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Drying Kinetics of Indian Gooseberry/Anola (*Phyllanthus Emblica)* in A Tray Dryer

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ABSTRACT

Aonla or Indian gooseberry (*Phyllanthus emblica.)* is one of the most important traditional and underutilized fruits of Indian origin, having immense potential for cultivation on marginal or waste lands. Drying is the important post-harvest operation with the maximum losses occurring during this period. Fresh Indian gooseberry fruits were purchased from a local market and cut into desirable sizes. The tray dryer was used for drying of aonla slices at different temperatures of 50, 60 and 70 °C. The drying rate decreased continuously throughout the drying period. Constant rate period was absent and the drying process of aonla slices took place in falling rate period. Drying time decreased with increase in temperature. The time taken for tray dryer at 70 °C was very short for complete drying of aonla slices. Mathematical models were fitted to the experimental data and the performance of these models was evaluated by comparing the coefficient of determination (R^2), reduced chi-square ($\div^2$) and root mean squre error between the observed and predicted moisture ratio. Page model gave the best results for describing the drying kinetics of anola.

Keywords: *Indian gooseberry/Anola, Mathematical modelling, Tray drying,*

Indian gooseberry or aonla (*Phyllanthus emblica*.) is an important fruit crop of tropical and subtropical region of India and is known as a rich source of vitamin C. The fruit is commonly consumed as a healthy food in both fresh and various preserved forms such as pickles, dried fruits, and beverage products (Montri, 1998). Indian gooseberry tea is an alternative product to instant beverage powder and pasteurized juice. It is usually drunk for thirst-quenching. In Indian gooseberry tea processing, drying is the main thermal treatment which affects the quality of product such as its ascorbic acid content and color. This quality loss has an influence on the consumer satisfaction.

Aonla is a very rich source of vitamin C and other nutrients like polyphenols, pectin, iron, calcium and phosphorus, the fruit is a potent antioxidant, hypolipidemic, antibacterial, antiviral and antacid. However, like other tropical fruits, aonla has a short shelf life as fruit is sensitive to bruises, browning, desiccation and various post-harvest diseases. Moreover, the fresh aonla fruit is highly acidic and astringent; it is not as popular as table fruit. But, it has got great potential in processed forms. A number of products such as murabba, pickle, candy, juice, squash, jam, jelly, powder, etc., are prepared from aonla fruits (Tripathi et al, 1988).

Drying is a common technique for preservation of food and other products; including fruits and vegetables. The major advantage of drying food products is the reduction of moisture content to a safe level that allows extending the shelf life of dried products.

Drying method is one of the factors affecting the drying kinetics and quality of food products. Hot air drying is the most common mode of thermal dehydration. Drying is done to decrease the water activity of the products, inhibiting development of microorganisms and decreasing spoilage reactions to prolong the shelf life. Added advantages of dehydrated products include reduction in costs of packaging, storage and transportation due to reduced bulk and mass of the dried product (Okos et al*,* 1992). Further-more, products with low moisture contents may be stored for long duration at normal environmental conditions (Jayaraman and Gupta, 1995).

Several phenomena related to heat mass transfers are involved in the drying process. The kinetics of mass transfer (mainly water) during drying process depends on temperature, relative humidity, air flow rate, product thickness, load density and shape of product. The predominant mechanism in food drying process is diffusion of water from as well as within the food to the surface in contact with drying air. Modeling of the drying process is an efficient tool for prevention of product deterioration, energy consumption, equipment stress and product yields. Therefore, validated mathematical drying models, which enable more detailed explanation of drying and the necessary information was mentioned (Cenkowski et al*,* 1993; Waananen et al*,* 1993). Number of empirical equations has been proposed to describe drying process, modeling kinetics and design of drying systems. All these equations derive a direct relationship between change in moisture content and drying time, and are strongly related to Fick's second law of diffusion.

Thin layer equations are useful to understand the drying process in a simple way without considering the control mechanism. Such equations have been used to estimate drying time of many agricultural products and to generalize drying curves. Therefore, present work was undertaken to test different mathematical models for drying characteristic of Indian gooseberry or aonla slices under tray dryer at various conditions.

