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Study on drying kinetics of date palm fruits in greenhouse dryer

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Abstract
Date palm (*Phoenix dactylifera* L.) fruits are considered as a major source of carbohydrate which includes simple sugars like glucose, fructose, and sucrose. Date palm fruits contain about 60% moisture, therefore drying of fresh dates is necessary to extend its shelf life. Hence, drying characteristics of date palm fruits were studied using greenhouse dryer and compared the results with open sun drying. A gable shaped greenhouse with east-west orientation has been constructed with 4.5 m length and 3.0 m width. The height of the greenhouse is about 3.0 m approximately. The walls of the greenhouse were wrapped with UV resisted polyethylene sheet. In open sun drying the date palm fruits were directly exposed to solar radiations. The results showed that the time taken to dry date palm fruits in greenhouse dryer and open sun drying was 40 hours and 58 hours respectively.

Keywords: Drying kinetics, conventional drying, forced convection, shrinkage

Introduction
Date palm is one of the most important fruit crops in the arid regions of the Arabian Peninsula, North Africa, and the Middle East. They are the main income source and staple food for local populations in many countries in which they are cultivated, and have played significant roles in the economy, society, and environment of those countries (Chao and Krueger, 2007) [3].
Dates in India are mainly grown in the Kutch region of Gujarat with about 18847 ha area under cultivation and with a production of 173997 tonnes of fresh dates during the year 2016-17. The major problem with the dates produced in this region is that the maturation stage of dates coincides with the onset of monsoon in the month of June. The exposure of date fruits to rain results in fruit rot and spoilage which makes the fruits unable to consume as fresh dates. As per the statistics, up to 60% of the dates are spoiled due to these rains. In some cases, experts say that damage may exceed as high as a 100% in full loss of the crop. Therefore, dates are harvested prematurely before the onset of monsoon to prevent spoilage and marketed. The TSSs of these immature dates are not fully developed and hence these dates have low marketability. Considering the above facts, it is highly necessary to fill in the gap through some effective, viable and practical means. Hence, processing of these immature dates into value-added products could improve the marketability (Kulkarni *et al*., 2008) [7].
The moisture content of the fruit vary from 60% at the mature to about 25% at the dried stage and the safe moisture content for storage of date is between 24% and 25%. Therefore, drying of fresh dates is necessary because it contains high moisture (about 60%) which limits the shelf life (Falade and Abbo, 2007; Barreveld, 1993) [5, 2]. Conventional drying methods cause many adverse effects in plant materials, such as shrinkage, discoloration, and oxidation of vitamins etc. On the other hand, the use of traditional drying methods leads to high energy consumption. Common convective drying of agricultural products is associated with uneven product quality, low efficiency and relatively high operating costs (Mujumdar and Devahastin, 2008; Chen and Mujumdar, 2008; and Jangam *et al*., 2010) [4, 9, 6]. Therefore, one of the best solutions to overcome these negative effects is to use a low-temperature drying or to reduce the drying time by adopting novel drying techniques such as greenhouse drying. Hence, a study has been taken place to dry the date palm fruits in greenhouse dryer and to compare the drying kinetics of greenhouse dried date palm fruits with open sun-dried date palm fruits.

Materials and methods
Construction of a greenhouse dryer
A gable roof type greenhouse dryer of span 4.5 x 3.0 m was constructed in College of FPT & BE, AAU, Anand. The total height of the greenhouse was around 3.0 m. The structure was covered with UV stabilized polyethylene sheet. Air enters from the bottom of the greenhouse and gets heated inside the greenhouse due to solar radiations.

This hot air is used to dry the date palm which is placed in trays inside the greenhouse. Front and side views of the greenhouse dryer are shown in Fig.1 & 2 respectively.

Fig 1: Front view of greenhouse dryer

Fig 2: Side view of greenhouse dryer

Pretreatment of date palm fruits

Date palm fruits of red variety were procured from Regional Research Station (RRS), Anand Agricultural University, Anand. Before drying of agricultural produce, pre-treatment is done to achieve faster drying rate. So, date palm fruits were washed in tap water and blanched in water in stainless steel steam jacketed kettle at 96±1ºC for 15 min and then treated with potassium metabisulphite solution (500 ppm) for 10 min. The material to water ratio was maintained at 1:3. The blanched material was loaded on to aluminum trays at a rate of 1 to 1.5 kg of material per tray. The pretreated date palm fruits and the trays loaded with date palm fruits inside the greenhouse dryer are shown in Fig.3 & 4 respectively.

