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A Preliminary Study of Modeling the Thin-layer Drying Kinetics of Wood Apple pulp in Hot-air Oven

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ABSTRACT
This research work is based on comparative study of the drying characteristics of wood apple pulp in convective hot air oven. Three different temperatures of 50˚C, 60˚C and 70˚C temperatures and air velocities of 0.5 m/s, 1 m/s and 1.5 m/s were considered as ideal drying parameters. Thin layer drying technology was used in the whole experiment with sample thickness of 4 mm. The samples were then subjected to drying at fixed interval of 10 mins, 30 mins, 60 mins and so on for1 hour,2 hours, next 3 hours and so in same sequence until three consecutive constant values were recorded. The data so obtained were fitted in thin layer drying models viz, Lewis, Handerson and Pabis, Page and Midilli. The values were investigated using coefficient of determination of R^2, X^2 and RMSE between the observed values and predicted values of the moisture ratios. Highest coefficient of R^2 = 0.99086 was found in Henderson and Pabis model at drying temperature of 70°C with lowest value of X^2 and RMSE of 0.00121 and 0.00211 respectively. Thus the result showed that the Henderson and Pabis model at drying temperature of70˚C was most suitable that fits the curve and best describes the drying kinetics of wood apple.
Key Words: Wood apple,Handerson and Pabis, drying kinetics, mathematical modeling, Coefficient.

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INTRODUCTION

Wood apple (*Feronia limonia*) is an under-utilised abundantly found fruit in almost all parts of Indian sub-continent. It is that type of tree which can be grown in diverse agro-climatic zones. It belongs to Rutaceae family. Almost all parts of wood apple tree are used in India since time immemorial. It is locally known as *Kath Bael* or simply *Bael* in India.

The fruit is round to oval in shape with woody hard protective shell which is greenish white in colour and turns yellow when ripe. The pulp is yellow sticky, resinous and sweet with numerous scattered seed around [11]. It has refreshing and aromatic flavor. It is rich in iron, protein and minerals [17]. It also possesses therapeutic values and can be seen its extensive use in Ayurveda practices. Jam, Jelly and other products can easily be made from its juices. Despite its huge potential it has not gained proper attention in processing industries unlike other fruits such as Mango, Banana, Papaya, etc. reason may be due to the challenges it possess during processing.

Wood apple is considered under seasonal fruit but it has long duration of shelf-life as compared to other fruits. It is one of the least used fruit in industrial sector may be due to lack of proper processing and preservation technology. Drying is one of the oldest and most commonly used methods for preservation and increasing shelf-life. The knowledge of temperature and moisture distribution in the product is essential for process design and quality control [6]. The drying process facilitates inhibition of micro-organisms increase storage capacity and reduces transportation freight [16]. In this research work thin layer drying method in convective hot air oven was undertaken for investigation. In this type of drying method formation of vapor blanket beneath the film can be prevented and offers lower resistance to the heat transfer [15]. The data so obtained were fitted in thin layer drying models viz, Lewis, Handerson and Pabis, Page and Midilli and Kucuk. The values were investigated using determination of R^2, X^2 and RMSE between the observed values and predicted values of moisture ratios.

MATERIAL AND METHODS

Materials

Fully ripe wood apple fruits were selected randomly from the local market nearby Assam University Silchar area for the experiment. Its protective shell was broken and seeds were removed manually.

Drying Equipment

Hot air oven with temperature range of ambient to 250° ± 1 °C with digital temperature indicator cum controller with timer (0-24) h and inner chamber 600 (W) X 600 (D) X 900 (H) mm was used for the determination of wet basis moisture content of raw material. For this purpose, samples were kept in oven at 105 °C ± 5 °C for one hour. The moisture content on per cent basis was determined.

Drying Method

Sample Preparation

The pulp of wood apple was cut out and pre-dried with hot air oven at 45°C for 30 minutes. Since the pulp of wood apple is a sticky jelly like material as shown below in Fig.1 hence for drying, the sample was put on a thin weightless considered butter paper with numerous pin holes. The oven temperature was kept at 50°C, 60°C and 70°C [6]. The air velocity of 0.5 m/sec, 1 m/sec and 1.5 m/sec were considered for the experiment. Fresh sample of weight 100 g was prepared for each set of experiment with maximum thickness of 4 mm. Average weight of triplicate reading of the dried sample was considered for determining the drying characteristics.

Sample 1 Sample 2 Sample 3

Fig.1: Different sample of wood apple pulp during at different temperature

The samples were dried and measured after every 10 minutes for initial 1 hour, then after every 30 minutes for next 2 hours and then after every 1 hour for next 3 hours and so on in same sequence till 3 consecutive values were found to be same [13]. The experiment was conducted in a controlled environment. Desiccator assisted with activated silica gel was used as a transporter for the dried sample from oven to electronic weight balance for measurement of reducing weight.

