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# Mathematical modelling of hot air drying of water chestnut kernels

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**Abstract**
Drying characteristics of water chestnut kernels were evaluated at different air temperatures (50, 60 and 70 °C) in commercially available hot air tray dryer and sun drying. Drying rate of water chestnut kernels 1.1880, 1.6181, 2.6688 and 0.7249 g water/ g dry matter-min were found at drying temperatures of 50, 60, 70 ºC and sun drying (38 ± 5 ºC), respectively at 15 min time interval. The Midilli–Kucuk model fitted better on the basis of higher $R^2$ value (0.99978) and lower values of $X^2$ and RSME values as 0.0000162 and 0.004028784 at 60 °C.

**Keywords:** Water chestnut kernel, hot air drying, drying rate, mathematical modelling

## Introduction

Water chestnut (*Trapa Natans*) belonging to the monogeneric family trapaceae. Water chestnut had been introduced as an ornamental plant by Europe. Its spreading is limited because of the large sinking nuts, but the fruit has persisted and spread northern, central and western states. It is aquatic angiospermic free floating plant which generally grown naturally in fresh water saturated land, marshes, ponds, bogs, sluggish reaches of river, swamps and brackish reaches of estuaries in both tropical and subtropical countries. It is one of the most important underutilized agricultural fruit crops. This fruit crops grow during the warmer part of the year and die out with the start of severe winter (Hummel and Kiviat, 2004) [11].

The fruit is used as a substitute for cereal in the Indian subcontinent during fasting days. In northern state of India, the harvested water chestnuts drying over mud Chulha up to 10-12 days, after that performing grinding to make flour. Rest of the place, mostly the drying of whole water chestnut is generally done by the “sun drying” method. Followed by roasting in the sand in large iron pans which account huge losses of time results less kernel recovery, low flour yield and in addition, produces the product of low quality. The dried flour is very low in fat and easily digestible and is helpful for dieting. Its flour is consumed in the form of sweet dish and for making bread, puri, halwa on several religious occasions. Besides, it has considerable importance in the manufacturing of product like biscuits; infants milk formula, starch as well as alcohol. Thus, this flour is gluten free and can be good replacement for wheat flour due to celiac disease caused by gluten intolerance. Effect of two drying temperatures 40 and 60 ºC on physicochemical properties of water chestnut. The morphological characteristics of fresh starch granules were characterized by round or oval shape having diameter length ranging from 3-15 mm. After drying and rehydration at 100 ºC, the granules appeared more shapeless and the surfaces were quite rough. The changes also caused more open pore volume fraction in samples dried at 60 ºC, than those dried at 40 ºC and many more than fresh samples. In this study, calorimetric behavior of starch and simple sugar changes after chestnut drying and rehydration were observed (Attanasio *et al*., 2004) [2].

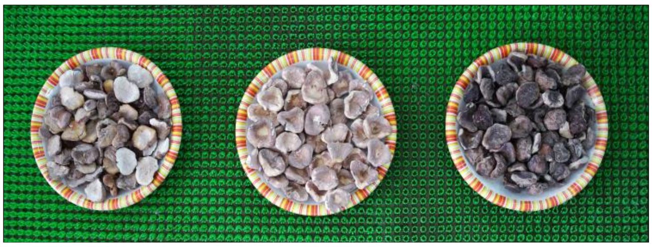
Drying of water chestnut slices at higher temperature and found quicker removal of water with shorter drying times. Drying rate of chestnuts was experimentally determined. The experiments were carried out in a pilot-plant scale dryer, with a closed air circuit, assisted by a heat pump. Experimental conditions were investigated; temperature (45-65 °C), relative humidity (20-40 %), and air velocity (1.8–2.7 m $s^{-1}$). The results show the drying rate was faster when the driving force was higher and the physical resistances were eliminated (Moreira *et al.*, 2004) [13]. Drying effect of air temperature and pretreatments on drying kinetics of other root crops like sweet potato slices and found that drying took place in the falling rate period and Page’s model was found well to describe the drying behavior (Singh *et al*., 2006) [18].

**Materials and Methods**

Fully matured fresh water chestnut red variety (*Trapa natan*) was procured from local market of Dahod, Gujarat. Examined each batch of water chestnut and care was taken to have water chestnut should free from any bruised. The water chestnut corms were then washed under running portable water to remove surface dirt and then air dried.

