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Drying Kinetics and Mathematical Modeling of Bottle Gourd

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Authors' contributions

This work was carried out in collaboration among all authors. Author MI designed the study, performed the statistical analysis. Author ART wrote the protocol and wrote the first draft of the manuscript. Author RN managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Aims: The aim of this study was to evaluate the drying behavior of bottle gourd slices using tray dryer.
Study Design: The bottle gourd slices were dried in a tray dryer at 50, 55, 60, 65 and 70 ± 1°C. The moisture loss was determined by gravimetry. Readings were taken at 30 minutes till constant weight was observed.
Place and Duration of Study: Experiments were done in Department of Food Science and Technology, MPKV Rahuri and completed within 12 months.
Methodology: The drying curves were fitted into four different drying models (Henderson, Logarithm, Page and Modified Page) widely accepted for modeling of agricultural materials drying. The best model describing the drying process was selected based on the low RMSE, low χ^2, and high R^2.
Results: The drying time at 50, 55, 60, 65 and 70ºC drying temperature were 630, 570, 450, 420 and 360 min respectively for bottle gourd slices. By comparing time required at 50ºC and 60ºC

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temperature and 60ºC and 70ºC there were 28.57% and 20.00% reduction in drying time respectively. At the beginning of a drying process, the moisture content of fresh bottle gourd was 92.09% (w.b.) which is reduced to 7.08% (wb). The drying rate decreased with increase in drying time. The drying rates were as high as 0.89 at 55ºC and as low as 0.1 at almost all the temperatures. The R^2 values ranged from 0.788 to 0.954, the adjusted R^2 values also ranged from from 0.777 to 0.951, χ^2 values between 0.029 and 0.681, and *RMSE* values between 0.0533 and 0.3742.

Conclusion: Henderson and Pabis model was found to be a better model for describing the drying characteristics of bottle gourd at all temperatures. The product quality was found well at all the temperature.

Keywords: Bottle gourds; drying; drying rate; mathematical models.

1. INTRODUCTION

Bottle gourd (*Lagenaria siceraria* L.) is an important vegetable crop of tropical and sub-tropical regions of the world belonging to family Cucurbitaceae. It is most popular in Indo-Pakistan sub-continent and cultivated throughout India. In Maharashtra it is being cultivated in all over Maharashtra [1].

Lagenaria siceraria fruit is traditionally used for its cardio-protective, cardiotonic, general tonic and aphrodisiac properties. It is also used in treatment of various allergic and inflammatory disorders like bronchial asthma, rhinitis, bronchitis, and rheumatism. Various extracts of fruit of *Lagenaria siceraria* were found to have anti-inflammatory, analgesic, hepatoprotective, anti-hyperlipidemic, diuretic and antibacterial activities [2].

Bottle gourd (*Lagenaria siceraria*) fruit is a good source of vitamin B complex and choline along with fair quantum of vitamin C [3]. Bottle gourd contents 1.6% choline on a dry weight basis; a precursor to acetylcholine, a chemical used to transfer nerve impulses and hence, it is believed to have neurological effects [4]. Bottle gourd contains cucurbitacins, polyphenols and two sterols namely; campesterol and sitosterol [5]. It is well known for their immunomodulatory, hepato-protective, antioxidant, anti-stress, adaptogenic, analgesic, anti-inflammatory, cardio protective, cardio tonic, antihyperlipidemic, diuretic, aphrodisiac, alternative purgative, antidote to certain poisons and cooling properties [6,7,8].

The post-harvest losses of fruits and vegetables are estimated to be 30-40% of the production [9]. Drying plays an important role in preservation of agricultural products by reducing its water activity [10,11]. Therefore, large quantities of food products are dried to improve shelf life, reduce packaging costs, lower weights, enhance appearance, retain original flavour and maintain nutritional value.

Modelling of drying processes and kinetics is a tool for process control and necessary to choose suitable method of drying for a specific product. The developed models are used for designing new drying systems as well as selection of optimum drying conditions and for accurate prediction of simultaneous heat and mass transfer phenomena during drying process. It also leads to produce the high quality product and increases the energy efficiency of drying system.

Many researchers studied the mathematical modelling of various fruits and vegetables viz. apple, apricot, mango, banana, date palm, basil leaves, beetroot, carrot, chilli, garlic, onion, mint leaves etc [12].

