Drying Kinetics of Pear slices in Greenhouse solar dryer

ABSTRACT

An experimental study was performed to determine the drying characteristics of pear using greenhouse based solar dryer and under open sun with natural convection. Prior to drying, sliced pear samples were pre-treated: i) control inside dryer i.e. with no dip, ii) blanching, iii) soaking in 2% KMS (Potassium Metabisulphite) solution, iv) blanching and soaking in 1% KMS solution, v) control outside dryer i.e. with no dip. The experimental drying data of pear were fitted to five different mathematical models viz. Exponential, Generalized exponential, Page's, Logarithmic and Power law models, and drying rate constants and coefficient of models tested were determined by non-linear regression analysis. Among the various models tested to interpret the drying behaviour of pear, Page's model was selected which gave best statistical indices of coefficient of determination (R^2) and standard error of estimation (SEE) values.

Key words: Drying Kinetics, Pear, Solar Dryer, Pre-treatments

Introduction

Fruits and vegetables play an important role in human nutrition. These are vital source of essential minerals, vitamins and dietary fibre and supply complex carbohydrates and proteins (Salunkhe *et al.*, 1991). Fruit culture is the main source of economy of Jammu & Kashmir state, and it provides employment (direct/indirect) to more than five lakh families. Pear occupies important place after apple among fresh fruits of temperate nature, because of its overall good quality, flavour and juiciness. The fruits of the pear (*Pyrus communis* L.) are bell-shaped and can be green, yellow, brown, red, or any combination of these colours. This helpful fruit is high in minerals, vitamins, and potassium. This fruit is commonly found in temperate zones whose flavour is determined by the amount of sugar and/or organic acid in it as well as the volatile aromatic chemicals present. The pear is a highly valued fruit by customers because of its nutritional qualities, tasty flavour, and low calorie content. The pear varieties grown in the valley are Bartlett, Beurre-de-Amanlis, Citron-des-Carmes, Chinese sandy pear, Clapp's-favourite, 'd' Anjou' and Vicar of Winfield. Among all of these varieties, Bartlett occupies major area under its cultivation and is considered an excellent commercial variety well suited to dessert, canning and drying purposes. Pear fruits are comparatively rich source of minerals. The value of different minerals found in mg per 100 g fruit pulp are calcium 8, phosphorus 15, copper 0.4 (Gopalan *et al.*, 1987). Pears have a short storage life due to higher respiration rate at all temperatures. The losses in fresh pear can be minimized by dehydration of pear halves.

Kashmir valley falls under temperate climatic condition, and there is no availability of local fruits and vegetables from November to April months. It is due to this fact that during winter season (November – April), fruits/vegetables could not be cultivated because of unfavourable temperature due to severe cold conditions. Therefore, there is a need for dehydrated fruits and vegetables so that their availability time can be extended.

Drying offers a possible outlet for some of the expected surplus pears as well as for certain grades/varieties that are not acceptable to canneries, due to excessive size, or slight deformity. Drying prolongs the shelf life of fruits and vegetables by lowering their moisture content and preventing chemical and biological deterioration. But during the drying process, several unfavourable physical and chemical changes, like discolouration, texture, and nutritional value, may also happen, which lowers consumer approval. In order to produce the finished product, drying procedures often occur at the end and following other operations. One of the most crucial techniques for keeping fruits on a wide scale is drying them, as this allows the items to be kept for an extended amount of time without going bad (Guine, 2006; Phuon *et al.*, 2021). After food is dried, its volume and weight can be reduced to make packaging, storing, and shipping easier. Thus, it is essential to dry food and agricultural produce using the most up-to-date and effective techniques (Defraeye & Radu, 2018).

For drying, ripe pears are peeled, cut into halves and cored, they are then sulphured for 15-20 min. and dried at (60-63 ^{0}C) for 15-24 hours. The yield varies from 14 to 19 percent (Lal *et al.*, 1960). McBean (1969) optimized various pre-drying treatments for prevention of enzymatic browning, improved flavour and textural properties of William pear. Dried pear of improved quality will offer an excellent snack item with potential nutritional benefits and values addition to the promising entrepreneurs. Sun drying of 'd' Anjou' pears are practiced in Charar-e-Sharief area of Kashmir valley traditionally, but the product quality is inferior due to discolouration and microbial contamination (Mir, 1993). Mir, 1993 reported that use of potassium metabisulphite and citric acid dip treatments before drying improved dried product quality of 'd' Anjou' pears and prevented microbial spoilage. The product was appealing in colour and appearance upto more than one year.

