estimated from Eq. (5). A typical variation in (D_{eff}) of osmosed pinepple slices with moisture content at different infrared power levels at air velocity of 1.0 m/s and temperature of 30 ºC is shown in Fig.4 and Table 2. The effective moisture diffusivity (D_{eff}) increased from 6.28 $\times 10^{-10}$ to 9.71 $\times 10^{-10}$ m^2/s with decrease in the moisture content at air velocity of 1.0 m/s and temperature of 30 ºC. However, the moisture diffusivity further was higher at any level of moisture content at higher infrared power level, resulting into shorter drying time. This may indicate that as the moisture content decreased, the permeability to water vapour increased as it provided more pore structure open. The temperature of the product would have risen rapidly in the initial stages of drying due to more absorption of infrared heat. This increased the water vapour pressure inside the pores resulted into pressure induced opening of the pores. Sharma et.al (2005) also reported similar finding on the effect of moisture content on moisture diffusivity during infrared drying of onion slices.

The regression analysis was carried out to establish a relationship between average effective moisture diffusivity and process parameters i.e., infrared power, air temperature and air velocity and is presented in Eqn. (5) below. The high values of

R^2 are indicative of good fitness of linear relationship to represent the variation in effective moisture diffusivity (D_{eff}) with various process parameters during drying.

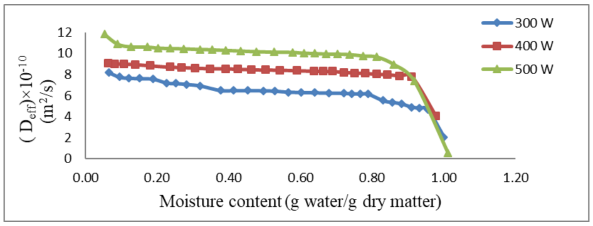

Fig. 4. Variation in effective moisture diffusivity with moisture content at air velocity of 1.0 m/s and air temperature of 30ºC

$$(D_{eff})_{avg} = 1.9171 \times 10^{-12}\,P + 1.1672 \times 10^{-11}\,T - 1.5844 \times 10^{-10}\,v - 1.5862 \times 10^{-10} \quad (5)$$

(R^2=0.85), Where, $(D_{eff})_{avg}$ is the effective moisture diffusivity, m^2/s, P is infrared power, W, T is air temperature, ºC, v is air velocity, m/s.

Table 2
Effect of process variables on average effective moisture diffusivity

Drying air conditions		300 W	400 W	500 W
Air velocity (m/s)	Air temperature (ºC)	$(D_{eff})_{avg} \times 10^{-10}$ (m^2/s)		
1	30	6.28	8.28	9.71
	40	7.18	8.89	10.8
	50	7.36	8.89	14.71
1.5	30	6.26	7.37	8
	40	7.04	8.85	9.93
	50	7.35	8.87	12.98
2	30	4.84	6.7	7.74
	40	6.33	6.96	9.23
	50	6.59	8.82	10.44

E. Quality evaluation of dried turmeric slices

The colour values (b-value) of infrared-convective dried osmosed pineapple slices increased ranged between 24.06 and 34.23. At IR power of 300 W and at air temperature of 30ºC, the b-value at air velocity 1.0 m/s was observed to be 29.58 which reduced to 28.55 when air velocity was increased to 2.0 m/s. It indicates that yellowness in the pineapple powder decreased when the air velocity was increased. The reason could be that drying time at a velocity of 2.0 m/s was more as compare to at an air velocity 1.0 m/s. They observed that by increasing the drying time, the color of the material became darker.

Vitamin C of infrared-convectivically dried pineapple slices ranged between 28.57 and 43.63 mg/mg dry matter. The significant effect of IR power, temperature and air velocity had observed on vitamin C.

The rehydration ratio was considered as one of the important quality attribute for the dried slices in the present study. The rehydration ratio values of dried osmosed pineapple slices were estimated as discussed in earlier sections, using standard procedure. It varied between 1.95 and 5.7, under different drying conditions.

4. Conclusion

The infrared convective drying of turmeric slices exhibited drying to have taken place in falling drying rate period. The drying rate was significantly influenced by infrared power, air temperature and air velocity. The drying time increased with the increase in air velocity at all infrared powers applied, however it reduced with increase in infrared power. The effective moisture diffusivity increased with decrease in moisture content of osmosed pineapple slices. There is good scope of producing a good quality dried slices using infrared radiations.

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