International Journal of Chemical Studies

P-ISSN: 2349–8528
E-ISSN: 2321–4902
IJCS 2019; 7(6): 1461-1464

Received: 25-09-2019
Accepted: 27-10-2019

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Study on effect of drying temperature and size of kair (*Capparis deciduas*) on effective moisture diffusivity

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Abstract
Drying or removal of moisture helps to reduce the water activity of food product and then increases the shelf life of the food. In the present study, fresh kair were categorized in two group on the basis of size (6.022mm and 9.275mm) and then pretreated in hot water at 100 °C for 5 minutes in 0.1% MgO and 0.1% $NaHCO_3$ solution. The method of drying used for the study was tray drying at three temperature levels i.e. 45, 50, and 55 ºC. The complete drying of kair follows falling rate period only. The total time for drying decreases with increase in temperature of drying air from 45 ºC – 55 ºC. The effective moisture diffusivity of kair varies from 3.68 $x10^{-8}$ to 1.21 $x10^{-7}$ m^2/s and it was also found that diffusivity increases with increase in temperature and it was higher for 9.275 mm samples as compare to 6.022 mm size samples.

Keywords: Drying, kair, kinetics, diffusivity, shelf life

Introduction

Kair (*Capparis decidua)* is a desert bushy plant, which grows wildly without much care in the Thar Desert of western Rajasthan and on farm boundaries. The green immature kair fruits are consumed fresh as vegetable and also processed for making pickles. It has both ecological and economic significance. It has the ability to stabilize sand dunes, check wind erosion, has fair tolerance to salinity, alkalinity and its green immature fruits are an important food item. Kair is also grown in the parts of Punjab, Uttar Pradesh and Haryana and in all wastelands having semiarid and arid conditions (Pareek 1978, Srivastava *et al.* 1998) [7, 9]. Kair is also indigenous to tropical Africa, Arabia, Sindh, Baluchisthan, Socotra, Egypt and India (Gupta *et al.* 1989) [3]. The green immature fruits of kair are berry shaped with diameter ranging from 0.7 to1.8 cm. The skin of the fruit is thick, shiny, bony, dark green and contains golden yellow pulp and many white seeds (Chauhan *et al.* 1986) [1]. It is locally referred as kair in Rajasthan, Karil in Uttar Pradesh, Teent in Haryana, Della in Delhi & Punjab and Nepti in western Maharashtra.

Blanching is the pre-treatment method used to arrest few physiological processes and to remove bitterness of kair. It also helps for inactivation of the enzymes, acceleration of drying rate and for reduction of the quality loss. It expels intercellular air from the tissues and also softens the product. Generally, blanching of fruits and vegetables is done by heating in steam or hot water (Xiao *et al*. 2012 and Mate *et al.* 1999) [10, 6].

The green immature kair fruits are available only for few weeks in March -April. They are highly nutritious and their medicinal demand in national and international market is increasing day by day. But due to their perishable nature they become almost unfit for human consumption within few days after harvest, therefore it is essential to process the green immature kair fruits. Further, the inherent bitterness present in fruits is also required to be reduced with suitable processing treatments. The shelf life of kair fruits can be increased after dehydration and long term availability of product can be assured for preparation of some medicine in the form of powder or in the form of bark *Gupta et al.* (1989) [3]. Removal of water or making it unavailable for microbial growth is the most important principal used in food processing. The, dehydration of fruits and vegetables is an important part of the food industry. The development of suitable dehydration process for fruits and vegetables necessitate the study of kinetics during drying process. Prior to dehydration process some pre-treatments are always

required to avoid the enzymatic browning and bitterness of the product which may be due to some chemical compound naturally present in the kair.
The objective of present research work was to compare the effect of size of sample (6.022 and 9.275 mm) and temperature of drying air (45, 50, and 55 °C) on effective moisture diffusivity for kair.

Material and Method
Sample
Green immature kair were procured from the local market of Jodhpur. They were cleaned manually to separate and discard the foreign material like other plant parts, sand particles, dust and the ripened /damaged fruits, sorted and graded on the basis of size. Finally, pre-treatments were applied to graded kair and drying experiments were performed.

