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Effect of tray and microwave drying methods on the drying kinetics of wood apple (*Limonia acidissima)*

Puja Das[1*] • Ajita Tiwari[2] • Prakash Kumar Nayak[1*] • Robin Subba[2*] • Vashkar Biswa[3*] • Thameridus B. Marak[4*]

[1]Dept. of Food Engineering and Technology, Central Institute of Technology, Kokrajhar
[2]Department of Agricultural Engineering, Assam University, Silchar
[3]Department of Biotechnology, Bodoland University, Kokrajhar, Assam
[4]ICAR Research Complex for NEH Region, Umiam, Meghalaya

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ABSTRACT

The primary objective of this study was to examine the effects of various drying methods on the drying kinetics and colour of powdered *Limonia acidissima* (wood apple). The wood apple samples were specifically dried in a tray dryer at 60°C and 180W in the microwave. A generalised model was developed to forecast moisture as a function of drying time and temperature after fitting drying models to the moisture ratio was used to analyse the data. In this study, models were utilized to depict the drying behaviour of wood apple pulp powder. The performance of these models was evaluated using various measures, such as the correlation coefficient (*R*), root mean square error (RMSE), and reduced chi-square (χ^2). The findings showed that two models effectively explained the drying characteristics of wood apple (with R values greater than 0.996). Two models with R values greater than 0.996 were found to be useful in describing the drying characteristics of wood apple, according to the study. Based on its low average values of RMSE (0.00439), χ^2 (2.0079310-5), and R^2 (0.99563), the Midilli model was the most effective at predicting the moisture transfer of wood apple pulp during tray drying at 60°C. Modified page model was found to be the best fitted or microwave drying at 180 W to predict the moisture transfer of pulp of wood apple owing to the lowest average values of RMSE (0.00456), χ^2 (2.21798×10-5) and R^2 (0.99668). The total color change was observed maximum in microwave drying at 180 W due to high microwave power and lowest was observed in tray drying at 60°C due to low drying temperature which had a little influence as compared with the colour of WAPP obtained from microwave drying.

1. Introduction

The use of medicinal plants has a long history that dates back thousands of years. People have relied on traditional medicines derived from various plant species to treat a variety of diseases throughout history. *Limonia acidissima* (L.) is one such plant that belongs to the Rutaceae family (also known as the Citrus family) and is found primarily in India, Sri Lanka, Pakistan, Bangladesh, the Eastern Ghats, Burma, and Thailand. *Limonia acidissima* is well-known for its medicinal properties and has long been used in traditional medicine. In India, Limonia acidissima is widely dispersed, particularly in the plains of Orissa, Assam, Tripura, West Bengal, Southern Maharashtra, Uttar Pradesh, Chhattisgarh, and Madhya Pradesh, according to Singh et al. (2014). The Western Himalayas, at elevations of up to 500 metres above sea level, are also home to the plant. The fruit's rind is roughly 6 mm thick and has a greyish-white appearance. Its diameter ranges from 5 to 12.5 cm. The rind, or outer shell, is extremely hard and woody, making it difficult to crack open. The brown, mealy, fragrant, resinous, sour, or sweetish pulp of *Limonia acidissima* is prized for its large number of tiny white seeds. The gooey pulp can be used

*Corresponding author: pdas12994@gmail.com

to make syrups, beverages, jams, and jellies. The raw fruit's mashed seedless pulp is used to treat dysentery, diarrhoea, and piles, among other ailments. The fruit is also well-known for its medicinal benefits, which include the treatment and prevention of scurvy, easing flatulence, and preventing and treating scurvy. Additionally, L. acidissima is regarded as a hepatoprotectant and has a variety of biological properties, including adaptogenic activity against blood impurities, leucorrhoea, dyspepsia, and jaundice, according to Kumar and Deen (2017). Because the trays are arranged at different levels, tray dryers allow for the loading of more products. However, as Misha et al. (2013) point out, uniform airflow distribution over the trays is critical to achieving uniformity in the final moisture content of the dried products. Microwave drying, on the other hand, has the potential to reduce drying time while also negatively impacting product quality. According to Wray and Ramaswamy (2015), drying efficiency may need to be sacrificed in order to maintain high-quality products. Higher power levels, according to Meisami-asl et al. (2009), result in faster drying rates, whereas lower power levels may result in higher quality products. The drying process can be better controlled to produce high-quality products by using mathematical modelling and simulation of the drying curve. This method can also be used to investigate drying variables and evaluate drying kinetics. According to Taheri-Garavand et al. (2011), the modelling principle is based on the use of a set of mathematical equations that can accurately describe the drying behaviour. Several studies, such as those conducted by Raveendran et al. (2015), Manikantan et al. (2014), Limpaiboon (2015), and Kakade & Hathan (2014), have successfully applied drying models to describe the drying kinetics of various agricultural materials. However, there is a surprising lack of research on the drying kinetics of wood apple pulp powder using tray and microwave drying. Therefore, the current study aimed to investigate the effects of tray and microwave drying on the drying kinetics and color of Wood Apple, considering various parameters.