**Drying of Water Chestnut Kernels**

Water chestnut kernels were dried in a tray dryer (NOVA make: Instruments Pvt. Ltd., Ahmedabad, Gujarat) at 50, 60 and 70 °C temperature at constant air velocity of 1 m/s. In each drying experiment, about 1200 g of water chestnut kernels were used. Moisture losses of samples were recorded at 15 min time intervals throughout the experiment. The experiments were repeated four times and data were recorded (Plate-1). Drying was carried out till the equilibrium moisture content achieved.



**50 °C** **60 °C** **70 °C**

**Plate 1:** Dried samples of tray dryer

Open sun drying experiments were also carried out as control during month of March-April, 2020 under the clean climatic conditions at Dahod. Each experiments were started at 8.00 am and continued till 6.00 pm. To determine the moisture loss of samples during experiments, water chestnut kernels were taken out from the perforated mesh tray and weighed 20 min time interval at the beginning stage of drying to 1 h during the last stage of drying process.

**Mathematical modeling of drying curves**

Moisture ratio (MR) of samples was obtained using the equation as below.

$$MR = \frac{M_t - M_e}{M_0 - M_e}$$

Where $M_t$, $M_0$ and $M_e$ are the moisture content at anytime, initial moisture content and equilibrium moisture content of samples (kg water / kg dry matter), respectively. The moisture ratio (MR) was simplified to $\frac{M}{M_0}$ instead of $\frac{M_t - M_e}{M_0 - M_e}$ by investigator Diamante *et al.*, 1993 and Adedeji *et al.*, 2008, because fluctuation of relative humidity of the drying air. The drying rate (DR) is expressed as the amount of the evaporated moisture over time. The drying rates calculated by using the following equation.

$$DR = \frac{Mt_1 - Mt_2}{t_2 - t_1}$$

Where, $t_1$ and $t_2$ are different drying times (min) during drying; $Mt_1$ and $Mt_2$ are the moisture content of samples (kg water / kg of dry matter) at time $t_1$ and $t_2$, respectively.

**Thin layer drying models for WCK**

The experimental moisture ratio data of water chestnut samples obtained were fitted to 12 most commonly used thin layer drying models. Non-linear least square regression analysis was performed using Origin pro-8 program. Three criteria of statistical analysis have been used to evaluate different models, the coefficient of determination ($R^2$), reduced chi-square $(\chi^2)$ and root mean square error (RMSE).

These parameters can be calculated as,

$$\chi^2 = \frac{\sum_{i=1}^{N}\left(MR_{\exp,i} - MR_{pre,i}\right)^2}{N - Z}$$

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{N}\left(MR_{pre,i} - MR_{\exp,i}\right)^2\right]^{1/2}$$

Where, $MR_{\exp i}$ and $MR_{prei}$ are the experimental and predicted dimensionless moisture ratios respectively, N is number of observation and Z is number of constants in the models. For quality fit, $R^2$ value should be higher whereas $\chi^2$ and RMSE should be lower.

Bulk sample of water chestnut kernels was produced using standardized pretreatment i.e 60 min in hot water treatment and 120 min residence time and optimized decorming parameter i.e. 240 rpm rotating speed of abrasive surface disk (16 no. grit size) for 14 kg feed samples and time duration 13 min. Water chestnut kernels so produced were dried under sun (as control) as well as in tray dryer at 50, 60 and 70 °C in single layer (bed thickness) in the month of March, 2020 when temperature was about 38 ± 5 °C.

**Results and Discussion**

The initial moisture content of water chestnut kernels was about 447.95% (db). The samples were dried to moisture content 7.71, 6.91, 5.85% and 8.62% (db) achieved at 50, 60 and 70 ºC and for sun drying approx, 38 ± 5 ºC, respectively.

The moisture content versus drying time curves of water chestnut kernels at different temperatures are shown in Fig.1. Time required to dry the samples were 1350, 1155 and 810 min for 50, 60 and 70 ºC drying temperatures respectively. While, 2640 min required to achieve EMC to sun dried sample. All the curve showed falling rate behavior and confirmed findings with Singh *et al.*, (2008) [17].

The moisture ratio progressively decreased as the drying temperature increased Fig.2. It took 310, 285, 210 and 730 min to remove the half of moisture at 50, 60, 70 ºC and sun drying temperature 38 ± 5 ºC, respectively which is one fourth of total drying time.