MATERIAL AND METHODS

Fresh Indian gooseberry fruits were purchased from a local market Madakasira, Anantapur, India. The samples were manually sliced. The initial and final moisture contents of samples were obtained by the standard method (AOAC, 1990).

Drying equipment

For drying of aonla slices, the HUMIDDRY Tray Dryer (TD-12-S-E), Electric heating model having 6 KW power and temperature 200°C was used. The tray drier, essentially a cabinet in to which material to be dried is placed on perforated stainless steel trays. Mainly consist of a thermostat, fan and temperature controller. The tray drier having 12 no.s of trays placed one above the other. The drying conditions are simply controlled and readily changed. The air velocity in the tray drier is 0.3 to 2.3 m/s.

Mathematical Modelling

The moisture ratio and drying rate during drying experiments calculated using the following equations:

$$Drying\ rate = \frac{M_{t+dt} - M_t}{d_t}$$

MR = exp (-kt)

$$\text{Moistutre ratio} = \frac{M - Me}{Mi - Me}$$

where, M_R, M, M_e, M_t and M_t+d_t are the moisture ratio, initial moisture content, equilibrium moisture content, moisture content at t and moisture content at t + dt (kg moisture/kg dry matter), respectively, t is drying time (min).

The air-drying curves were fitted with different mathematical modelsas given in **Table 1.** The regression analysis was performed using the STATISTICA 10.0 computer program. Non-linear regression, which used to evaluate goodness of fit of the mathematical models to the experimental data are coefficient of determination (R^2) and the reduced chi-square (÷^{2}), was used for data analysis. The higher value for $R^2$and the lower values for ÷2 and root mean square error analysis (RMSE) indicate the better fitness of model (Sarsavadia et al, 1999; Togrul and Pehlivan, 2003). These parameters were calculated as follows:

Chi-square: χ^2 =

$$\frac{\sum_{i=1}^{n} (MRexp,i - MRpre,i)^2}{N - n}$$

Root mean square error: RMSE =

$$\left[t/n \sum_{j=1}^{n} (MRexp,1 - MR\ pre,i)^2\right]^{½}$$

Where:

N = No. of observation,

$MR_{exp,i}$ = ith experimental data,

$MR_{pre,I}$ = ith predicted data.

Z = No. of constant.

In general, the higher the R^2 values and the lower the ÷^{2} and RMSE values indicate that the model is best fitted. Non – linear Regression analysis was performed using Microsoft Excel Solver (Microsoft Office, USA)

RESULTS AND DISCUSSION

Drying characteristics of Aonla

Dehydration is one of the important food processing step and oldest method of food preservation. Dehydration of fresh food raw materials not only facilitate reduction in the bulk, easy transport but also ensures availability in off-season. The samples of aonla were dried in tray drier at different conditions and moisture content was calculated at different drying time intervals and data were analysed.

The relationship between moisture content and drying time was non-linear, moisture decreasing with increase in drying time, and total drying time varying with drying air temperatures. The samples dried at 70 °C took minimum time to achieve the desired final moisture content.

Fig. 1 shows that the variation in moisture content with drying time at different drying conditions i.e. 50, 60 and 70 °C. It was observed that the moisture content of aonla samples of different conditions decreases with increase in drying time. During drying process at every 1 h interval, the moisture content of aonla slices was determined. At different drying conditions, the drying experiment is started from 9.00 AM to 5.00 PM.

During drying process at temperature 50 °C, the moisture content of samples decreased from 81.24% (w.b) to 7.96% (w.b) in a total drying period of 13 h. At 60 °C, the moisture content of samples decreased from 80.06% (w.b) to 7.03% (w.b) in a total drying period of 12 h. Similarly at 70 °C, the moisture content of aonla samples decreased from 79.06% (w.b) to 7.19% (w.b) in a total drying period of 11 h. As the temperature was increased by difference of 10 °C, from 50 to 70 °C, the drying time decreased by 13, 12 and 11 h correspondingly.

Drying rate

The drying rates of aonla with drying time are seen. The drying in falling rate period showed that internal mass transfer occurred by diffusion. It was observed that moisture with time while drying rates were higher at higher drying temperatures. In some cases, drying rate was initially less, then increased and later on remained constant for some time. The period for which drying rate initially increased is known as heating period.