2. Materials and Methodology

2.1 Sample Preparation

The initial weight of the raw wood apple was measured in weighing balance. Pulp of the fruit was scooped out with seed from hard shell with the help of knife and spoon. Weight of pulp, outer shell and wastes/ loss was measured using weighing balance. Then, wood apple pulp (seedless) was placed in two different dryers (Tray and Microwave) to produce wood apple pulp powder (WAPP). While drying operation, the weight of sample was measured after specific predetermined time interval to obtain drying nature of the sample i.e., for drying kinetics. After drying of sample, WAPP was obtained after drying the pulp in tray dryer and microwave oven. Then the dried pulp was ground using mixer grinder and sieved well using vertical vibratory sieve shaker. The final product was then being measured using digital weigh balance.

2.2 Experimental drying process

2.2.1 Tray drying

The fresh wood apple pulp was scooped out from the hard shell and out of which 300 g were dried at temperature 60°C, air velocity 2 m^3/s and loading density 1 cm/m^2 (Sonawane & Arya, 2015).

2.2.2 Microwave Oven Drying

Similarly, 300 gm were dried at microwave power 180 W, drying time 40 min and loading density 1 cm/m^2 (Celen & Kahveci, 2013).

2.3 Drying Kinetics

Using standard formulas described in Manikantan et al. (2014), the moisture ratio, drying rate, coefficient of determination (R2), reduced chi-square (χ^2), and root mean square error (RMSE) for each drying process were calculated.

2.3.1 Equilibrium moisture content

The value of M_o (initial moisture content) and M_t (moisture content at specific time) for wood apple pulp during drying process is to be obtained after every 30 min of interval of drying. However, the values of M_e (equilibrium moisture content) for sample at experimental temperature and relative humidity could not be recorded. Therefore, these values were estimated by using trial method (Pedro *et al.,* 2010).

2.3.2 Moisture ratio

The moisture ratio (MR) during drying experiments was calculated using below mentioned equation (Rayaguru *et al.,* 2011).

$$MR=\frac{(M_t-M_e)}{(M_O-M_e)} \qquad \text{...Eq. (1)}$$

Where, MR= Moisture ratio, dimensionless; M_t= Moisture content at a specific time, g water/ g dry sample M_e= equilibrium moisture content, g water/ g dry sample; M_o= Initial moisture content, g water/ g dry sample

2.3.4 Drying rate

Drying rate (DR) was calculated by using the equation mentioned below (Rayaguru *et al.,* 2011).

$$DR=\frac{W_m\ (g)\times 100}{t\,(min)\times \text{total bone dry wt of sample (g)}} \qquad \text{..Eq. (2)}$$

Where, DR= Drying rate, g water/ min 100 g of dry matter; W_m= Amount of moisture removed, g; t= drying time, min

2.3.5 Drying models

To obtain moisture ratio with respect to time, 10 models, namely, Newton, Page, Modified Page, Henderson and Pabis, Exponential, Wang, and Sing, Midilli, Logarithmic, Verma, and Modified Page II as listed in the below table were used. Origin 8 software was used to obtain the nature of drying (drying kinetics) using drying data. The coefficient of determination (R2), reduced 2, and root mean square error (RMSE) were used to evaluate the fitness of the mathematical models tested against the experimental data. Greater R^2 values and the reduced χ^2 and RMSE values suggested a better goodness of fit (Karaaslan & Tuncer, 2008).

