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## Research Article

# A STUDY ON DRYING KINETICS OF INDIAN GOOSEBERRY – AONLA (*Phyllanthus emblica* Linn.)

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**Abstract-** Aonla slices were dried at 50, 60 and 70°C temperature and the drying rate decreased continuously throughout the drying period. The drying process of aonla slices were carried out 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 ($R^2$) and reduced chi-square ($\chi^2$) between the observed and predicted moisture ratio. Page model gave the best results for describing the drying kinetics of aonla. The tray dried powder at 50°C drying temperature found the highest ascorbic acid content followed by 60°C and 70°C.

**Keywords-** Drying kinetics, Aonla (*Phyllanthus emblica* L.), Mathematical models

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### Introduction

Aonla (*Phyllanthus emblica* L.) an important fruit crop of tropical and subtropical regains of India, belongs to the family *Euphorbiaceae* is one of the important minor fruit crops in India. It is called by various vernacular names such as Aonla, Nelli, Amla, Amlika, Dhotri, Emblica and Usuri. The fruit commonly consumed as a healthy food in both fresh and preserved forms *viz.* pickles, dried fruits, and beverage products [1]. Drying is a common technique for preservation of food and other products; including fruits and vegetables. The major advantage of drying food products is to reduce moisture content to a safe level that permits extending the shelf life of dried products. The removal of water from foods provides microbiological stability and reduces deteriorative chemical reaction. Draying technology offer an alternative way of consumption of other crops like tomato. The dehydration in tomato has been practiced for many years as a mean of preserving tomato. With regards to anola, drying process in the form of slice or powder helps to develop new food materials for ready to eat products. Recently, there is a great demand for natural sun / solar dried organic or bio-cultivated aonla in the international markets [2]. 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 [2]. 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 and equipment stress and product yields [2]. Therefore, validated mathematical drying models, which enable more detailed explanation of drying [3, 4]. Number of empirical equations has been proposed to describe drying process, modeling kinetics and design of drying systems [5]. 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 [6].

### Tray dryer

For drying of aonla slices, the Tray Dryer (TD-12-S-E), Electric heating model having 6 KW power and temperature 200°C was used. The air velocity in the try dryer is 0.3 to 2.3 m/s essentially a cabinet in to which material to be dried is placed on perforated stainless steel trays. The dryer mainly consist of thermostat, fan and temperature controller. The tray drier having 12 numbers of trays placed one above the other. The drying conditions are simply controlled and readily changed.

### Drying characteristics of aonla slices in tray dryer

The aonla slices be placed in cleaned perforated stainless steel trays. These trays are kept in tray drier for drying as shown in [Plate-1]. Aonla slices are dried at 50°C and Constant air circulation rate of 1.5 m/s was maintained during drying. The drying was performed continuously for 12 hours, until the material was dried to approximately less than 10% of moisture content. Reduction in weight due to moisture loss was recorded continuously at every two-hour interval during drying. During the experiment, the air temperature and relative humidity inside and outside should also be recorded with glass bulb thermometer and hygrometer. For measurement of moisture tests a hot air oven, model MSW-211, with electrically heated and thermostatically controlled, was used. Drying is continued until there was no large variation in their weights. The dried samples were taken out from the tray and cooled to room temperature and packed in polythene covers on which the concentrations be noted accordingly. The drying experiment can be repeated in tray dryer at temperatures of 60 and 70°C.

### Determination of moisture content

Moisture content of the aonla while drying on each plot should be measured [7]. For that, the samples are taken in moisture boxes from each plot. The boxes be kept in hot air oven at 105°C±3 for 24 hours and the weights are measured on electronic digital balance having an accuracy of 0.01g.

**Plate 1 Drying of aonla slices in tray dryer**

From the initial and final moisture box weights, the moisture content of samples is determined and expressed in percent (w.b.) by using the following formula:

$$\text{Moisture Content (w.b.)} = \frac{W_1 - W_2}{W_1} X100 \qquad [1]$$

Where, W1 = Dry weight of the sample, W2 = Wet weight of the sample

### Calculation of drying rate

Drying rate an important parameter that supports in observation by calculation with as the ratio of moisture removed per kg of dry weight of material in unit time. The amount of moisture removed on each of experimentation is initially determined and then the drying rate is calculated. It is computed for different plots during experiment for each day using the following formula:

$$R = \frac{dm}{d\theta} = \frac{\text{amount of moisture removed}}{\text{time taken (h) X Bone dry weight of the sample}} \qquad [2]$$

### Determination of moisture ratio

Heated air is used as drying medium, the primary factor influencing the rate of drying is temperature [9]. In drying of thin layers of agricultural crops, Newtonian Model among others is used. However, The formula for Newtonia Model can be given follows :

MR = exp (-kt)

$$MR = \frac{M - Me}{Mi - Me} \qquad [3]$$

Where: MR = Moisture Ratio, Mi = Initial moisture content (%db), Me = Equilibrium moisture content time (%db), M = Moisture content in time t (%b), T = Drying time (h), k = Drying constant

According to [9], the moisture ratio can be simplified to:

$$MR = \frac{M}{Mi} \qquad [4]$$

### Modeling of drying data

The main objective of development of mathematical models for the system is to predict change of temperature and humidity of both product and drying air during the process. The first stage in the modeling is to separate the drying system with their components (subsystems) on which the change of parameters will be investigated. The next stage based on the heat balance for each component and moisture balance for air and product, mathematical model might be expressed in the subsystems.