The drying rate decreased continuously throughout the drying period. It is obvious that the constant rate period was absent and the drying process of aonla took place in falling rate period. These results are in good agreement as compared to the earlier studies on herbal leaves by Doymaz et al. (2006).

The variations of drying rate with drying time and drying temperature conditions are shown in **Fig. 2**. The graphs indicate that, drying is taking place in falling rate regime irrespective of type of drying method. The absence of initial constant rate of drying suggests that drying may have occurred both by diffusion and capillary action as observed in most agricultural materials. The average drying rate at 50, 60 and 70°C is 0.11202, 0.12327 and 0.06719 kg/kg-h. It is clear that, average drying rate is more in tray dryer at 60°C followed by 50 and 70°C.

Moisture ratio

The moisture ratios of aonla with drying time are as shown in **Fig.3**. The moisture ratio (MR) was calculated using the aonla drying data for different drying temperatures i.e. 50, 60 and 70 °C and analysed with drying time are as shown in Appendix-B. The moisture ratio reduced exponentially as the drying time increased (Doymaz, 2007). Continuous decrease in moisture ratio indicates that diffusion has governed the internal mass transfer. A higher drying air temperature decreased the moisture ratio faster due to the increase in air heat supply rate to the aonla samples and the acceleration of moisture migration. Experimental results showed that drying air temperature is effective parameter for the drying of aonla slices.

Establishment of Thin Layer Drying Models

The moisture ratio (MR) was calculated using the aonla drying data for different drying air temperatures and analyzed with drying time for non-linear regression using Statistica 10.0 version software for all of the models studied. The coefficients of models, correlation coefficient, $\div^2$, and RMSE values were established (**Table 2**).

It is evident that drying constants (k, a, c) increased with increase in drying temperature, whereas 'n' for Page model, 'a' for Henderson and Pabis model, 'a', 'k' and 'c' for logarithmic model, 'a' and 'k' for Magee model, 'k' for Newton model decreased with the increase in drying air temperature

All models well described aonla drying behaviour with R^2 values more than 0.90. **Table 2** shows that the model proposed by Page better

Table 1 Thin Layer Drying Models Tested for Aonla drying

Model name	Model	Reference
Newton	MR= exp(-kt)	Mujumdar, (1987)
Page	MR=exp(-kt^n)	Diamante and Munro, (1993)
Logarithmic	MR=a exp(-kt)+ c	Yagcioglu et al, (1999)
Handerson and Pabis	MR=a exp(-kt)	Handerson and Pabis, 1961)
Magee	MR=a+kt$^{1/2}$	Magee, (1983)