2.4 Color of wood apple pulp

To determine the color of the sample, a Hunter Color lab (Color Flex EZ) was utilized. Before the determination, a standard white and black ceramic plate was used to calibrate the colorimeter. The Hunter LAB is a color scale that operates based on the Opponent-Color Theory, which postulates that the receptors in the human eye perceive color as opposing pairs. From the L, a, and b values, the chroma (C), hue angle (α), and total color change (ΔE) were determined through calculations (Ansorena *et al.,* 1997).

$$C=\sqrt{a^2+b^2} \quad \text{…Eq. (3)}$$

$$\alpha=\tan^{-1}(b/a) \quad \text{…Eq. (4)}$$

$$\Delta E= \sqrt{(L_0- L_1)^2+(a_0-a_1)^2+(b_0+b_1)^2} \quad \text{…Eq. (5)}$$

Where, L_0 = L before drying, L_1 = L after drying, a_0 = a before drying, a_1 = a after drying, b_0 = b before drying, b_1 = b after drying

3. Results and Discussion

3.1 Tray drying of wood apple pulp at 60° C

The tray drying of wood apple pulp was done in triplicates in the month of March 2018. Based on the triplicate samples, the final values for moisture content (% db), moisture ratio, and drying rate (g/min) at 60°C were calculated.

3.1.1 Variation of moisture content with respect to time

The variation of moisture content (% db) of wood apple pulp with respect to time (min) dried by tray drying is shown in Fig. 1. The initial moisture content of the wood apple pulp was 61% (db) and then it is being dried up to moisture content 5.64 % (db). It was observed that in tray drying method, the required final moisture content was attained at 14 hours 30 minutes in tray drying at 60 ^{0}C. Fig. 1 shows a trend in which drying time increases and moisture content decreases. The findings show that during the first hour of drying, moisture loss was at its greatest magnitude, while later stages of drying witnessed a decrease in moisture loss.

3.1.2 Variation of drying rate with respect to moisture content

The relationship between drying rate (g water/ min per 100 g of dry matter) and moisture content (kg of dry material) in tray drying of wood apple pulp is presented in Fig. 2. The data indicate that the drying rate declined from 0.186 to 0.172 g moisture/ min/ 100 g of dry sample. The moisture removal rate was higher during the initial adjustment period, followed by a constant rate period, which suggests that internal mass transfer occurred via diffusion from an initial moisture content of 61% (db) to a final moisture content of 5.65% (db). Same results were observed in the previous findings for jambhul and wood apple using tray drying as reported by the authors (Sonawane & Arya 2015).

Table 1. Modeling and simulation of temperature and moisture distribution in wood apple during drying (Mathematical models used to test the drying kinetics)

SL No.	Model name	Model	References
1	Newton	MR= exp(-kt)	Fudholi *et al.,* 2011
2	Page	MR= exp(-kt^n)	Akpinar *et al.,* 2003
3	Modified page	MR= exp(-(kt)^n)	Akpinar *et al.,* 2003
4	Henderson & Pabis	MR= a exp (-kt)	Wankhade *et al.,* 2013
5	Exponential	MR= exp(-kt)	Cihan *et al.,* 2007
6	Wang & Sing	MR= 1 + at+ bt^2	Sigari *et al.,* 2015
7	Midilli	MR= a exp (-kt^n)+ bt	Zhang & Chen, 2016
8	Logarithmic	MR= a exp (-kt) + c	Akgun & Doymaz, 2005.
9	Verma	MR= a exp (-kt) + (1-a) exp (-gt)	Doymaz, 2005
11	Modified Page II	MR= exp(-k(t/L^2)^n)	Guan *et al.,* 2013

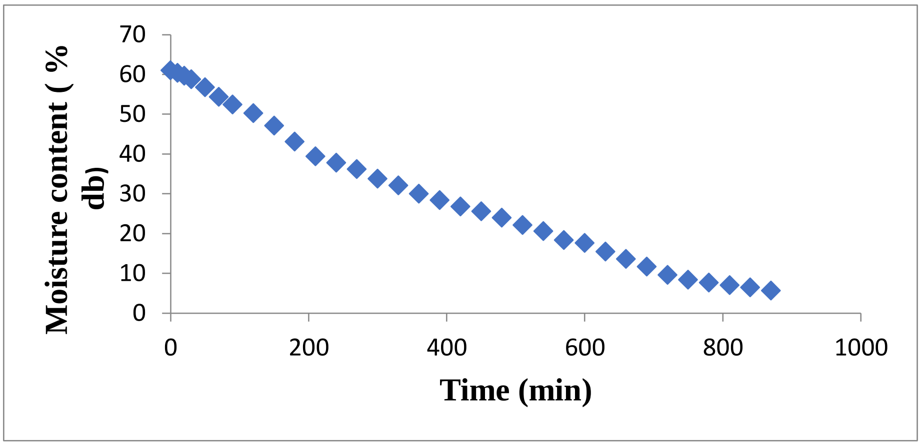

Figure 1. Variation of moisture content with respect to drying time in tray drying at 60°C of wood apple pulp