Methods
Blanching of green immature kair at 100 °C for 5 minutes was performed with 0.1% MgO and 0.1% $NaHCO_3$. The kair after blanching were cooled immediately with tap water to prevent over blanching and subsequently soaked in 0.5% KMS solution for 30 minutes. Pretreated graded kair was then dried in tray dryer in single layer at 3 levels of temperature (Kohli *et. al.* 2017 and Kohli *et. al.* 2018) [4, 5]. The weight of sample was recorded in interval of one hour to check the change in moisture content. The drying was continued till the two to three consecutive weights which didn't vary more than 3 – 5 mg and that fnal weight was recorded. The dried samples were packed in polyethylene bags of 200 gauge in air tight condition and stored at room temperature in desiccators. The initial moisture contents of green immature untreated and treated kair were determined by oven drying method as described by *Ranganna,* 2000 [8].

$$\text{Percent moisture content (wb)} = \frac{Ww}{Ww + Wd} \times 100 \qquad \text{...... (1)}$$

$$\text{Percent moisture content (db)} = \frac{Ww}{Wd} \times 100 \qquad \text{..... (2)}$$

Where, Ww is weight of moisture evaporated and Wd is weight of dry matter.

Drying characteristics
Drying rate
The moisture content data recorded during experiments were analysed to determine the moisture lost by sample in unit time interval. The drying rate R of sample was calculated by following weight balance equation (Kohli et. al 2017) [4]:

$$R = \frac{\text{WML (kg)}}{\text{Time interval (hours) x DM (kg)}} \qquad \text{...... (3)}$$

Where, R is drying rate at time θ, g water lost/g of bone dry matter/h

WML = Initial weight of sample – Weight of sample after time θ, g
DM = dry matter, g

Diffusivity
In drying, diffusivity is used to indicate the flow of moisture out of material. In the falling rate period of drying, moisture is transferred mainly by molecular diffusion. Diffusivity is influenced by shrinkage, case hardening during drying, moisture content and temperature of material. In the falling rate period of drying, water is transported by diffusion from interior to surface of material. The falling rate period of drying of biological materials is best described by Fick's diffusion model as

$$\frac{\partial M}{\partial t} = D\frac{\partial^2 M}{\partial r^2} \qquad \text{... (4)}$$

Where, D = Diffusion coefficient, m^2 /s, M is the moisture content, R is the distance from the center line and t is the time elapse during the drying. Assuming uniform initial moisture distribution and negligible external resistance, the solution of above mentioned equation as proposed by Crank (1975) [2] is

$$\frac{M - M_e}{M_o - M_e} = \frac{6}{\pi^2}\sum_{n=1}^{\infty}\frac{1}{(n)^2}\exp\left[-(n)^2\pi^2\frac{Dt}{r_s^2}\right] \qquad \text{... (5)}$$

Neglecting the higher values of n, that is n>1

Then, $$MR = \frac{M - M_e}{M_o - M_e} = \frac{6}{\pi^2}\exp\left[-\pi^2\frac{Dt}{r_s^2}\right] \qquad \text{... (6)}$$

Where, *MR* = Moisture ratio, dimensionless
M_e = Equilibrium moisture content, g water / g dry matter
M_o = Initial moisture content, g water/ g dry matter
M = Moisture content at time (t), g water / g dry matter
Rs = Radius of sphere, m
t = Time, s
D = Diffusion coefficient, m^2 /s

Rearranging the above mentioned Eq. as

$$\ln(MR) = \ln\left[\frac{6}{\pi^2}\right] - \left[\pi^2\frac{Dt}{r_s^2}\right] \qquad \text{... (7)}$$

or

$$\ln(MR) = -0.4977 - \left[\pi^2\frac{Dt}{r_s^2}\right] \qquad \text{... (8)}$$

If the ln (MR) versus time is plotted, then it will result in a straight line and the slope of the straight line can be used to predict the diffusivity.

Result and Discussion
Properties of Kair
The average size of two categories of kair was found 6.022 and 9.275 mm respectively. The sphericity of green immature kair of 6.022 mm and 9.275 mm were observed as 0.92 and 0.96 respectively. The average initial moisture content of untreated kair on wet basis was found to be 69%.

Moisture content
Variation in moisture content with drying time of green immature kair is shown in Fig. 1 and 2. It took 30, 23 and 18 hours of drying for reducing the moisture content from 222.58% to 10.97, 10.97 and 10.65 percent for drying air temperature of 45°, 50° and 55 ^{0}C respectively. It can also be seen that moisture content reduced at a faster rate in first two hrs and then at a slower rate for all three temperatures.