[10] classified and analyzed mathematical models, for drying of porous solids, required for the formulation of convection drying theory. Thin-layer drying models can be classified into three categories, namely theoretical, semi-theoretical and empirical. Theoretical models consider only internal resistance to moisture transfer while the other two depend only on external resistance to moisture transfer resistance between product and air [11-13]. Diffusion coefficient (D) is independent of the local moisture content, provided the resistance to moisture flow gets uniformly distributed throughout the interior of the homogeneous isotropic material. If the volume shrinkage is negligible, diffusion coefficient is constant and unidirectional. Fick's second law of diffusion can be simplified as [14]:

$$\frac{\delta M}{\delta t} = D\Delta^2 M \qquad [5]$$

[15] gave the analytical solutions of [Eq-1] for various regularly shaped bodies such as rectangular, cylindrical and spherical. Drying characteristics of many food products such as hazelnut [16] and rapeseed have been successfully predicted using Fick's second law with Arhenius-type temperature dependent diffusivity. These are semi-theoretical and empirical models used in literatures. Semi-theoretical models are derived based on theoretical model (Fick's second law) but are simplified and added with empirical coefficients in some cases to improve curve fitting. In the empirical models, a direct relationship is derived between moisture content and drying time and the parameters associated with it have no physical meaning at all. In these models, the moisture ratio (MR) is defined as (Mi-Me)/(Mo-Me) where the subscripts i, e and o denote at time i, equilibrium and initial moisture content, respectively. Non-linear regression was performed using the least square method. Statistical parameters such as the coefficient of determination ($R^2$), reduced chi=square for Page model and root mean square error for Logarithmic model were used as the criteria for selecting the best model.

**Table-1** *Thin Layer Drying Models Tested for Aonla drying*

| Model name | Model | References |
|---|---|---|
| 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) |

$$\text{Chi-square: } \chi^2 = \frac{\sum_{i=1}^{n} (\text{MRexp,i} - \text{MRpre,i})^2}{N - n} \qquad [6]$$

### Root mean square error:

$$RMSE = [t/n \sum_{j=1}^{n} (\text{MRexp}, 1 - \text{MR pre}, i)2]\ ½ \qquad [7]$$

Where: N = No. of observation, MRexp, i= ith experimental data, MRpre, I= ith predicted data. Z = No. of constant.

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

### Mathematical modeling

The experimental data were analyzed for the models given in [Table-1] to determine the best fit model to describe the drying behavior of aonla in thin layer on the basis maximum $R^2$ value, least $\chi$2 and root mean square error (RMSE).

### Results on tray drying of aonla

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 analyzed. 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.

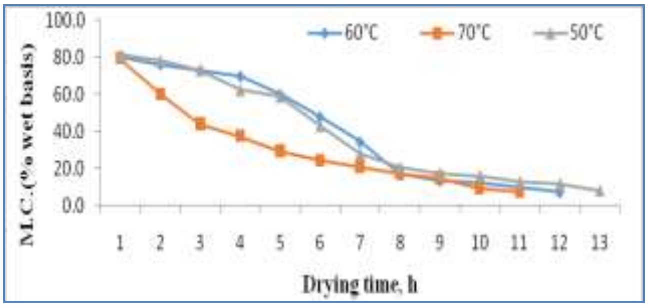


**Fig-1 Variation of moisture content against drying time at 50, 60 and 70°C in a tray dryer**

### Drying rate

The drying rates of aonla with drying time were observed. 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 from the [Fig-2] 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[ 17]. 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 [14]. The average drying rate at 50, 60 and 70°C 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.

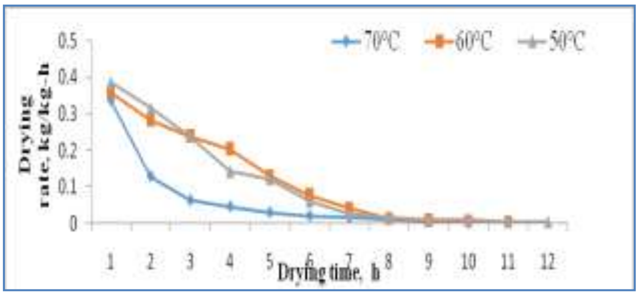


**Fig-2 Variation of drying rate against drying time at 50, 60 and 70°C in a tray dryer**

### 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 analyzed with drying time are as shown in Appendix-B. The moisture ratio reduced exponentially as the drying time increased [18]. 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 [19]. Experimental results showed that drying air temperature is effective parameter for the drying of aonla slices.