Simulation models are helpful in designing new or in improving existing drying systems or for the control of the drying operation, optimization of the drying process and the description of the entire drying behaviour. Drying kinetics are influenced by the type of dryer, the drying conditions, and the properties of the item to be dried. For the purpose of designing, optimizing, and improving the quality of products, the optimal drying conditions are crucial, and this is where the drying kinetics models come into play (Giri & Prasad, 2007). Therefore, it is crucial to research the kinetics model of each unique product in order to understand the drying behaviour of fruits and vegetables. The drying kinetics of materials may be described completely using their transport properties (thermal conductivity, thermal diffusivity, moisture diffusivity, and interface heat and mass transfer coefficients) together with these of the drying medium (Vagenas & Karathanos, 1993; Togrul & Pehlivan, 2004). Azeez et al. (2019) examined the tomato slice drying process (at temperatures of 30–120 ^{0}C over 30 and 60 min) and found that the Page model (R^2 = 0.9986) was the most accurate model for predicting when tomato slices will dry. Proietti et al. (2018) looked at the kinetics of pear drying at 45–55 degrees Celsius using convective drying. They claimed that a more even dispersion of water in the pear tissues and a quicker drying rate with associated energy savings were achieved at 55°C. Their moisture ratio experiment data during drying was accurately anticipated by the diffusion model. In the case of food drying, the drying constant K is used instead of transport properties. The drying constant combines all the transport properties and may be defined by the thin layer equation. Thin layer equations describe the drying phenomena in a unified way, regardless of the controlling mechanism. They have been used to estimate drying times of several products and to generalise drying curves. In the development of thin layer drying models for agricultural products, generally the moisture content of the material at any time after it has been subjected to a constant relative humidity and temperature conditions is measured and correlated to the drying parameters (Midilli *et al*., 2002). The drying kinetics is greatly affected by air velocity, air temperature, material thickness, and etc. (Akpinar & Bicer, 2005; Erenturk & Erenturk, 2007). The present study was undertaken to study the effects of pre-treatment on drying characteristics of pear in greenhouse type solar dryer and to evaluate the various drying models for their suitability in characterizing the drying behaviour of pear.

MATERIALS AND METHODS

Experimental Procedure

The pear (variety: Vicar of Winfield) was procured from the University farm for conducting the experiments during September – October 2008 before the onset of winter (available between August to October months in the Kashmir valley). The medium size pear sample from single tree was undertaken in the experimental study. The sample was prepared by cutting the pear into six parts lengthwise by using a stainless-steel knife and seed was discarded. It was kept in mind to select approximately equal size of pears for sample preparation without any physical defect. Five samples were prepared for all the treatments *viz.* (i) control inside dryer (T1), (ii) blanched (T2) i.e. steam blanching for 4 minutes, (iii) soaking in 2% KMS (Potassium Metabisulphite) solution (T3) i.e. sulphitation for 60 minutes, (iv) blanched samples soaked in 1% KMS solution (T4) i.e. both Steam Blanching (4 minutes) and Sulphitation for 60 minutes and (v) control outside dryer (T5). Untreated samples were taken as control. The temperature varied from 23 to 27 ^{0}C in the laboratory where the sample fruit was kept and prepared for the different pre-treatments.

Pre-treatments: For blanching the samples, water was boiled in a sufficiently large pot, at neck of which cotton cloth was wrapped for holding the cut samples of pear over it. Steam or vapour produced in this way was allowed to cross through the cut samples of pear for 4 minutes. For blanched +1% KMS dip treatment (T4), the steam blanched samples were further dipped into a 1% KMS solution for 60 minutes in which solid to syrup ratio was kept as 1:5 to ensure the exposure to each piece of pear with the solution. The same procedure was followed for 2% KMS dip treatment (T3) in which freshly prepared samples were dipped in the solution without blanching for 60 minutes.

Drying: The different pre-treated samples were spread uniformly on trays and placed inside the dryer (Plate 1) as well outside of it as control outside dryer sample (T5). The drying of pears took place over eight trays placed inside the dryer (5.0 m long x 4.0 m wide). The tray tables consisted of angle iron structures with 0.9 m high and 0.78 m^2 each in area (1.3 m long x 0.6 m wide), over which a nylon net (25 µ) was fixed. Throughout the drying experiment, the temperature and relative humidity of the drying chamber as well the outside was recorded with the help of digital hygro-thermometer (Make: Mextech J411TH). The weight of the samples was recorded at pre-determined time intervals with the help of digital balance. The consequent weight reduction of the samples were recorded and converted into moisture content on dry basis for further analysis.

Plate 1: Greenhouse type solar multi-tier dryer

Moisture Ratio:

The moisture content data during drying were converted into moisture ratio and expressed by the following equation (Hayaloglu et al., 2007):

$$MR = \frac{M - M_e}{M_0 - M_e} \quad \text{….. (1)}$$

where, MR is the moisture ratio; M_0 is the initial moisture content in % d.b. (i.e. at zero time); M is the moisture content at time t in % d.b.; M_e is the equilibrium moisture content in % d.b.