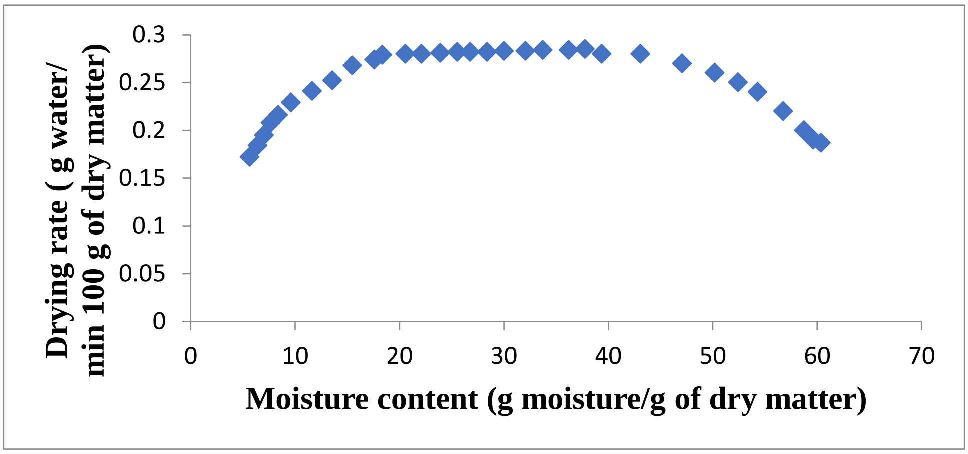

Figure 2. Variation of drying rate with respect to moisture content in tray drying of wood apple pulp

Table 2. Constant, coefficient of determination (R^2), reduced chi-square (χ^2) and root mean square error (RMSE) values for tray drying at 60°C of wood apple pulp

SL No.	Model name	Model constant	R^2	χ^2	RMSE
1	Newton	k = 0.51824	0.97362	6.67389×10^{-4}	0.03738
2	Page	k = 0.61182, n= 0.81932	0.96437	7.26435×10^{-5}	0.00945
3	Modified page	k = 0.52867, n= 0.81932	0.96437	7.26263×10^{-5}	0.00945
4	Henderson & Pabis	a = 0.96874, k = 0.48176	0.94318	6.47217×10^{-4}	0.03376
5	Exponential	k = 0.51824	0.97362	6.67389×10^{-4}	0.03738
6	Wang & Sing	a = 0.27436, b= 0.01689	0.86174	0.05385	0.23613
7	Midilli	a = 1.00124, k = 0.61375 n= 0.71253, b = -0.00251	0.99563	2.00793×10^{-5}	0.00439
8	Logarithmic	a = 0.95382, k = 0.53692, c = 0.01672	0.97345	5.62855×10^{-4}	0.04256
9	Verma	a= 0.28673, k = 1.68397 g= 0.38428	0.98749	4.66306×10^{-5}	0.00679
10	Modified Page II	k = 0.17735, L= 0.48678, n= 0.83628	0.96437	2.38296×10^{-5}	0.01372