Moisture content determination

The moisture content was determined using AOAC (1980) official method. The initial moisture content is denoted as M_o and final moisture content is denoted as M_f of wood apple. The average of triplicate reading was considered for calculations and was calculated as-

$$\%Moisture = \frac{Weight\ of\ dry\ matter}{Initial\ weight} \times 100 \qquad (1)$$

Mathematical modeling

In mathematical modeling of thin layer drying of Wood Apple semi-theoretical models such as Henderson and Pabis, Lewis, Modified Page and Midilli were used. The experimental moisture ratio of wood apple at different initial moisture content at time (t) was computed as the following equation.

$$\text{MR} = \frac{M_t - M_e}{M_o - M_e} \qquad (2)$$

Since the value of M_e (Moisture content equilibrium) is negligible as compared to the values of M_t and M_o therefore it does not bring huge change in simplification hence it can be neglected [1].

$$\text{MR}=\frac{M_t}{M_o} \qquad (3)$$

Where, MR is the moisture ratio, M_t is the moisture content at different time and M_o is the initial moisture content.

The table below is the mathematical modeling used to study the drying characteristics of wood apple pulp.

Table.1: Thin-layer models for drying kinetics

Sl. No.	Model Name	Model expression	References
1	Henderson and Pabis	MR=aexp(-kt)	[18]
2	Lewis	MR=exp(-kt)	[20]
3	Modified Page	$MR=\exp(-kt)^n$	[3]
4	Midilli	$MR=a\exp(-kt^n)+bt$	[9]

The statistical analysis was made with Origin 2018 analysis software. The goodness of curve fit was determined by following equations-

$$R^2 = 1 - \frac{\sum_{i=1}^{n}(MR_{i,pre.} - MR_{i,exp.})^2}{\sum_{i=1}^{n}(MR_{i,exp.} - MR_{i,pre.mean})^2} \quad (4)$$

$$X^2 = \frac{\sum_{i=1}^{N}(MR_{i,exp.} - MR_{i,pre.})^2}{N-Z} \quad (5)$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}\sum_{i=1}^{n}(MR_{i,pre.} - MR_{i,exp.})^2}{N}} \quad (6)$$

Where, R^2 is the statistical measure of how close the data are to the fitted line. It is the coefficient of determination for multiple regressions, the higher the R^2 the better model fits the data [5]. $MR_{i,pre.}$ is the i^{th} predicted moisture ratio, $MR_{i,exp}$is the i^{th} experimental moisture ratio, N is the number of observations and Z is the number of constants in the mathematical model.

RESULTS AND DISCUSSION

Drying kinetics

The moisture ratio of wood apple pulp at different temperature of 50°C, 60°C and 70°C as shown in Fig.2 (a), (b), and (c) respectively. The moisture ratio trend shows that at 50°C and 70°C the moisture ratio is diminishing optimally during the drying process. Also, it was noted that the trend of moisture ratio declines at 60°Cbehavesas an irregular deviation during the drying process.