In the present study, focus is on the studying drying characteristics of bottle gourd using tray dryer. The paper discusses the experiments conducted for drying of bottle gourd and fitting of mathematical models for drying.

2. MATERIALS AND METHODS

2.1 Raw Materials and Sample Preparation

Freshly harvested matured bottle gourds having initial moisture content around 92% (w.b.) were obtained from the local market of Rahuri, Dist. Ahmednagar. The samples were cleaned, washed, peeled and cut into slices (3-5 mm) using stainless steel kitchen knife. These slices were blanched, cooled and spread in a thin layer form inside stainless steel trays of tray dryer for onward drying.

The samples were dried at 50, 55, 60, 65 and 70 ±1ºC temperature. Its moisture loss was determined using gravimetry in triplicate at 30 min. interval until a constant weight was observed. The samples moisture content and drying rate were determined at various temperatures using equation 1 and 2.

Moisture content (Mc), % w.b.

$$Mc = \frac{\mathrm{Mi} - \mathrm{Md}}{\mathrm{Mi}} \times 100 \quad (1)$$

where *Mi* is the mass (kg) of sample before drying and *Md* is the mass of sample after drying.

Drying rate (Rd)

$$Rd = \frac{\mathrm{Mi} - \mathrm{Md}}{\mathrm{t}} \quad (2)$$

where *Mi* is the mass of sample before drying; *Md* is the mass of sample after drying and 't' is time in min.

2.2 Mathematical Modeling

The experimental drying data of bottle gourd at different drying temperatures were fitted into four r drying models (Table 1).

Moisture ratio was calculated using equation 3:

$$MR = \frac{\mathrm{M} - \mathrm{Me}}{\mathrm{Mci} - \mathrm{Me}} \quad (3)$$

where, MR = dimensionless moisture ratio; M = moisture content at any time (kg water/kg dm); Me = the equilibrium moisture content (kg water/kg dm) and; Mci = initial moisture content (kg water/kg dm) [17,14].

2.3 Correlation Coefficients and Error Analysis

The ability of the tested mathematical model to represent the experimental data was evaluated through the correlation coefficient (R^2), the reduced ($\chi 2$) and the root mean square error (RMSE) parameters. The higher the R^2 and lower the $\chi 2$ and RMSE values, the better is the fitting procedure [18,19]. The regression analysis was performed by using the SAS software. These parameters are defined as follows:

$$\chi 2 = \sum \frac{(\mathrm{MRpre,i} - \mathrm{MRexp,i})^2}{\mathrm{MRpre,i}}$$

$$\mathrm{RMSE} = \left[\frac{\frac{1}{\mathrm{N}}\sum_{\mathrm{i=1}}^{\mathrm{N}}(\mathrm{MRexp,i} - \mathrm{MRpre,i})^2}{N}\right]^{\frac{1}{2}}$$

where, MRexp,i and MRpre,i are the experimental and predicted moisture ratio respectively, N is the number of observations and z is the number of parameters.

3. RESULTS AND DISCUSSION

3.1 Fitting of Drying Curves

The moisture content of bottle gourd decreased with increased drying time at various drying temperature. It showed that the moisture removal is rapid during the initial period of drying than in next phase of drying which shows constant rate for removal of moisture (Fig. 1). The moisture removal was influenced by surface area of the slices and also by drying temperature. The results revealed that as the drying temperature increased the moisture removal increased and resulted in decrease in drying time. The drying time at 50, 55, 60, 65 and 70ºC drying temperature were 630, 570, 450, 420 and 360 min respectively for bottle gourd slices.

3.2 Drying Rate

The drying rate rapidly increased and then slowly decreased as drying progressed (Fig. 2). In general, it was observed that drying rate reduces with time or with the reduction of moisture content. The drying process took place in the falling rate period. Similar results have been observed in the drying of different fruits and vegetables: kiwifruit [20]; hazelnut [21]; carrot pomace [22]; pineapple, mango, guava and papaya [23] and apple pomace [18].