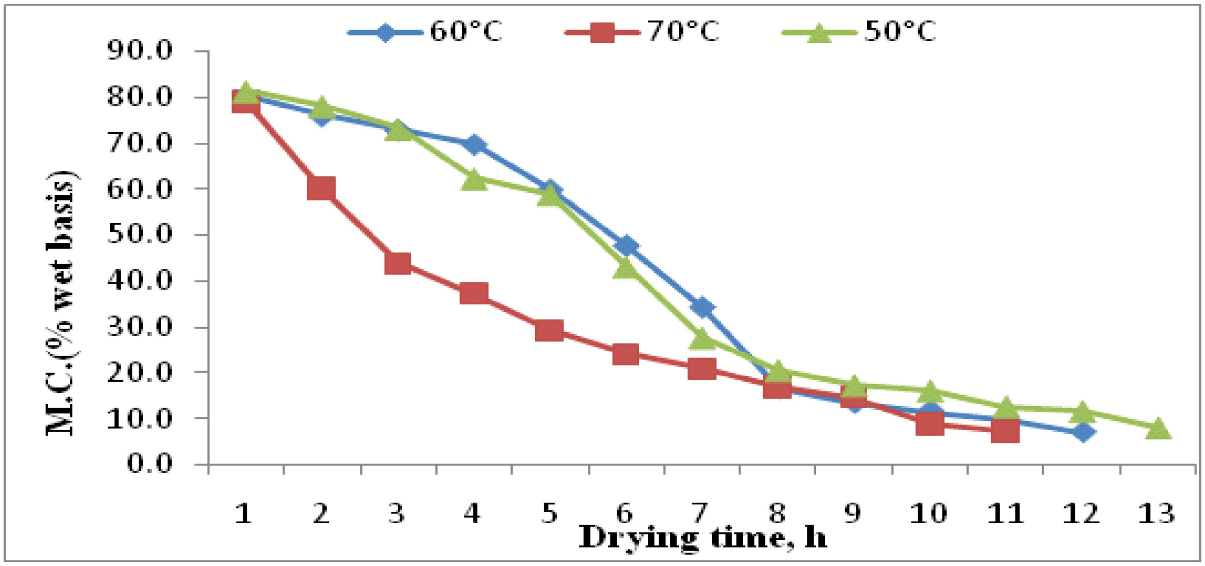

Fig. 1 Variation of moisture content against drying time at 50, 60 and 70 °C in a tray dryer

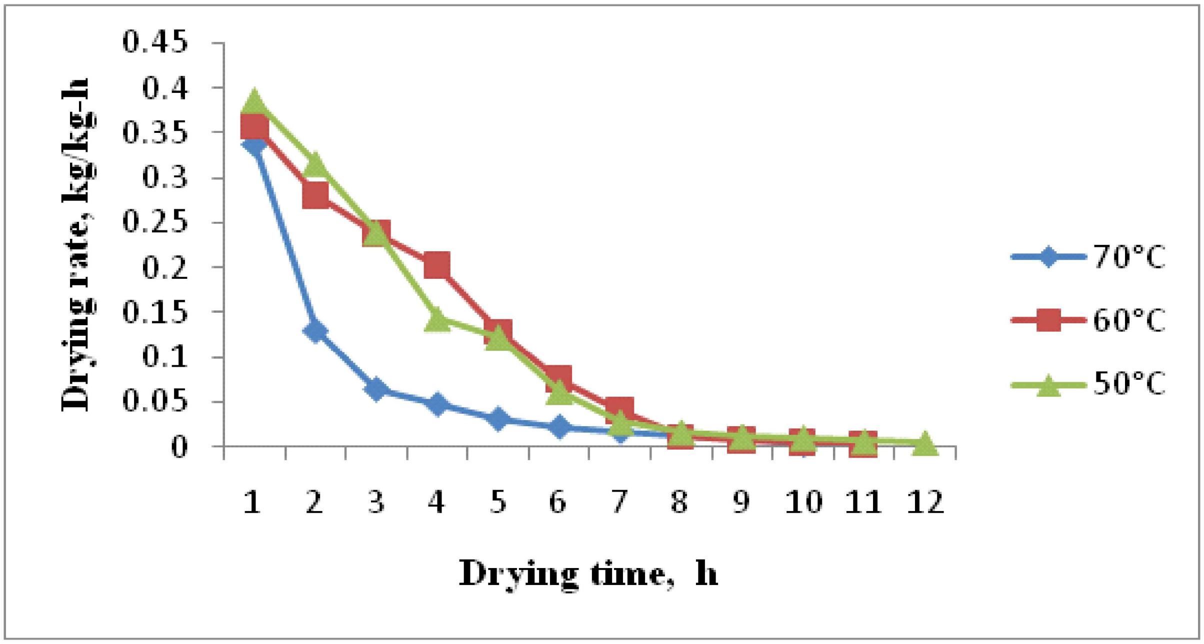

Fig. 2 Variation of drying rate against drying time at 50, 60 and 70 °C in a tray dryer