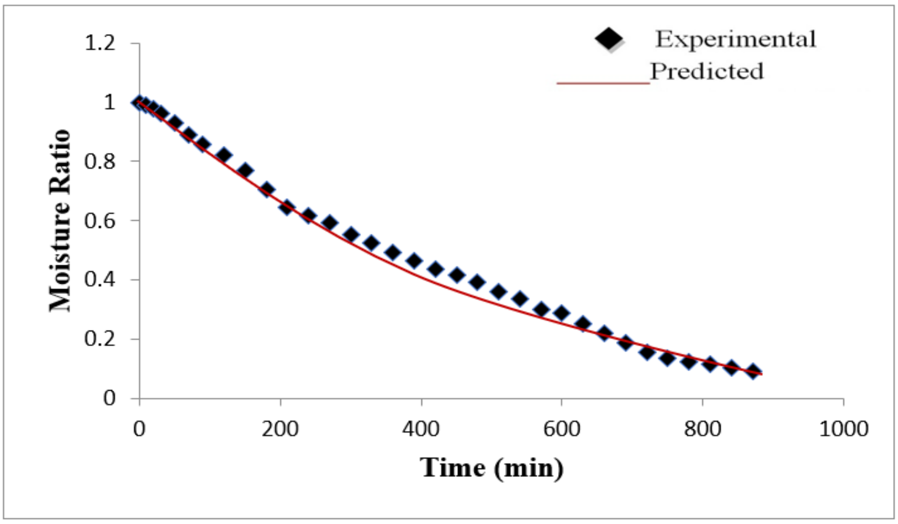

Figure 3. Variation of experimental and predicted curves (values) by using Midilli model moisture ratio with respect to time

To obtain moisture ratio with respect to time 10 models, namely, Newton, Page, Modified Page, Henderson and Pabis, Exponential, Wang and Sing, Midilli, Logarithmic, Verma and Modified Page II as listed in the Table 2 were used. Origin 8 software was used to obtain the nature of drying. The experimental data was compared to the models using the coefficient of determination (R^2), the reduced χ^2, and root mean square error (RMSE) methods in order to evaluate the fitness of the mathematical models that were used. A better goodness of fit, according to Wang et al. (2006), is demonstrated by higher R^2 values and lower χ^2 and RMSE values.

With the lowest average values of RMSE (0.00439), χ^2 (2.00793×10^{-5}) and R^2 (0.99563), the Midilli model was found to be the most accurate for predicting moisture transfer during the tray drying of wood apple pulp at 60°C. Fig. 3 shows the relationship over time between the experimental and predicted moisture ratios, with the initial moisture ratio at the start of the drying process falling from 1 to 0.0924.

3.1.3 Microwave drying of wood apple pulp at 180 W

Wood apple pulp was microwave dried in triplicates in the month of March 2018. Calculations were made from triplicate samples to determine the moisture content (% db), moisture ratio, and drying rate (g/min) at 180 W.

3.1.4 Variation of moisture content with respect to time

The moisture content (% db) of wood apple pulp was monitored during microwave drying and is presented in Fig. 4. The initial moisture content of 65.40% (db) decreased to 5.01% (db) after the drying process, which was completed within 1.4 hours at 180 W. As shown in the figure, the moisture content decreased steadily over time, with the highest rate of moisture loss occurring during the first hour of the subsequent drying period.

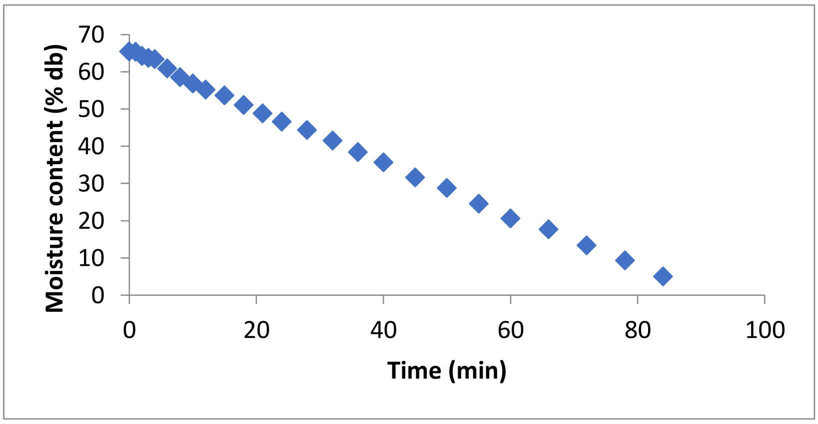

Figure 4. Variation of moisture content with respect to drying time in microwave drying at 180 W of wood apple pulp

3.1.5 Variation of drying rate with respect to moisture content

Fig. 5 depicts changes in drying rate (g water/min per 100 g dry matter) as a function of moisture content (kg dry matter) during microwave drying of wood apple pulp. The drying rate decreased from 2.11 to 2.12 g water/min per 100 g dry matter, according to the results. The drying of wood apple pulp in a microwave oven proceeded in two stages: a constant drying rate period and a falling rate period. This indicates internal mass transfer through diffusion, which reduced the initial moisture content of 65.40% (db) to 5.01% (db) at the end of the process. Krishna Murthy and Manohar (2012) reported comparable results for microwave-dried mango and ginger powder.