The moisture ratios at different time intervals were calculated by using equation (1) to study the drying characteristics of pear slices.

Drying Models

Since the moisture ratio curve can better explain the drying behaviour than that of moisture content curve, as the initial was one (unity) in each of the experiment. These moisture ratio values were used to predict the drying model for blanched and blanched plus soaked samples of pear slices. The following models were tried to describe the drying characteristics of pear slices.

Table 1. Models used for fitting experimental data of MR

Model name	Model
Exponential model	MR = e^{-Kt}
Generalized exponential model	MR = Ae^{-Kt}
Page's model	MR = $e^{-Kt^{n}}$
Logarithmic model	MR = a + b ln (t)
Power law model	MR = At^{B}

These models were fitted in the experimental data in their linearized form using regression technique (using NLREG ver. 6.2). The comparison of the applicability of all five models was done on the basis of coefficient of determination (R^2) and standard error of estimation (SEE).

RESULTS AND DISCUSSION

The mean ambient temperature and relative humidity with the corresponding temperature and relative humidity inside the drier at different hours during the period of experimentation (September – October 2008) are presented in Figure 1. The polyhouse drying was observed to be quicker than in the open condition. This is due to the 'greenhouse effect' phenomenon observed inside the greenhouse solar dryer in which the entrapped solar radiation during daytime enhances the temperature. The inside temperature of dryer was constantly observed to be higher than the ambient by a difference of maximum and minimum of about 23.9 ^{0}C & 5.4 ^{0}C respectively. The maximum temperature inside was observed to be 54.5 ^{0}C in dryer. This is because the dryer being based on the greenhouse effect and with trapping of the high intensity solar radiation resulting in a subsequent increase in temperature.

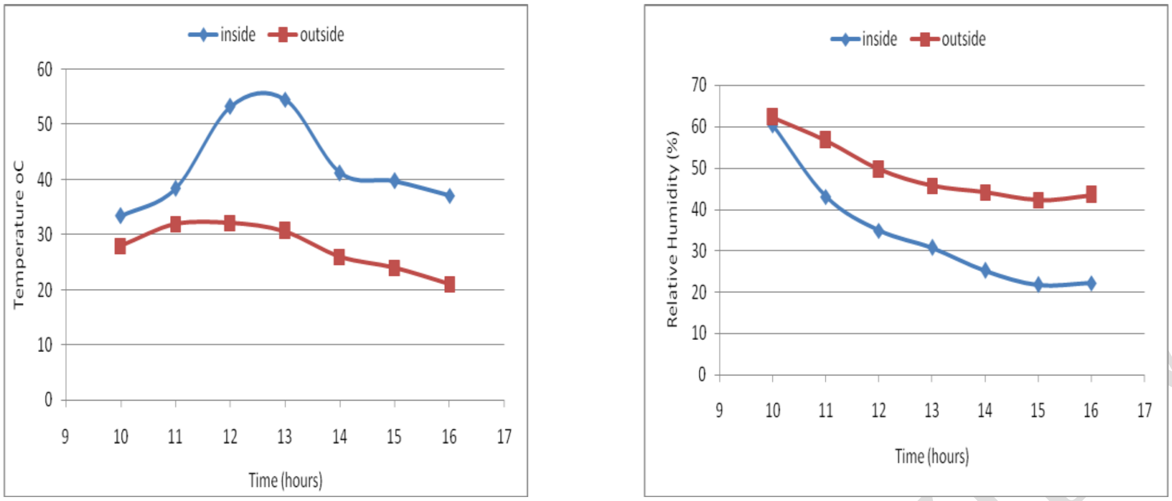

Fig. 1: Average temperature and relative humidity recorded in open sun and inside greenhouse solar dryer during the period of experimentation

Drying Characteristics: In order to characterize the drying characteristics of pear which comes under category of high moisture foods, the moisture content (% d.b.) was estimated at different drying time. The corresponding drying rate as well as moisture ratio was also determined with respect to time and plotted. The plotting of the curves for different treatments was grouped as T1, T2 and T5 in First group and then T1, T3 and T4 in Second group. The grouping of the curves was done to access the comparison between different pre-treatments upon drying time and rate.