Table 1. Drying models

Model No.	Name	Model equation	References
1	Page	$\mathrm{MR} = \exp(-\mathrm{kt}^{\mathrm{n}})$	[13]
2	Modified Page	$\mathrm{MR} = \exp[-(\mathrm{kt})^{\mathrm{n}}]$	[14]
3	Henderson and Pabis	$\mathrm{MR} = \mathrm{a}\exp(-\mathrm{kt})$	[15]
4	Logarithmic	$\mathrm{MR} = \mathrm{a}\exp(-\mathrm{kt}) + \mathrm{c}$	[16]

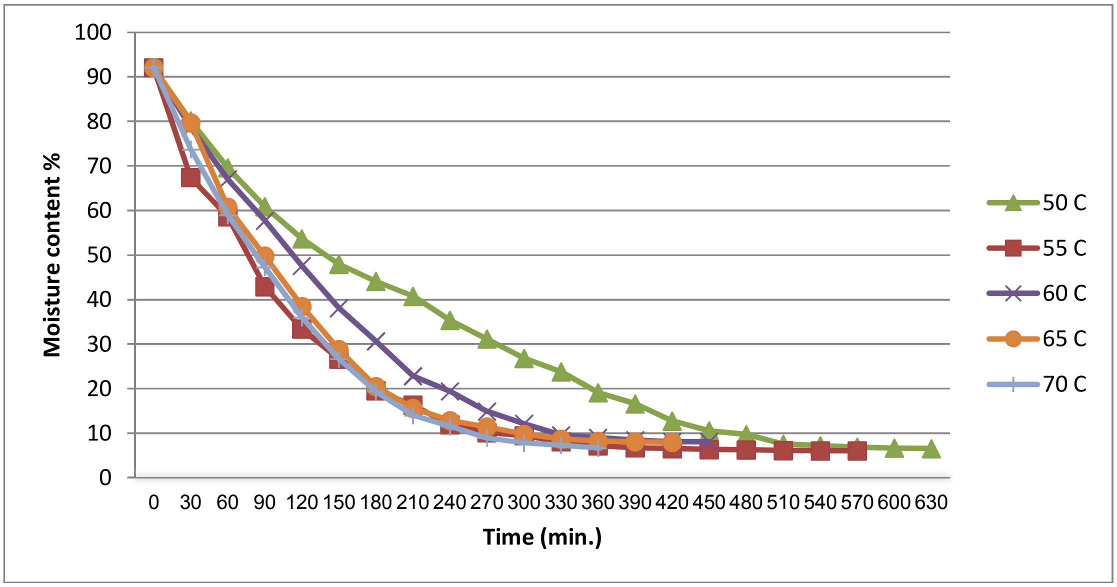

Fig. 1. Moisture content of bottle gourd as a function of drying time at different drying temperatures