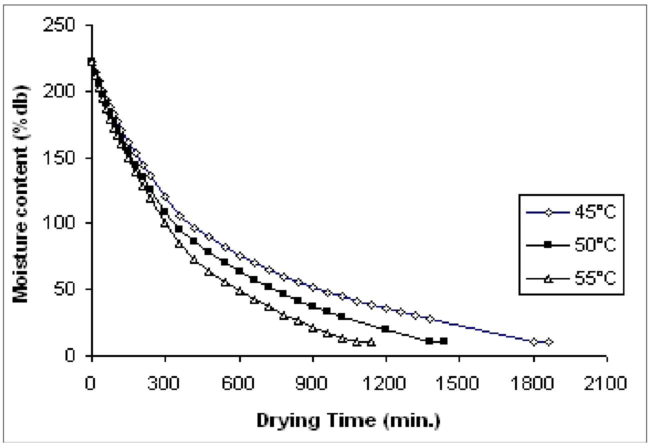

Fig 1: Effect of drying time on moisture content at different drying temperatures for 6.022 mm

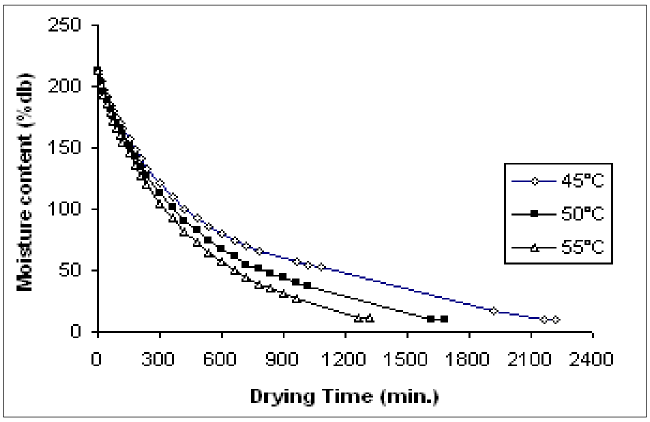

Fig 2: Effect of drying time on moisture content at different drying temperatures for 9.275 mm

Drying rate curve
It was found that the complete drying of pretreated green immature kair took place in falling rate period and the constant rate period was completely absent in the all air drying experiments. It was also implicit from the curve that drying rate was higher in initial period of drying and subsequently it reduced as decrement in moisture content took place. The maximum drying rate of 32.26, 38.71 and 45.16 g water/g BDM/h were observed at 45°, 50° and 55 °C temperatures respectively. It revels that at commencement of the air drying experiment when moisture content of the pretreated green immature kair was quite high and there was less résistance to the moisture flow. The effect of moisture content on drying rate at different drying temperatures for 6.022 and 9.275 mm is shown is Fig. 3 and 4.

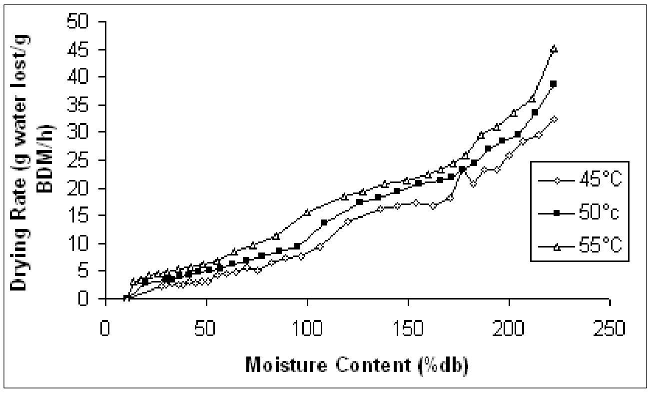

Fig 3: Effect of moisture content on drying rate at different drying temperatures for 6.022 mm

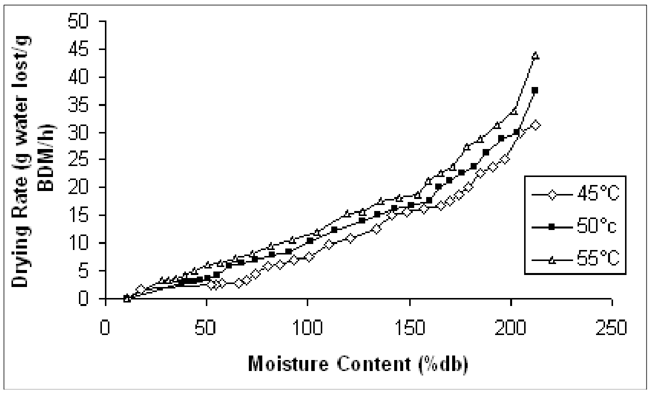

Fig 4: Effect of moisture content on drying rate at different drying temperatures for 9.275 mm

Diffusivity during convective air drying of green immature pretreated kair
The diffusivity of water in the green immature pretreated kair during convective air-drying was calculated by the method of slope as explained in materials and method. The effect of dehydration temperature on variation in ln (MR) at different drying time during subsequent air drying of green immature pretreated kair of 6.022 mm and 9.275 mm size are shown in Fig. 5 and 6. It can be observed from these figures that ln (MR) versus time followed a straight line relationship with negative slope for all temperatures under study. It is found that the diffusivity of water molecules during the air drying of green immature pretreated kair of 6.022mm and 9.275 mm size varied from 3.68 x10^{-8} to 1.21 x10 $^{-7}$ m^2/s. It is also observed from the Table 1 that the values of diffusivity obtained from the drying experiments did not vary much for 45°, 50° and 55 °C temperatures for green immature pretreated kair of 6.022 and 9.275 mm size.