Pear Drying: The initial moisture content of pear for T1, T2, T3, T4 and T5 was found to be 614.286, 737.143, 678.331, 610.0 and 565.142 % d.b. respectively by using hot air oven method as discussed in Ranganna (1986). The moisture content curves for drying of pear with respect to time are as follows:

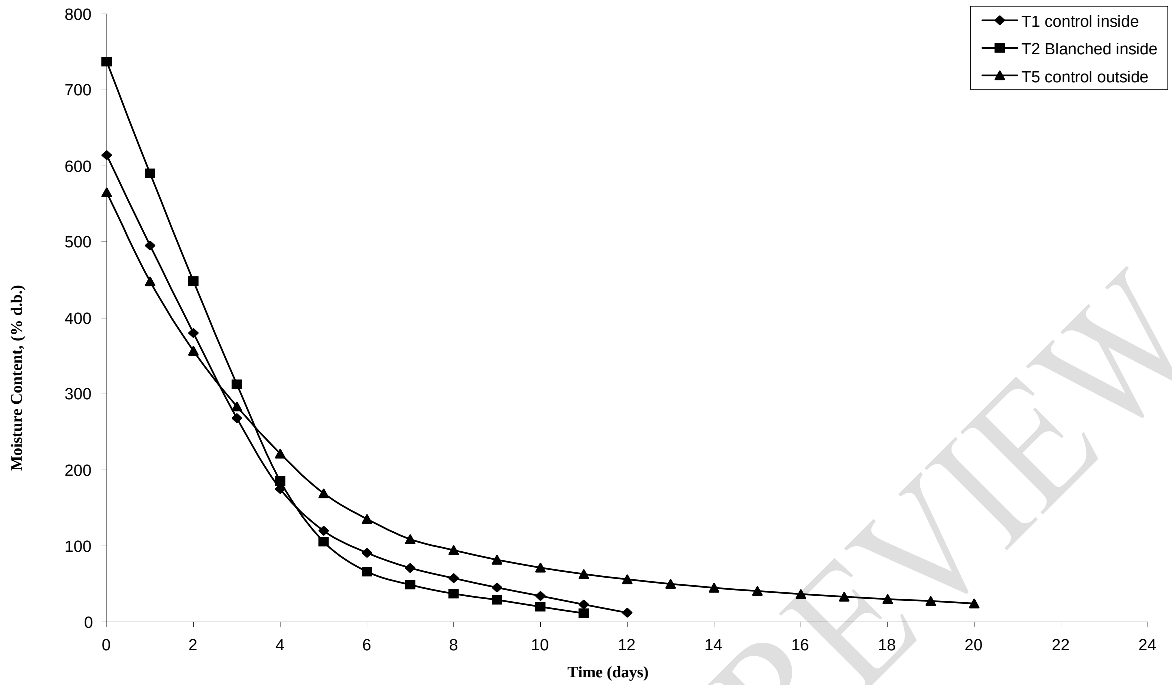

Fig. 2(i): Effect of moisture content with time of Drying for T1, T2 and T5 treatments of pear