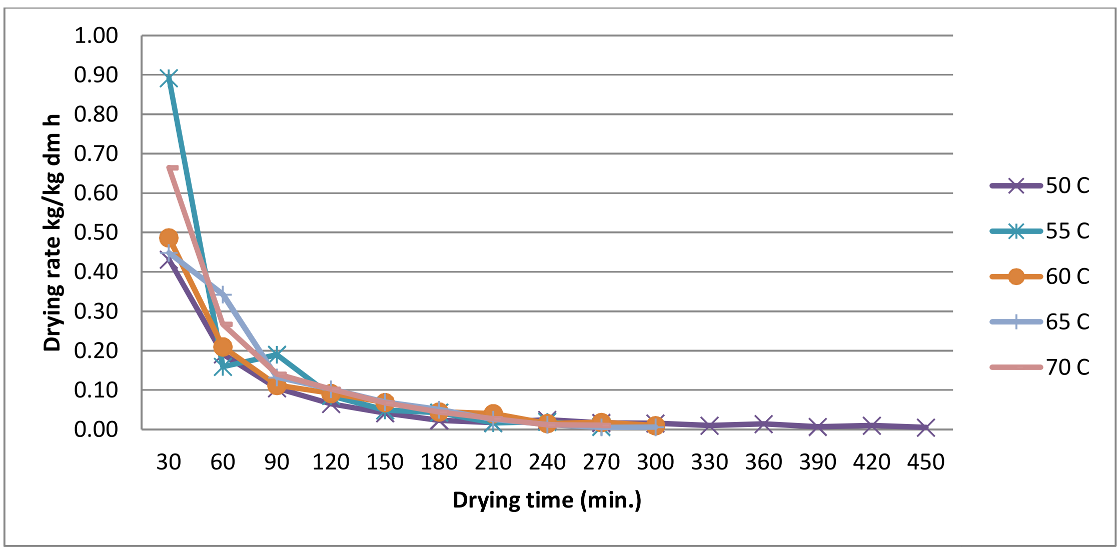

Fig. 2. Drying rate of bottle gourd slices at different drying temperatures

The moisture content of the material was very high during the initial phase of the drying which resulted in a higher absorption of heat and higher drying rates due to the higher moisture diffusion. As the drying progressed, the loss of moisture in the product caused a decrease in the absorption of heat and resulted in a fall in the drying rate. This indicated that the drying temperature had a crucial effect on the drying rate. Similar findings were reported in previous studies by Wang et al. [18]; Soysal et al., [24] and Therdthai and Zhou [25].

3.3 Modeling of Drying Characteristics

The first set of experiments was conducted to obtain moisture curves at different temperatures (50 to70ºC) as shown in Fig. 1. Moisture content decreased from 92.09% to 7.08% of wet basis at all the temperatures whereas the drying time

Table 2. Results of the model fitting statistics of various thin layer drying models for bottle gourd slices

Sr. no.	Model Name	Temp (°C)	k	n	R^2	Adj R^2	χ^2	RMSE	P	% Error Modulus
1	Page	50	0.0629 ± 0.1562	-0.2417 ± 0.0274	0.788	0.777	0.166	0.1062	3.3E-16	0.65174
		55	0.0629 ± 0.0839	-0.2412 ± 0.0151	0.934	0.931	0.032	0.0533	3.7E-16	0.1415
		60	0.0676 ± 0.1267	-0.2138 ± 0.0236	0.854	0.844	0.044	0.0721	2.8E-16	0.21563
		65	0.0643 ± 0.1012	-0.2406 ± 0.0188	0.921	0.915	0.029	0.0576	5.6E-16	0.15625
		70	0.0603 ± 0.1446	-0.2606 ± 0.0275	0.882	0.872	0.046	0.0768	6.3E-16	0.28714
2	Modified Page	50	0.2604 ± 0.1562	-0.2417 ± 0.0274	0.788	0.777	0.166	0.1062	3.3E-16	0.65174
		55	0.2606 ± 0.0839	-0.2412 ± 0.0151	0.934	0.931	0.032	0.0533	3.7E-16	0.1415
		60	0.3161 ± 0.1267	-0.2138 ± 0.0236	0.854	0.844	0.044	0.0721	2.8E-16	0.21563
		65	0.2673 ± 0.1012	-0.2406 ± 0.0188	0.921	0.915	0.029	0.0576	5.6E-16	0.15625
		70	0.2314 ± 0.1446	-0.2606 ± 0.0275	0.882	0.872	0.046	0.0768	6.3E-16	0.28714
3	Handerson and Pabis	50	-0.2417 ± 0.0274	15.8875 ± 0.1562	0.788	0.777	0.166	0.1062	3.3E-16	0.65174
		55	-0.2412 ± 0.0151	15.9086 ± 0.0839	0.934	0.931	0.032	0.0533	3.7E-16	0.1415
		60	-0.2138 ± 0.0236	14.7949 ± 0.1267	0.854	0.844	0.044	0.0721	2.8E-16	0.21563
		65	-0.2406 ± 0.0188	15.5465 ± 0.1012	0.921	0.915	0.029	0.0576	5.6E-16	0.15625
		70	-0.2606 ± 0.0275	16.5767 ± 0.1446	0.882	0.872	0.046	0.0768	6.3E-16	0.28714
4	Logarithmic	50	-1.0097 ± 0.0965	9.8567 ± 0.5505	0.839	0.831	0.681	0.3742	1.1E-15	1.01652
		55	-1.0989 ± 0.0571	10.3521 ± 0.3185	0.954	0.951	0.147	0.2024	8.4E-16	0.2355
		60	-1.0487 ± 0.1007	10.3977 ± 0.5412	0.886	0.877	0.253	0.3079	-6E-17	0.4475
		65	-1.1143 ± 0.0783	10.3274 ± 0.4162	0.94	0.935	0.134	0.2291	2E-15	0.27563
		70	-1.1669 ± 0.1032	10.4352 ± 0.542	0.914	0.907	0.203	0.2879	2E-15	0.48857