Fig 3: Pretreated date palm fruits

Fig 4: Trays loaded with date palm fruits inside the greenhouse dryer

Greenhouse drying

The total material loaded into greenhouse dryer was around 10 kg. The dryer was operated from 8.30 am to 5.30 pm for a period of 5 days to reduce the moisture content from 62% to 15%. The temperature and relative humidity were measured using the sensors fixed inside the greenhouse. After drying the dehydrated material was packed in flexible packaging material for further analysis.

Open sun drying

Open sun drying is usually practiced as a conventional technique for drying the agricultural produce. In this study, the drying kinetics of greenhouse dryer were compared with the drying kinetics of open sun drying method. Hence the pretreated sample was loaded in aluminum trays but was placed in the open environment for direct exposure of date palm fruits to sun rays as shown in Fig. 5. Similar to greenhouse drying, the temperature and relative humidity of outside environment were measured using the sensors.

Fig 5: Open sun drying of date palm fruits

Results and discussion

Temperature and relative humidity inside the greenhouse

Better drying conditions are achieved in the greenhouse dryer by maintaining a higher internal ambient as compared with external ambient temperature. The temperature and relative humidity inside the greenhouse were measured using RTD sensors. The temperature and relative humidity were found to be varied at different time periods. The air inside the greenhouse flows by natural convection mode only.

Variation of temperature inside the greenhouse

The temperature inside the greenhouse was recorded for every one hour time interval from 8:30 am to 5:30 pm from 15/6/2016 to 19/6/2018. The variation in temperature and relative humidity inside the greenhouse are shown in Fig.6 & 7 respectively.

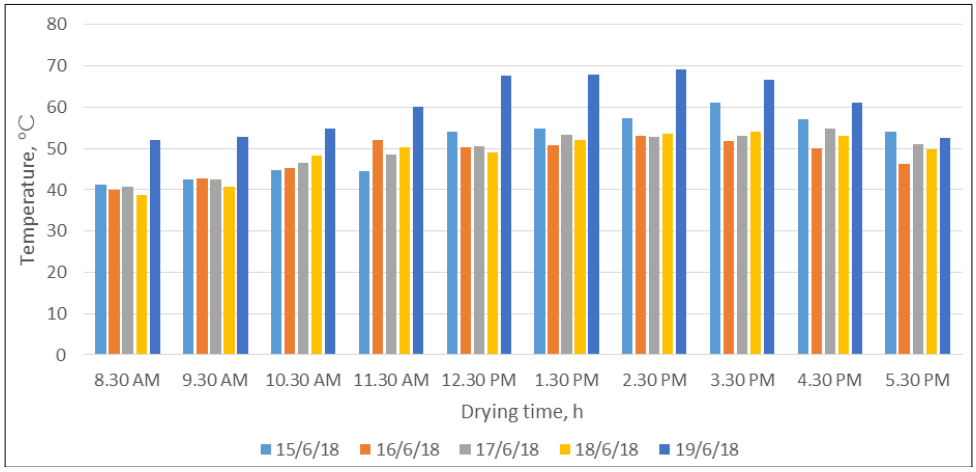

Fig 6: Temperature variation inside the greenhouse

From Fig.6, it is clear that on an average the temperature inside the greenhouse varied from 42.5ºC to 57.4ºC. Initially, the temperature inside the greenhouse was lower but as the time proceeds the temperature was found to be higher between 12:30 pm to 3:30 pm. After 3:30 pm the temperature inside the greenhouse was found lower. During the experimental period, the temperature recorded inside the greenhouse was almost similar for all five days.