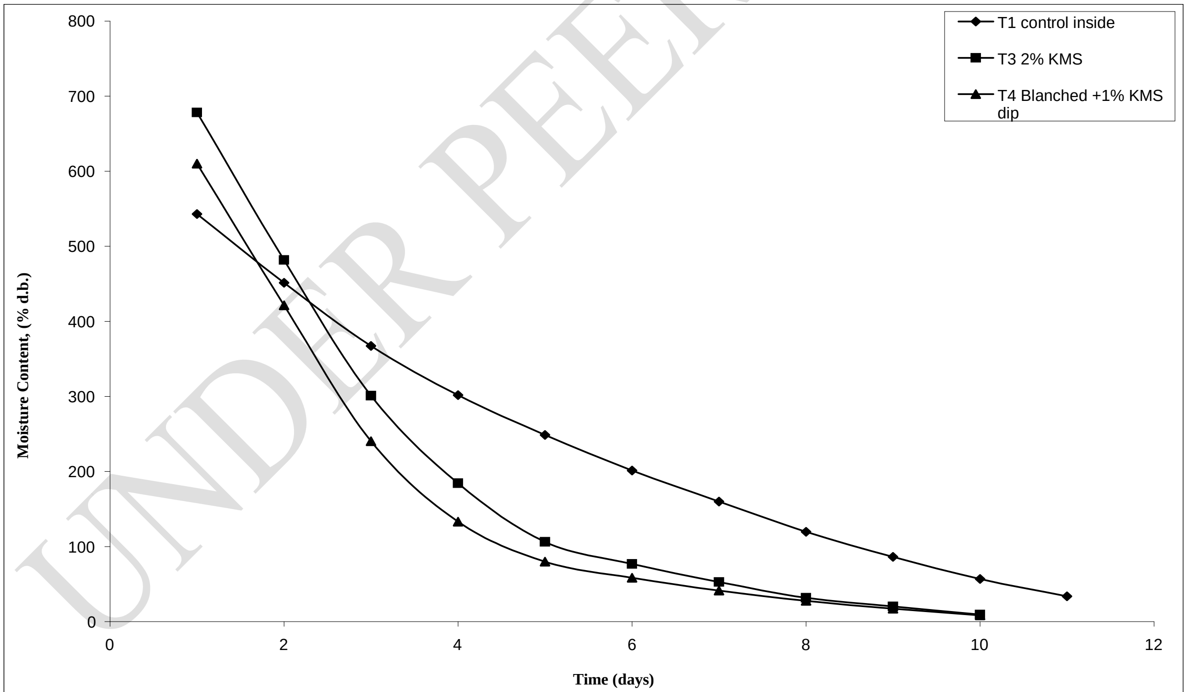

Fig. 2(ii): Effect of moisture content with time of Drying for T1, T3 and T4 treatments of pear

In Fig. 2(i) as shown above, the moisture content curve for control outside dryer (T5) was above the others, while its initial moisture content was lower than the others. It clearly illustrates that the sample kept outside the dryer was found to take longer duration for drying as compared to samples inside the dryer. Further from Fig. 2(i) and 2(ii), it was found that the moisture reduction in blanched samples (T2) was higher as compared to the control samples inside the dryer. Also it takes much lesser time to loose moisture up to safe level of storage as compared to control outside dryer samples (T5). Fig. 2(ii) shows that the rate of moisture removal was slowest in case of control inside dryer (T1) and highest for blanched +1% KMS dip samples (T4). All these three samples namely T1, T3, and T4 takes almost same time to come to the safe level of moisture but the rate of moisture removal was different for all.

Drying Rate

For further analyzing the moisture removal rate, the drying rate curves were prepared with respect to average time of drying. Drying rate (dm/dt) was calculated for each interval of time and plotted against average time.

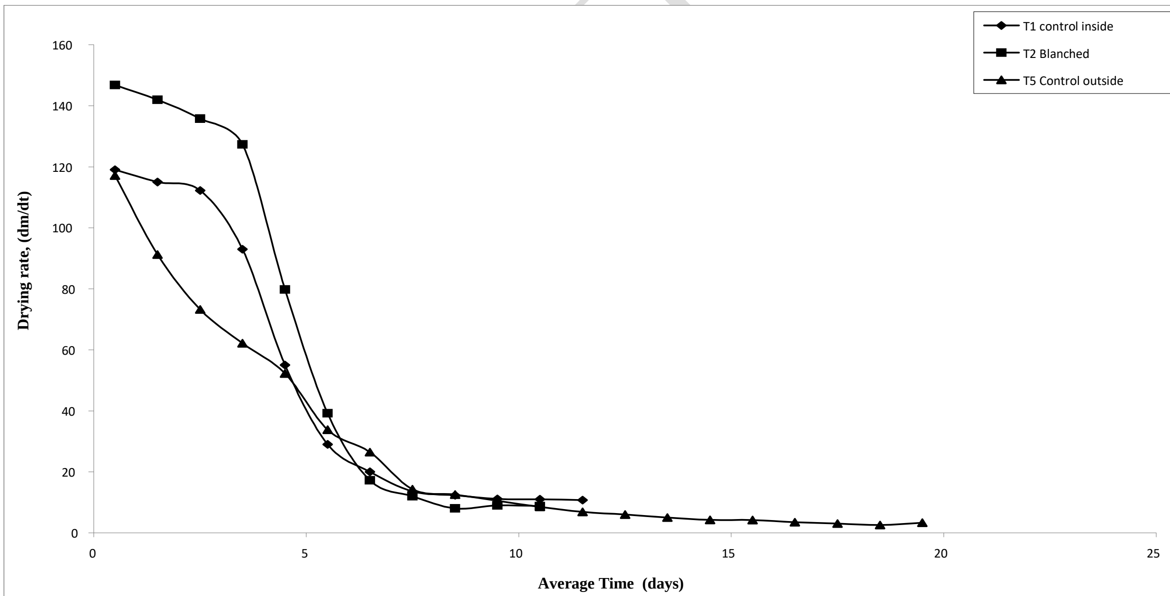

Fig. 3(i): Effect of drying rate with average time for T1, T2 and T5 treatments of pear.