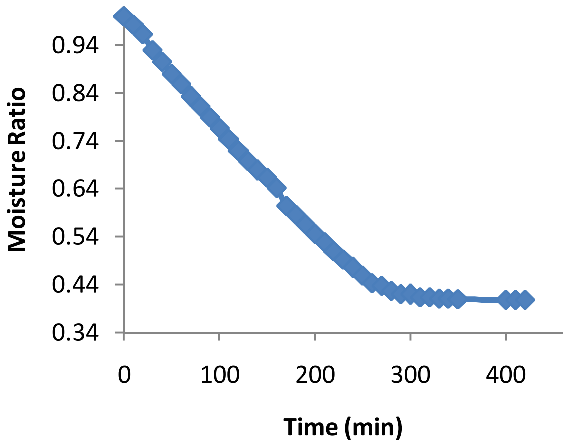

Fig.2 (a): MR V/s Time of 50°C

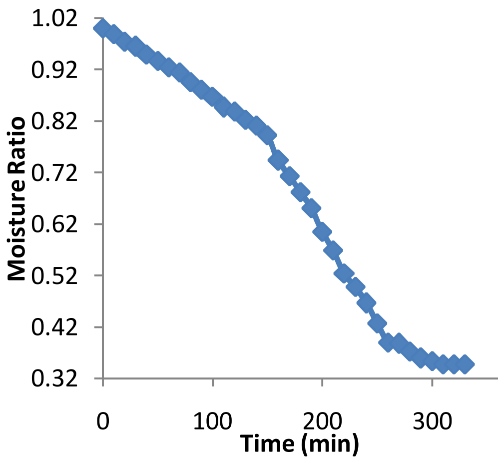

Fig.2 (b): MR V/s Time of 60°C

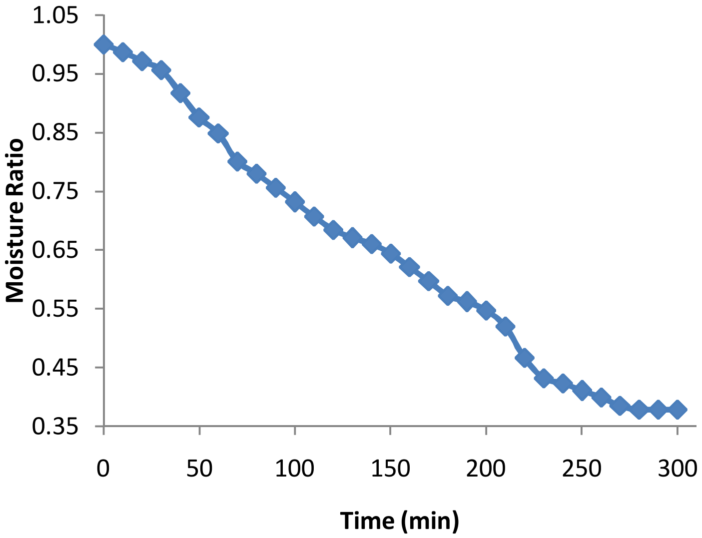

Fig.2 (c): MR V/s Time of 70°C

Model curve fitting

The moisture ratio of wood apple dried at different temperature of 50°C, 60°C and 70°C were fitted with four various thin layer drying models to identify their suitability to describe the drying behavior. The coefficient of correlation (R^2), chi-square ($\chi 2$), RMSE, and different model coefficients values are found from nonlinear regression modelling analysis are given in table 2. The best-fitted model to describe the drying kinetics of wood apple was identified in accordance with the highest value of R^2 and the lower value obtained of $\chi 2$ and RSME value. From the model analysis results, it was found that that the Henderson and Pabis gave the highest value of R^2 is 0.99086 at70°C and identified as best suitable model to expressed the drying behavior of wood apple. The actual and predictedgraph of best fitted model has been shown in Fig.3.

Table: 2. Statistical parameters and the coefficients of drying models

Model Name	**Temperature**	**R^2**	**χ^2**	**RMSE**	**Estimated parameters**			
					a	b	k_0	n
Henderson and Pabis	50	0.97216	0.00121	0.00211	1.06889	-	0.00317	-
	60	0.90861	0.00463	0.03797	1.10435	-	0.00314	-
	70	**0.99086**	0.00394	0.00547	1.03748	-	0.00345	-
Modified Page	50	0.95059	0.00214	0.00117	-	-	0.05282	0.8807
	60	0.86472	0.00685	0.00455	-	-	0.05086	1.1425
	70	**0.98478**	.006535	0.00276	-	-	0.05686	1.0414
Lewis	50	0.95059	0.00207	0.00175	-	-	0.00279	-
	60	0.86472	0.00663	0.00588	-	-	0.00259	-
	70	**0.98478**	0.006317	0.00115	-	-	0.00323	-
Midilli	50	0.940077	0.03722	0.00289	1.03071	-0.0022	0.050.51	1.4028
	60	0.928692	0.03881	0.00193	1.08318	-0.0024	0.068518	1.3021
	70	**0.978201**	0.03773	0.00093	0.97847	-0.0022	0.004955	1.6432

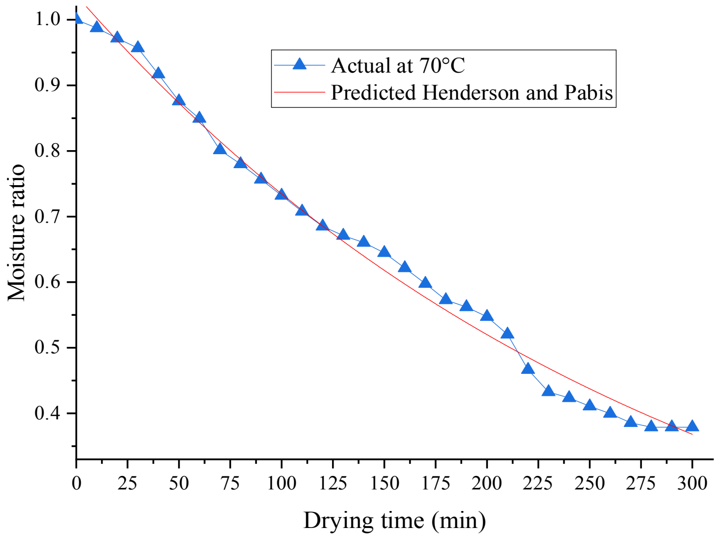

Fig.3: Actual and predicted graph of Henderson and Pabis model

CONCLUSION

The wood apple pulp was dried in hot air oven at different temperatures. The drying kinetics of moisture ratio declined effectively at 50°C and 70°C during the drying process. The Henderson and Pabis model was identified as best suitable model with higher coefficient of determination (R^2) to describe the drying kinetics of wood apple during drying progression in a hot air oven. Furthermost the result concluded that the wood apple pulp can be dried effectively at 50°C for longer period to achieve bone dry in hot air oven and at 70°C for comparatively shorter period of time. The dried pulp can be further processed for preparing powder for the various food application and health drinks.

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