Table 1: Effect of drying temperature and size of sample on diffusion coefficient

Size (mm)	Temp. (°C)	Equation developed	R^2 values	Diffusion coefficient (m^2/s)
6.022	45	y = -0.0018x - 0.074	0.997	3.68 x10^{-8}
	50	y = -0.0024x - 0.0153	0.9941	4.91 x10^{-8}
	55	y = -0.0034x + 0.1037	0.967	6.95 x10^{-8}
9.275	45	y = -0.0016x - 0.0583	0.9854	7.76 x10 $^{-8}$
	50	y = -0.002x - 0.0585	0.9979	9.70 x10 $^{-8}$
	55	y = -0.0025x - 0.0235	0.9991	1.21 x10 $^{-7}$

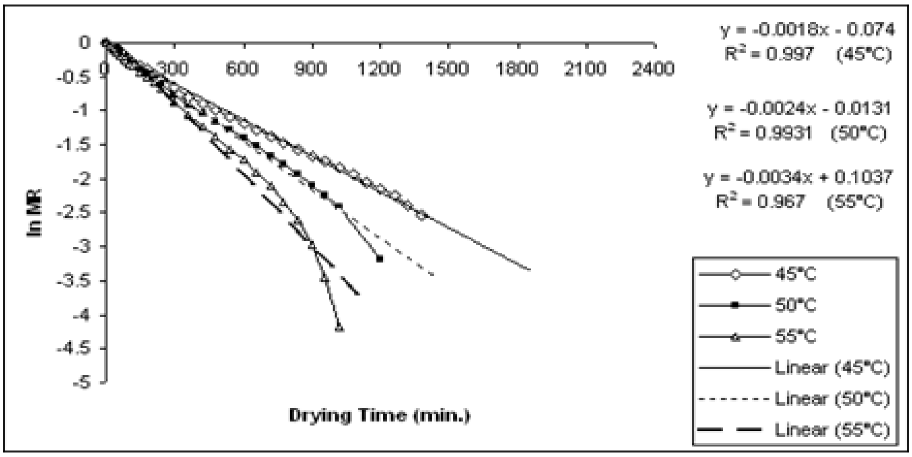

Fig 5: Effect of drying time on moisture ratio at different drying temperatures for 6.022 mm

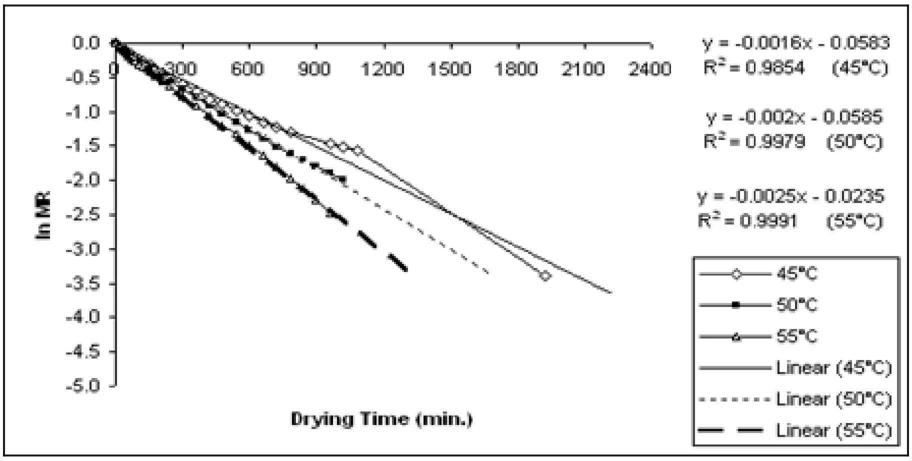

Fig 6: Effect of drying time on moisture ratio at different drying temperatures for 9.275 mm

Conclusion

The present study concludes that the drying of *kair* was carried out only in the falling rate stage which shows that the moisture removed from the product was governed by diffusion phenomenon. The drying time of *kair* decreases and the effective diffusivity increases as the air temperature was increased. The highest effective diffusion was found to be 1.21×10^{-7} m^2/s for a drying at temperature 55 °C of 9.275 mm sized kair. The lowest effective diffusion was 3.68×10^{-8} m^2/s for drying at temperature 45 °C of 6.022 mm sized kair.

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