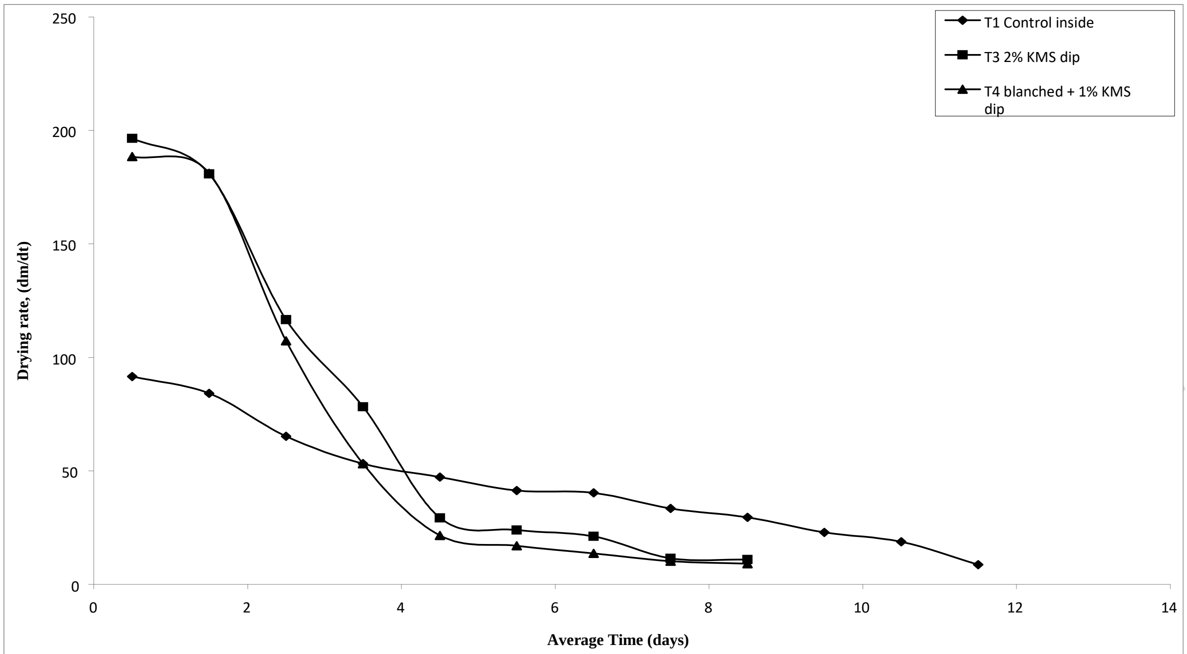

Fig. 3(ii): Effect of drying rate with average time for T1, T3 and T4 treatments of pear.

The drying rate curves as shown in Fig. 3(i) and 3(ii) shows that the initial rate of moisture removal was constant and afterward it reduces drastically and then the curves were almost asymptotic to the time axis. The rate of drying was found to be highest in case of T2 in First group of curves and T3 in case of Second group of curves. The drying rate was almost constant in both the treatment namely T3 and T4. The rate was observed slowest for control outside dryer (T5) and highest for T3. The dried samples' increased vapour pressure with rising temperatures and allowed moisture to migrate to the product surface more quickly, which cut down on the drying time. According to the graphs shown in Fig. 3, it can be said that in the initial minutes of drying, the MC reduces more quickly at the dryer's higher air temperature, which is consistent with the findings of other researchers (Li, Chen, et al., 2021; Li, Li, et al., 2021; Okonkwo et al., 2021; Zhao et al., 2021).

Moisture ratio

Since initial moisture content was different for all samples so it was difficult to make a comparative assesment of different treatments over moisture removal. The initial value of moisture ratio values for all the samples was always one inspite of actual value of initial moisture content, so it provide a better opportunity to make a comparative assessment. The moisture ratio curves was again plotted in the same groupping of experiments as follows:

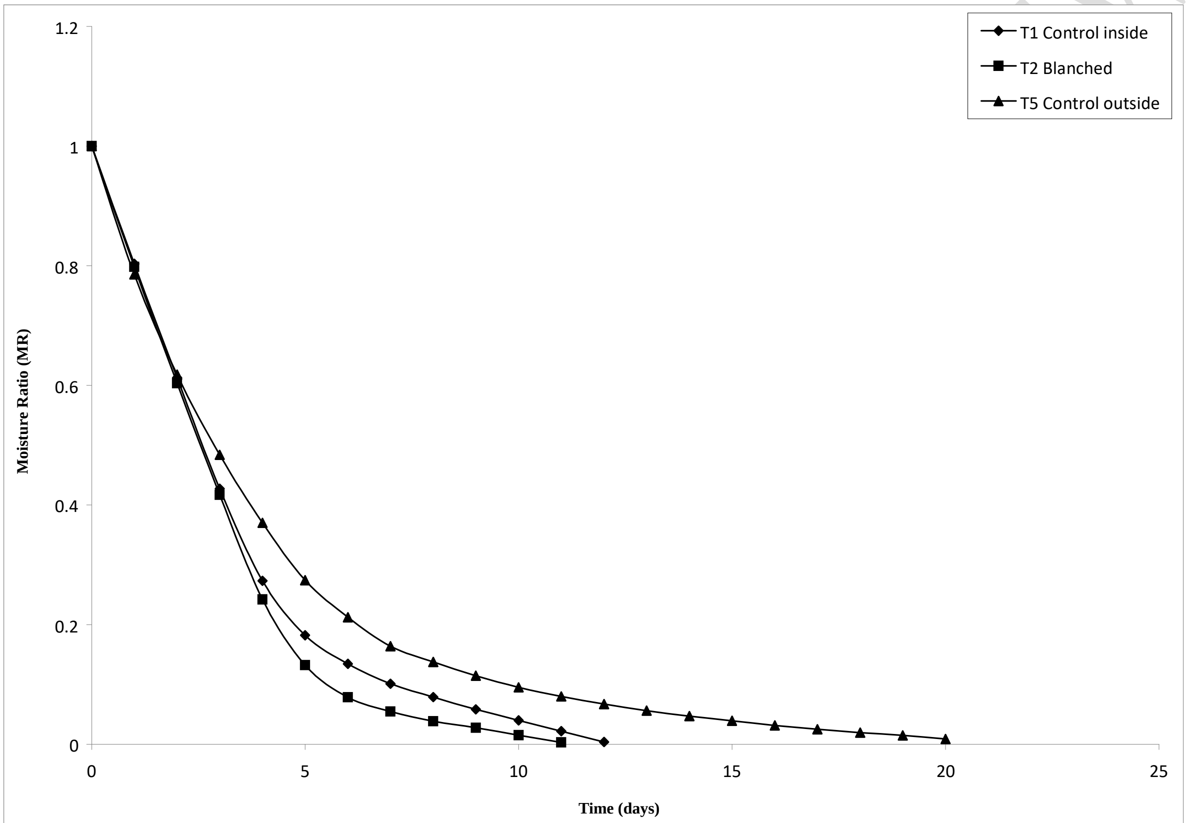

Fig. 4(i): Effect of moisture ratio with time for T1, T2 and T5 treatments of pear.

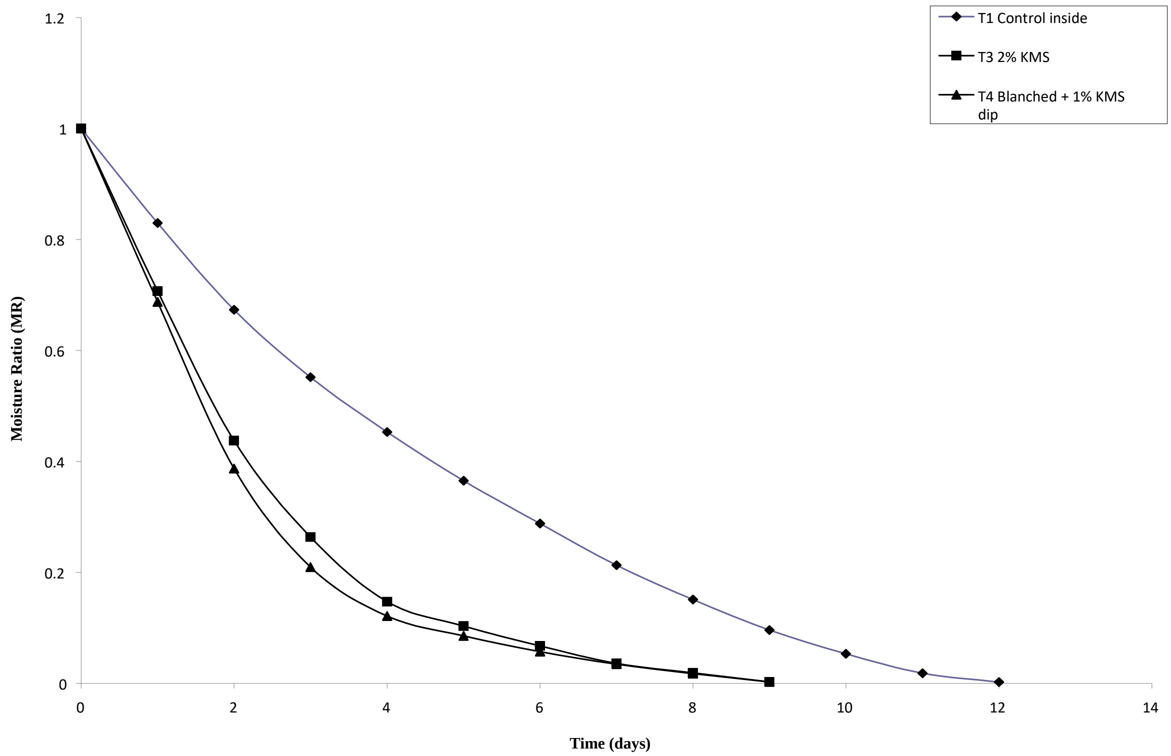

Fig. 4(ii): Effect of moisture ratio with time for T1, T3 and T4 treatments of pear.