Variation in relative humidity inside the greenhouse

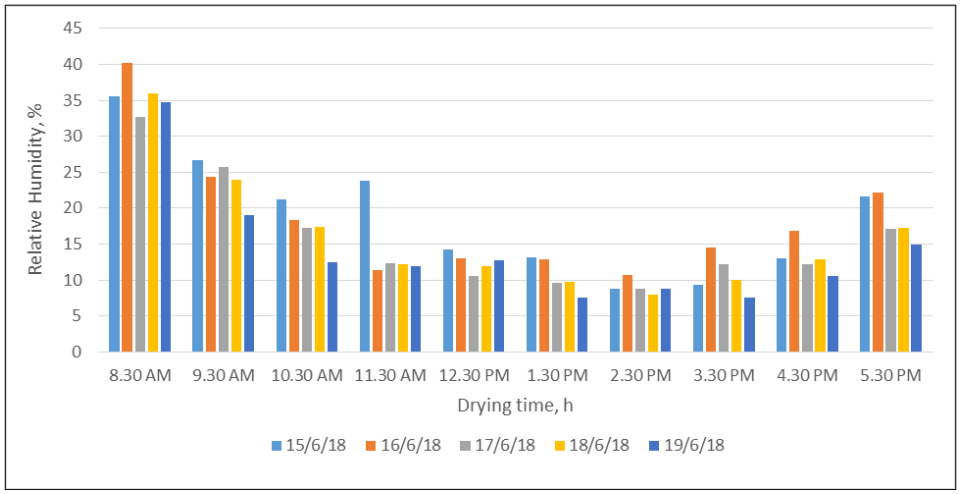

Fig 7: Relative humidity variation inside the greenhouse

From Fig.7, it is clear that initially when the temperature was lower around 8:30 am, relative humidity was found to be high. But as time proceeds, the temperature inside the greenhouse increases due to trapping of solar radiations under natural convection mode. Therefore, the relative humidity was found to be decreasing during the peak temperature hours i.e. from 12:30 pm to 3:30 pm. Similar results were observed by Rintu *et al*., (2017) [10] for temperature and relative humidity variation inside the greenhouse.

Drying kinetics of date palm fruits dried in greenhouse dryer

To establish the effect of drying air conditions inside the greenhouse on drying characteristics of date palm fruits, the moisture content versus drying rate are plotted as shown in Fig.8.

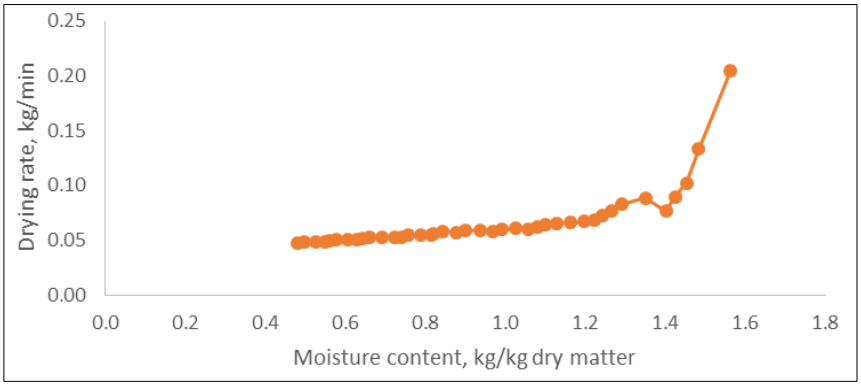

Fig 8: Variation in drying rate with moisture content

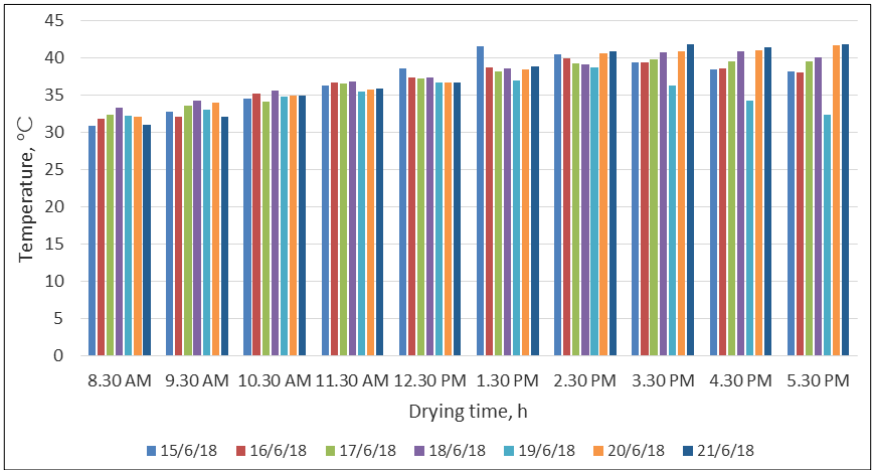

Fig 9: Variation in temperature in open sun drying of date palm fruits

It can be observed from Fig.9 that the temperature shows an increasing trend from 8:30 am to 2:30 pm. Further, the temperature starts decreasing slowly after 2:30 pm. On an average, the ambient temperature varied from 32ºC to 41ºC during the whole experimental period. The total time taken for drying of date palm fruits in open sun drying was seven days.