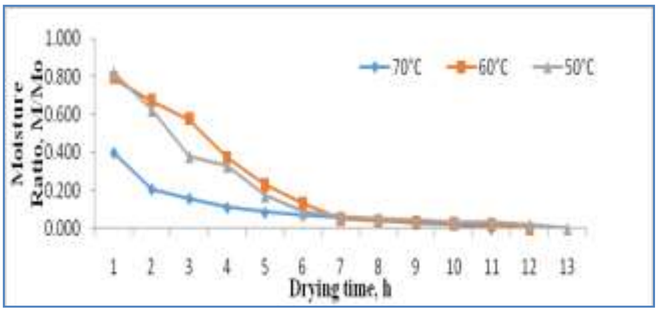


**Fig-3 Variation of moisture ratio against drying time at 50, 60 and 70°C in a tray dryer**

### 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, $\chi^2$, 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 behavior with $R^2$ values more than 0.90. [Table-2] show that the model proposed by Page better represented aonla drying kinetics with highest values of $R^2$ and lowest values of $\chi^2$ and RMSE. Thus, the Page model was treated as the best suited one for the experimental data to describe drying behavior 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].

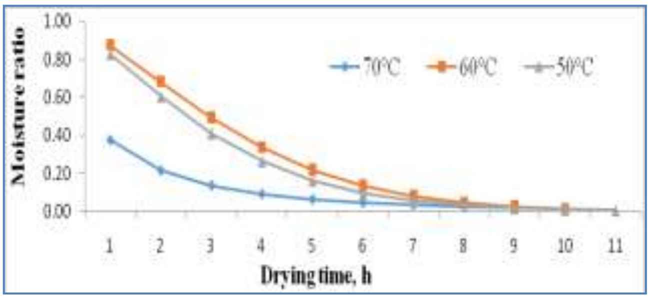


**Fig-4 Experimental values of moisture ratio against drying time at different temperatures in a tray dryer**

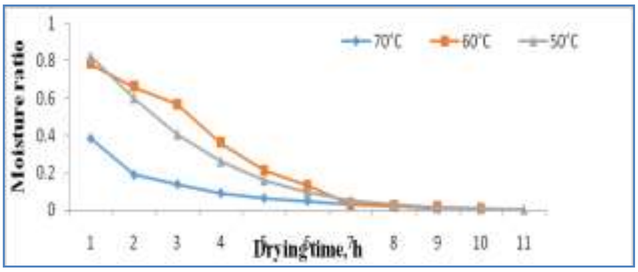


**Fig-5 Predicted values of moisture ratio against drying time at different temperatures**

**Table-2** *The Fitness of Different Models at Different Temperatures*

| Model | T, ºC | Coefficient | $R^2$ | chi-square($\chi^2$) | RMSE |
|---|---|---|---|---|---|
| Newton | 50 | k=0.249480 | 0.9297012 | 3.11996E-05 | 0.02300734 |
| | 60 | k=0.221595 | 0.9179398 | 0.001244441 | 0.03129703 |
| | 70 | k=0.495438 | 0.9886592 | 0.000859416 | 0.00426003 |
| | | | | | |
| Page | 50 | k=0.191715, n=1.401459 | 0.9962248 | 1.29072E-05 | 0.00501814 |
| | 60 | k=0.136091, n=1.499491 | 0.9890103 | 0.000131948 | 0.00754405 |
| | 70 | k=0.985084, n=0.651004 | 0.9958206 | 7.13047E-05 | 0.00257271 |
| | | | | | |
| Logarithmic | 50 | a=1.249611,k=0.356326,c=-0.036078 | 0.9940843 | 2.7266E-05 | 0.00688794 |
| | 60 | a=1.271197,k=0.209990,c=-0.198480 | 0.9871869 | 0.0002839 | 0.01189148 |
| | 70 | a=0.636166,k=0.590932, c=0.021915 | 0.9927493 | 0.000122307 | 0.00354417 |
| | | | | | |
| Handerson and Pabis | 50 | a=1.891261, k=0.400565 | 0.9923976 | 3.33662E-05 | 0.0078257 |
| | 60 | a=1.674844, k=0.332268 | 0.9736684 | 0.000456578 | 0.01680381 |
| | 70 | a=0.951549, k=0.478343 | 0.9889183 | 0.000105556 | 0.00388138 |
| | | | | | |
| Magee | 50 | a=1.221919,k=-0.388572 | 0.9366332 | 0.000220479 | 0.02238973 |
| | 60 | a=1.196187,k=-0.408251 | 0.9758426 | 0.000352228 | 0.01607966 |
| | 70 | a=0.461326,k=-0.164144 | 0.9286317 | 0.000760086 | 0.01140866 |

## Conclusion

Drying is the important post-harvest operation among hot-air method of drying is one of the most widely used one for preservation of food in commercial processing. Drying tends 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[20]. Further-more, products with low moisture contents also be stored for long duration at normal environmental conditions [21]. 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. 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.

**Application of research:** 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 ($\chi^2$) between the observed and predicted moisture ratio. Page model gave the best results for describing the drying kinetics of aonla. The tray dried powder at 50°C drying temperature found the highest ascorbic acid content followed by 60°C and 70°C.

**Research Category:** Agriculture Process and Food Engineering

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