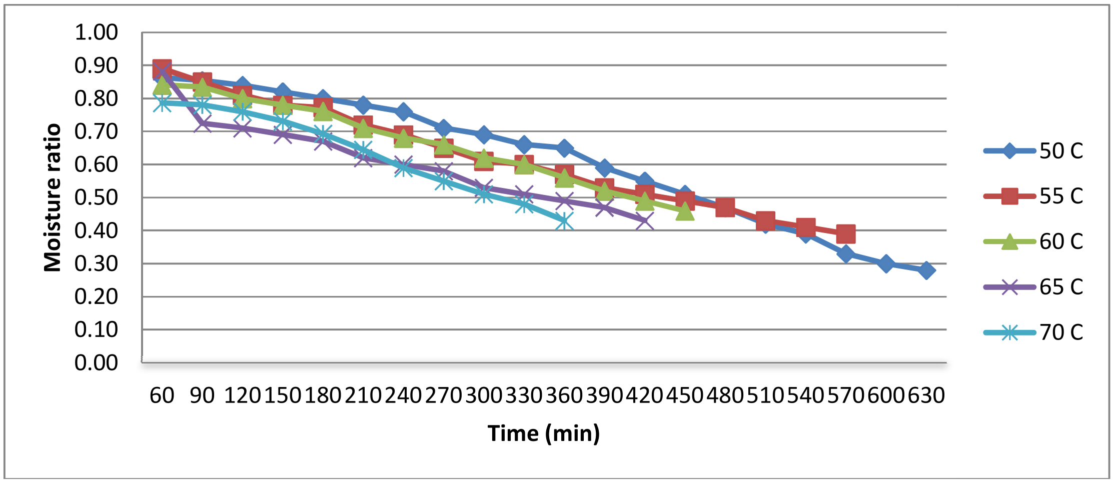

Fig. 3. Moisture ratio of drying of bottle gourd as a function of drying time at different drying temperatures

decreased from 630 to 360 min; lowest time at highest temperature. The first step of modeling was to define drying curves for beet. Drying rates (Rd, kg water evaporated/m^2·min) were estimated as per the given equation. Drying rate as a function of moisture content was plotted (Fig. 2). After a short initial time of sample heating, constant rate drying was observed for some time. As expected, at higher drying temperatures, constant drying rate was higher to reach the critical moisture content in lesser time. At lower drying temperatures, constant drying rate was lower and moisture kept on diffusing to the surface resulting in lower critical moisture content. It was seen that at higher moisture content and increases in temperature increased the drying rate considerably compared to lower moisture content, which was almost negligible towards the end.

In the next step, dimensionless moisture ratio was calculated and moisture ratio as a function of drying time is given in Fig. 3. It can be seen that moisture ratio decreases exponentially with time. This data was further used for mathematical modeling.

The four drying models were compared in terms of the statistical parameters R^2, $\chi^2$and RMSE to describe the drying curves of bottle gourd at different temperatures. Nonlinear regression using the least square method was used to calculate the constants and coefficients. Constants and coefficients, correlation regression coefficients, RMSE, and χ^2 obtained for all the models by statistical computing are summarized in Table 2. The best model describing the drying process was selected based on the low RMSE, low χ^2, and high R^2 [26] For the current experimental data, the R^2 values for some models were greater than 0.90, indicating a good fit. The R^2 values varied between 0.788 and 0.954, the Adj R^2 is also calculated for the better fit of the model which was vary from 0.777 to 0.951, χ^2 values between 0.029 and 0.681, and *RMSE* values between 0.0533 and 0.3742 (Table 2). The model fitting procedure also indicated that the results obtained with the Henderson and Pabis model might be used to model the drying of bottle gourd in different temperatures.

Similar model has been recommended by Karathanos & Belessiotis [27] for most of the fresh and semidried-fruits.

4. CONCLUSION

Increased in air drying temperature decreased the drying time. Drying mostly occurred in the falling rate period. Henderson and Pabis model was found to be a best fit model for describing the drying characteristics of bottle gourd at all temperatures. The product quality was found well at all the temperature. Finally, it can be concluded that drying can be used for the preservation of bottle gourd slices.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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