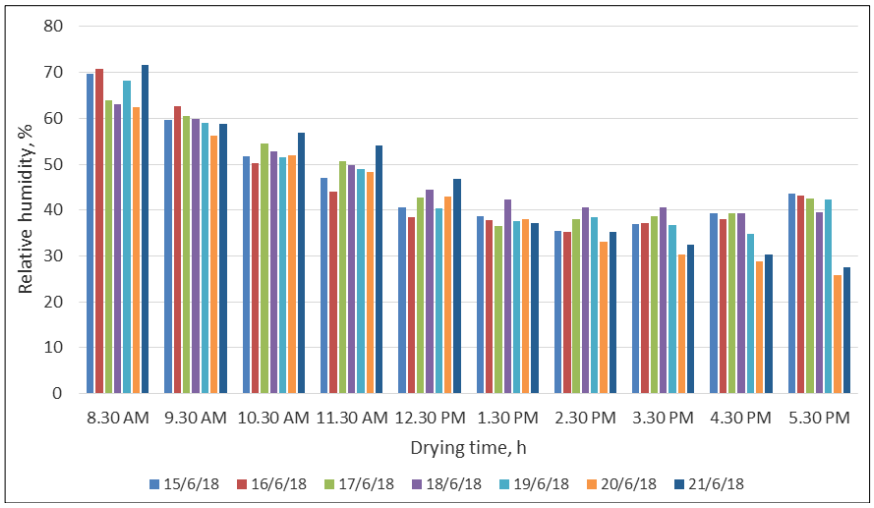

Fig. 10: Variation in relative humidity in open sun drying of date palm fruits

From Fig.10 it can be inferred that the relative humidity was found to be higher around 8:30 am but as the time proceeds the relative humidity followed a decreasing trend up to 4:30 pm and then increased due to decrease in temperature after 4:30 pm. On an average, the relative humidity varied from 35% to 67% during the whole duration of open sun drying of date palm fruits.

Drying kinetics of date palm fruits dried in open sun drying

To establish the effect of drying air conditions of open sun drying on drying characteristics of date palm fruits, the moisture content versus drying rate are plotted as shown in Fig. 11.

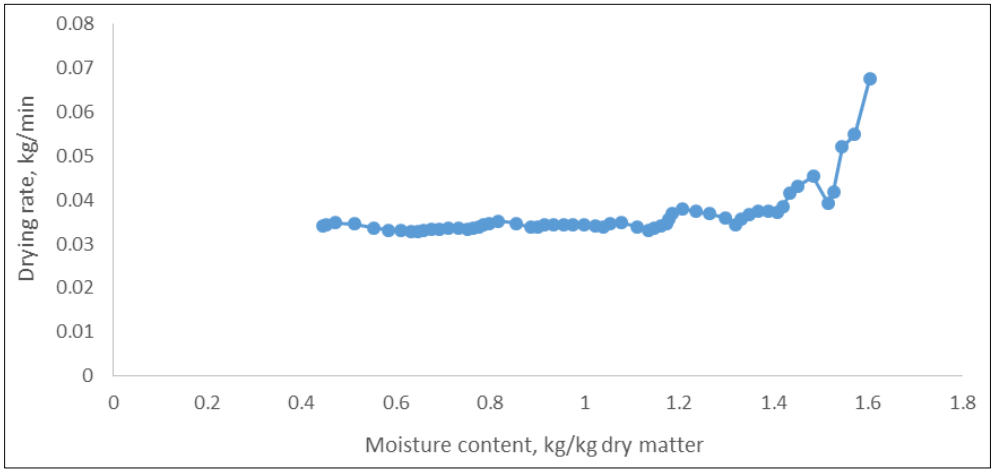

Fig 11: Variation in drying rate with moisture content

It can be seen from Fig. 11 that similar to greenhouse drying, there is no constant rate drying period and drying rate keeps falling with the moisture content of date palm fruits in almost linear manner throughout the drying period except in the last stage. Also, it can be inferred that initially, the availability of free moisture in the date palm fruits was high, hence drying rate was high (0.06 kg/min), whereas, in the later stages, the moisture migration from inside of the product to the surface was less and hence a less drying rate was observed. Similar results were observed by Abdelghani *et al*., (2007) [1] for their work on solar drying of date palm fruits.

Comparison of drying kinetics of date palm fruits in greenhouse drying and open sun drying

The variation of drying rate versus drying time in greenhouse drying as well as open sun drying is compared in Fig. 12.