From the moisture ratio curves as above in Fig. 4(i) and 4(ii), it is clear that the moisture removal for blanched sample (T2) was highest and it takes lowest time to dry upto safe level of moisture in the first group of curves, whereas the control outside dryer sample (T5) was taking longest time to dry and the rate of removal of moisture was also found to be lowest in this case. The control inside dryer (T1) was in between these two in terms of moisture removal and time of drying.

In the next group of curves as shown in Fig. 4(ii), control inside dryer sample (T1) was taking longest time to dry and the rate of moisture removal was also slowest among the three samples in this group. Rest of the two different pre-treated samples namely T3 and T4 was found to be almost same in terms of drying time as well as rate of moisture removal.

It is apparent that moisture content decreases continuously with drying time. Curves of moisture ratio versus drying time for drying pear showed that moisture ratio of pear reduced exponentially as the drying time increased. In case of pear drying, constant rate of drying was found to be dominating up to initial two days and then afterward falling rate was dominant. In the falling rate period, the material surface was no longer saturated with water and drying rate was controlled by diffusion of moisture from the interior of solid to the surface (Diamante & Munro, 1993).

Modelling of Pear drying curves

The moisture ratio data of pear slices dried under different pre-treatments were fitted into drying models listed in Table 1. The model constant along with detailed statistical indices including coefficient of determination (R^2) and standard error of estimation (S.E.E.) are summarised in Table 2. In all the cases, the values of R^2 were greater than 0.90 indicating a good fit (Erenturk *et al*., 2004). The Page's model resulted in comparatively higher R^2 values (0.9984**)** and lower values of SEE (0.013317). Hence, the Page's model could be considered better to represent the drying behaviour of pear slices under different pre-treatments. The Page's model has been successfully applied by several researchers to the drying of high moisture foods, such as parboiled rice, sugarcane baggase, peas and potato cubes. Goyal *et al*., (2006) found suitability of Page's model under tunnel drying of mango slices.

Table 2. Values of model constant and statistical parameters

Models		**T1**	**T2**	**T3**	**T4**	**T5**	**Average**
Exponential	R^2	0.9895	0.9783	0.9947	0.9937	0.9984	0.99092
	SEE	0.03338	0.050472	0.024643	0.026585	0.011065	0.029229
	k	0.302118	0.331553	0.431722	0.476839	0.245651	0.357577
Generalized Exponential	R^2	0.9919	0.9824	0.9955	0.9945	0.9984	0.99254
	SEE	0.030657	0.047756	0.023975	0.026439	0.011353	0.028036
	A	1.045863	1.060989	0.023975	1.025457	0.999707	0.831198
	k	0.3149	0.349138	0.441998	0.487635	0.245579	0.36785
Page's	R^2	0.9979	0.9985	0.9992	0.9979	0.9985	0.9984
	SEE	0.015454	0.013813	0.009841	0.016502	0.010976	0.013317
	k	0.223723	0.200331	0.361782	0.405463	0.25393	0.289046
	n	1.21933	1.392193	1.169957	1.174858	0.979384	1.187144
Logarithmic	R^2	0.9737	0.9621	0.9699	0.9457	0.9641	0.9631
	SEE	0.043727	0.055632	0.043769	0.056264	0.042684	0.048415
	a	0.786866	0.786631	0.658136	0.612404	0.742954	0.717398
	b	-0.33553	-0.35669	-0.32325	-0.30524	-0.26489	-0.31712
Power law	R^2	0.9083	0.8887	0.9483	0.9679	0.9086	0.92436
	SEE	0.081627	0.095294	0.057366	0.043216	0.068105	0.069121
	a	0.880181	0.874614	0.741663	0.712228	0.885346	0.818806
	b	0.880181	-1.01178	-1.125	-1.2158	-0.8401	-0.6625

Abbreviation: R^2: coefficient of determination; SEE: Standard error of estimation.

CONCLUSIONS

1. The temperature inside the greenhouse solar dryer was found to be approximately 15 ^{o}C higher than the ambient temperature throughout the experimentation.
2. The greenhouse solar dryer was found to be suitable for drying of high moisture foods like pear on the basis of time taken to dry upto safe moisture level.
3. In case of pear drying, constant rate of drying was found to be dominating up to initial two days and then afterward falling rate was dominant.
4. On the basis of moisture removal rate and drying time T4 (Blanched + 1% KMS dip) treatment was found to be best pre-treatment for pear drying.
5. Of all the five models tested, the Page's model showed the best fit with high values for the coefficient of determination, R^2 (0.9984) and low values for standard error of estimation, SEE (0.013317).

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