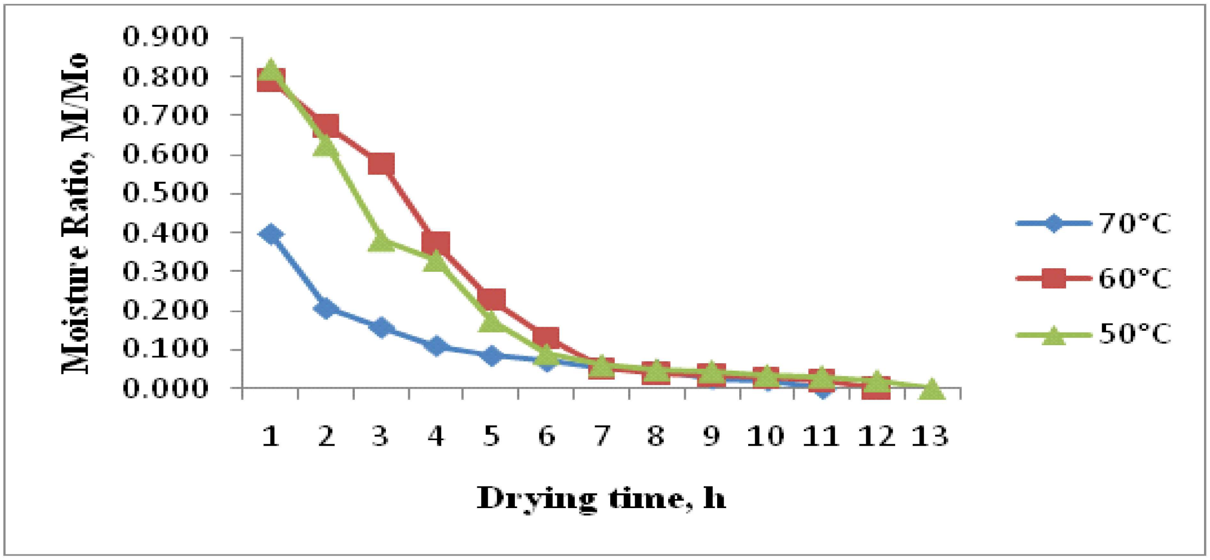

Fig. 3 Variation of moisture ratio against drying time at 50, 60 and 70^{0}C in a tray dryer

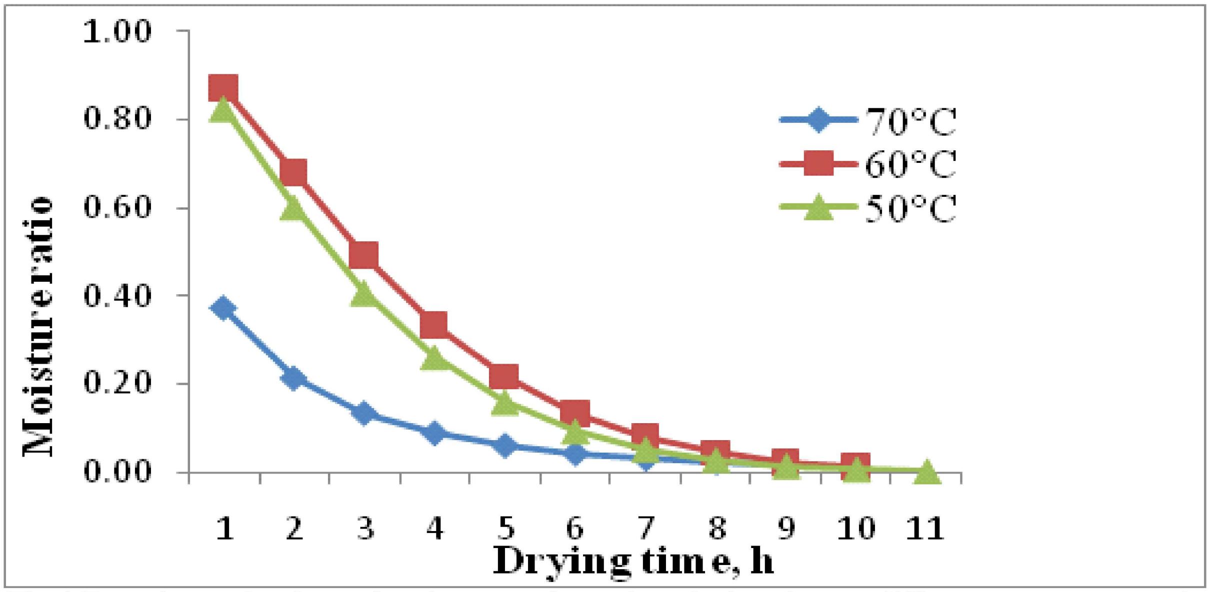

Fig.4 Experimental values of moisture ratio against drying time at different temperatures in a tray dryer