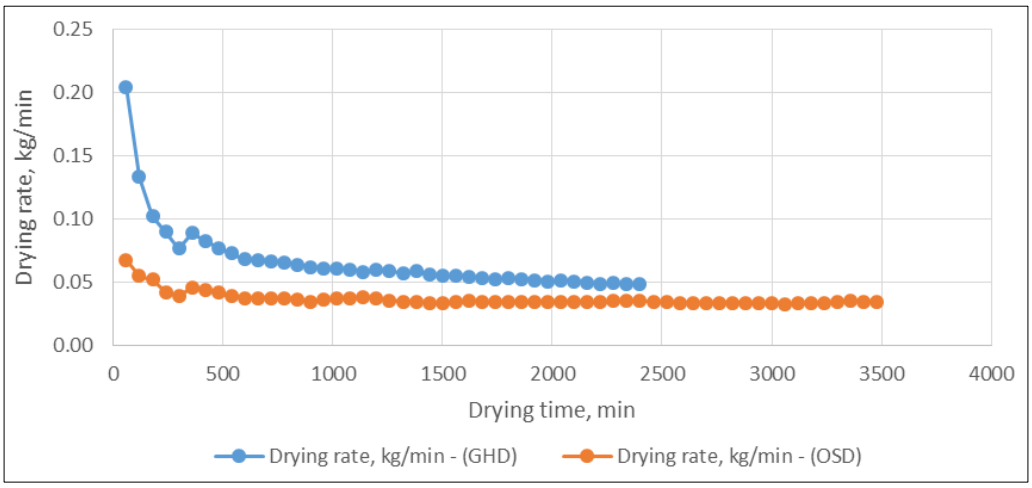

Fig. 12: Variation in drying rate with drying time

It can be observed from Fig.12 that the drying rate was much higher in greenhouse drying as compared to open sun drying. Time taken to dry the date palm fruits in greenhouse dryer was almost 5 working days i.e. 40 hours, whereas in the open sun drying it has taken 7 working days i.e. 58 hours to bring down moisture content from 62% to 15%. Initially, the drying rate in both the cases was high but as the time proceeds i.e. after 25 h the drying rate was found to be decreasing with time.

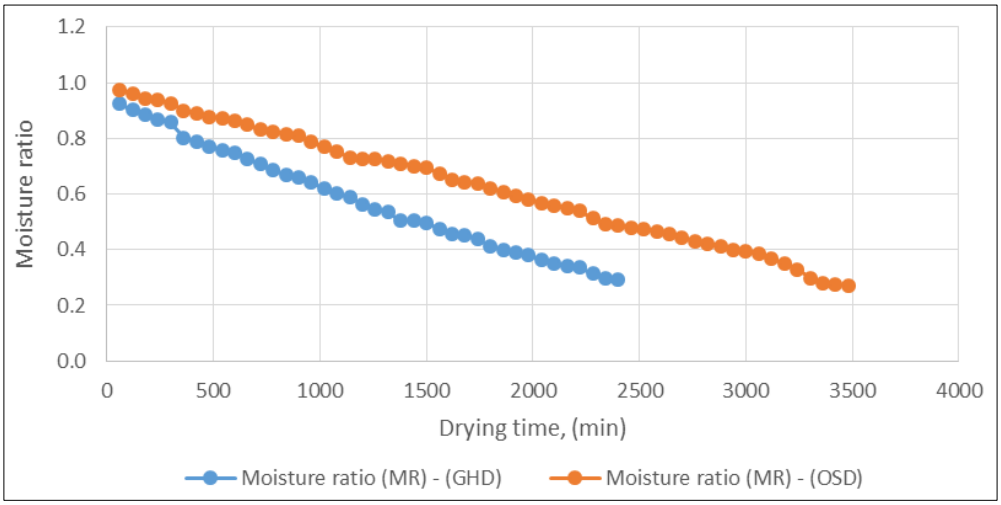

Fig. 13: Variation in moisture ratio with drying time

The variation in moisture ratio with respect to drying time is shown in Fig.13. It can be evident from the Fig.13 that the moisture ratio was found to be in decreasing trend for both greenhouse drying and open sun drying. Also, the desired moisture ratio of (0.3) was achieved in a short time in greenhouse drying as compared to open sun drying.

Shelf life of date palm fruits

The quality of dried date palm fruits in both methods of drying was observed and found that there is uniform drying of date palm fruits in greenhouse dryer compared with open sun drying. Also in open sun drying contamination of samples due to dust and insects were observed. During the storage period, the samples of open sun drying were found to be spoiled within 60 days whereas greenhouse dried samples have a shelf life of 90 days. Less shelf life in open sun drying is due to contamination and non-uniformity in moisture content of the samples.

Conclusions

Drying of date palm fruits is highly necessary to extend the shelf life of date palm fruits and also to enjoy its taste during off season too. During the study, date palm fruits were dried in greenhouse dryer and open sun drying. The drying kinetics

of date palm fruits in both the dryers were compared. The results showed that greenhouse drying has a faster drying rate with temperatures recorded greater than the ambient temperatures. The time taken to dry 10 kg of fresh date palm fruits in greenhouse dryer was two days less as compared to open sun drying. Also, greenhouse dried dates are of superior quality than open sun dried dates. Hence greenhouse drying can be adopted for drying of date palm fruits.

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