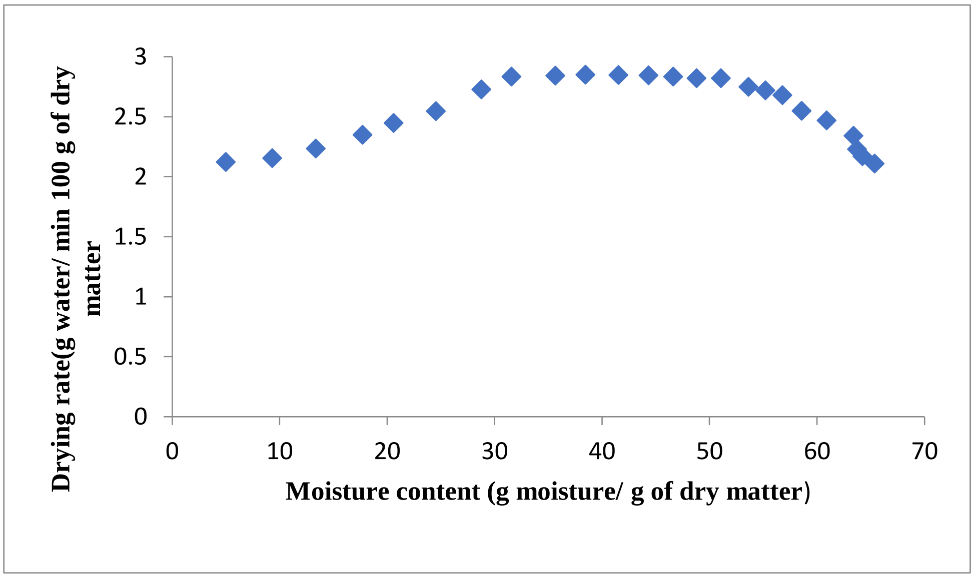

Figure 5. Variation of drying rate with respect to moisture content in microwave drying at of 180 W wood apple pulp

Table 3. Constant, coefficient of determination (R^2), reduced chi-square (χ^2) and root mean square error (RMSE) values for microwave drying at 180 W of wood apple pulp

SL No.	Model name	Model constant	R^2	χ^2	RMSE
1	Newton	k = 0.01237	0.98634	5.5827×10^{-4}	0.0241
2	Page	k = 0.05844, n= 0.66641	0.99668	2.24749×10^{-5}	0.00459
3	Modified page	k = 0.01542, n= 0.66839	0.99668	2.21798×10^{-5}	0.00456
4	Henderson & Pabis	a = 0.98375, k = 0.01255	0.98571	5.46124×10^{-4}	0.02418
5	Exponential	k = 0.01237	0.98634	5.5827×10^{-4}	0.0241
6	Midilli	n = 7.05684, k = 1.46328 a= 1, b = 6.67411×10^{-6}	0.77853	0.00967	0.09864
7	Logarithmic	a = 0.97345, k = 0.01321, c = 0.00952	0.98684	4.84336×10^{-4}	0.02253
8	Verma	a= 0.45732, k = 0.04097 g= 0.00697	0.00694	2.41234×10^{-5}	0.00477
9	Modified Page II	k = 0.13643, L= 1.76684, n= 0.66828	0.99668	2.24165×10^{-5}	0.00475

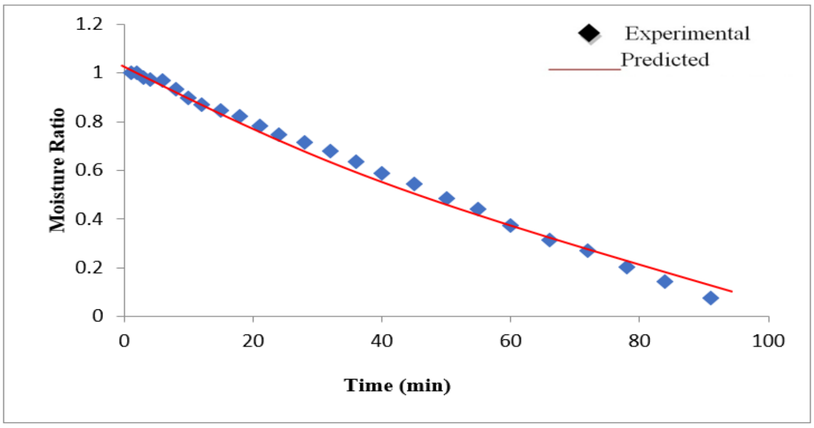

Figure 6. Variation of experimental and predicted curves (values) by using Modified page model moisture ratio with respect to time