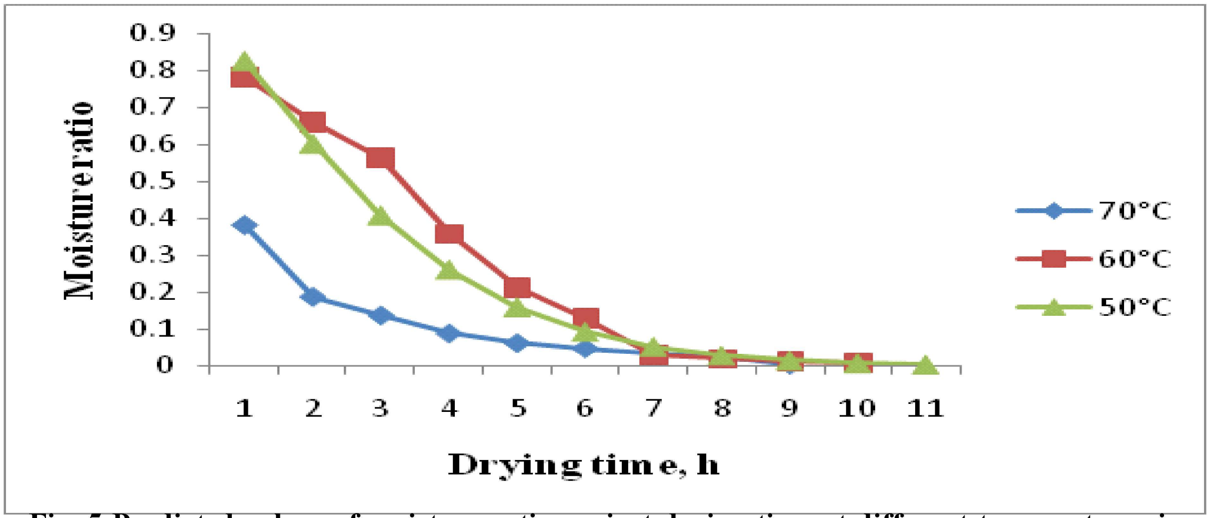

Fig. 5 Predicted values of moisture ratio against drying time at different temperatures in a tray dryer

Table 2 Fitness of models at different temperatures

Model	Temparature (T), ^{0}C	Coefficient	Coefficient of	chi-square (χ^2)	RMSE
Newton	50	k=0.249	0.929	3.12E-05	0.023
	60	k=0.221	0.918	0.001	0.031
	70	k=0.495	0.989	0.001	0.004
Page	50	k=0.192, n=1.401	0.996	1.29E-05	0.005
	60	k=0.136, n=1.499	0.989	0.000	0.007
	70	k=0.985, n=0.651	0.996	7.13E-05	0.002
Logarithmic	50	a=1.249,k=0.356326,c=-0.036	0.994	2.72E-05	0.007
	60	a=1.271,k=0.201,c=-0.198	0.987	0.00	0.012
	70	a=0.636,k=0.591, c=0.021	0.993	0.00	0.004
Handerson and Pabis	50	a=1.891, k=0.400	0.992	3.336E-05	0.008
	60	a=1.675, k=0.332	0.974	0.00	0.017
	70	a=0.952, k=0.478	0.988	0.00	0.004
Magee	50	a=1.221, k=-0.389	0.937	0.00	0.022
	60	a=1.196, k=-0.408	0.976	0.00	0.016
		a=0.461, k=-0.164	0.929	0.00	0.011

represented aonla drying kinetics with highest values of R^2 and lowest values of $\div^2$ and RMSE. Thus, the Page model was treated as the best suited one for the experimental data to describe drying behaviour of aonla in thin layer. The model was able to estimate the moisture content reasonably over most of the drying. The experimental and predicted values of moisture ratio against drying time are as shown in Fig. 4 and 5.

Conclusion

Aonla slices were dried at 50, 60 and 70°C temperature, the drying rate decreased continuously throughout the drying period. Constant rate period was absent and the drying process of aonla slices took place in falling rate period. Mathematical models were fitted to the experimental data and the performance of these models was evaluated by comparing the coefficient of determination (R^2) and reduced chi-square ($\div^2$) between the observed and predicted moisture ratio. However, the model proposed by Page gave the best fit on the basis of highest R^2 value, least $\div^2$ and RMSE.

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