The modified page model was discovered to be the most effective at predicting the moisture transfer of wood apple pulp during microwave drying at 180 W. This judgement was made in light of the model's low average RMSE (0.00456), χ^2 (2.21798×10^{-5}) values, which point to the model's predictions' accuracy (Krishna Murthy & Manohar, 2012) in tray drying. Fig. 6 shows the change in moisture ratio over time as wood apple pulp is microwave dried at 180 W, as predicted by the modified page model and contrasted with the experimental results. The model was found to have the lowest average RMSE and to be the most accurate at predicting the moisture transfer in this process. During drying, the moisture ratio dropped from 1 to 0.076733.

3.3 Drying characteristics of wood apple pulp in tray dryer and microwave

The increase in vapour pressure within the product, which causes a faster migration of moisture to the product surface, can be used to explain the decrease in total drying time observed with increasing temperature. The drying curve's steeper slope and overall increase in drying rate are both caused by this temperature rise. For wood apple pulp, drying took place primarily during the periods of constant drying rate and falling rate. According to a study by Zhu and Jiang (2014), the improvement in convective heat transfer between the product and the air was responsible for the increase in drying rate.

3.4 Evaluation of model parameters

The experimental moisture removal rate during drying was converted to a dimensionless moisture ratio (MR), which decreased over time. The difference between moisture ratios increased gradually from the beginning to the end of drying, as reported by Doymaz et al. (2005). Empirical models shown in Table 2 and 3 were fitted to determine the experimental moisture ratio as a function of drying time. The models consistently yielded high coefficient of determination (R^2) values in the range of 0.995-0.996, indicating their ability to satisfactorily describe the fast drying of wood apple pulp, as shown in Fig. 3 and 6.

3.5 Influence of Drying methods on colour of WAPP

It was observed that total color change in tray dryer and microwave drying of WAPP were 42.68 (60 ^{o}C) and 50.07 (180 W). The highest total color change was observed in microwave drying at 180 W due to high microwave power and lowest was observed in tray drying at 60 ^{o}C due to low drying temperature.

Table 4. Colour determination of wood apple pulp and WAPP

Color Determination of Sample	**L**	**a**	**b**	**Total Color change (ΔE)**			**Chroma (C)**	**Hue (α)**
Fresh Wood Apple Pulp	72.39 ± 0.14	10.37 ± 0.20	31.05 ± 0.11	-			32.73 ± 0.18	71.50 ± 0.26
Wood Apple Pulp Powder	**L**	**a**	**B**	**Dryer**	**Temperature/ Power level**	**ΔE**	**C**	**α**
1	32.83 ± 0.27	17.06 ± 0.13	16.48 ± 0.19	Tray Dryer	60 ^{0}C	42.68 ± 0.34	23.71 ± 0.17	43.83 ± 0.11
2	26.79 ± 0.31	7.78 ± 0.25	10.51 ± 0.24	Microwave	180 W	50.07 ± 0.26	13.07 ± 0.19	53.47 ± 0.14

Values are mean ± from triplicate analyses.

4. Conclusions:

The drying kinetics of wood apple was investigated in a laboratory-scale tray dryer and microwave oven. Midilli model was found to be the best fitted or tray drying at 60°C to predict the moisture transfer of pulp of wood apple owing to the lowest average values of RMSE (0.00439), χ^2 (2.00793×10-5) and R^2 (0.99563) in tray drying. At the beginning moisture ratio was 1 and decreased to 0.0924. Modified page model was found to be the best fitted one for microwave drying at 180 W to predict the moisture transfer of pulp of wood apple owing to the lowest average values of RMSE (0.00456), χ^2 (2.21798×10^{-5}) and R^2 (0.99668). Tray dryer gave better result as compared to microwave dryer in view of drying kinetics. Evaluation showed the best fitted model with tray dryer as compared with microwave drying. Hence for drying of wood apple pulp it has been recommended to use tray dryer.

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