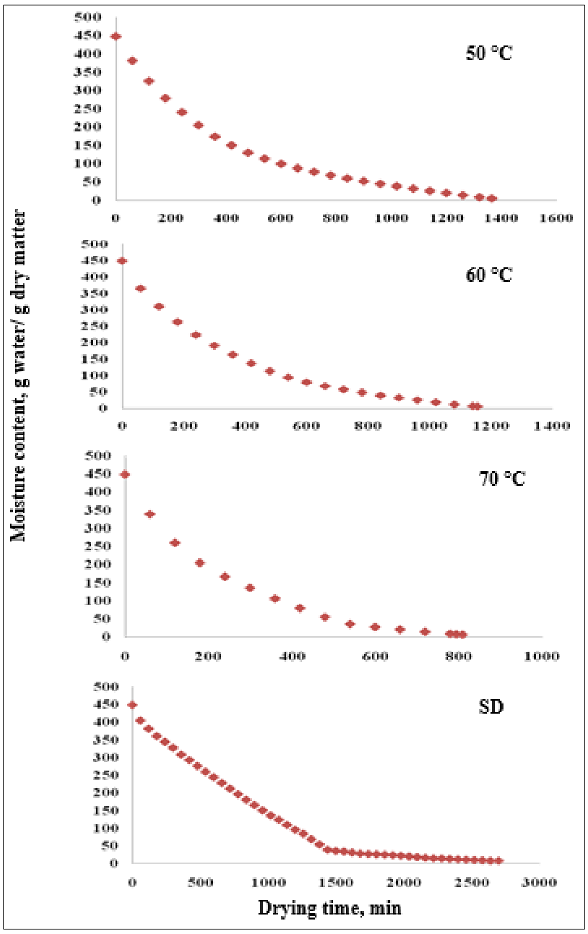



**Fig 1:** Moisture content versus drying time of WCK at 50, 60, 70 ºC and Sun drying

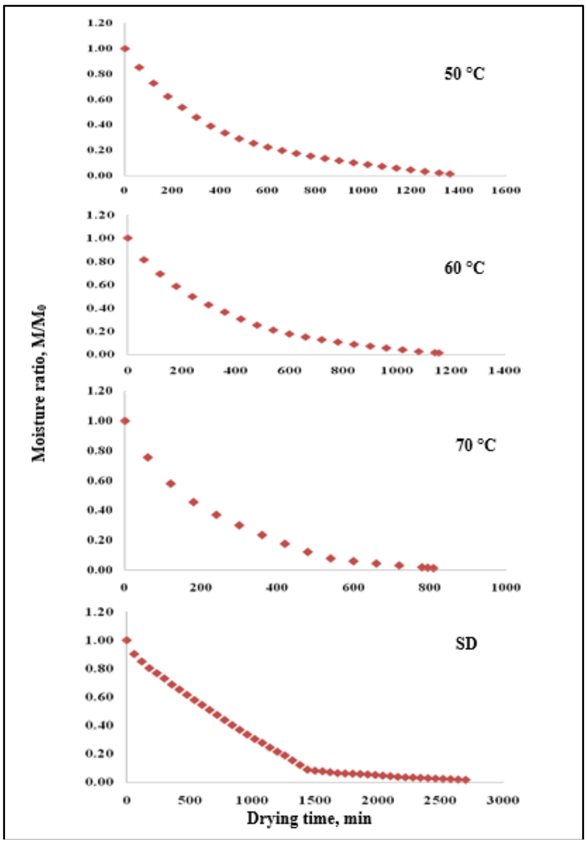



**Fig 2:** Moisture ratio versus drying time of WCK at 50, 60, 70 ºC and Sun drying

Drying rate of water chestnut kernels 1.1880, 1.6181, 2.6688 and 0.7249 g water/ g dry matter-min were found at drying temperatures of 50, 60, 70 ºC and sun drying (38 ± 5 ºC), respectively at 15 min time interval. However, the minimum drying rate was observed as low as 0.0146 g water/ g dry matter-min for sun drying condition. The average drying rate

0.3225, 0.3769, 0.5343 and 0.1517 g water/ g dry matter-min were observed at temperature 50, 60, 70 °C and sun drying conditions. The maximum drying rate was about three times more than the average drying rates. It was found that the drying rates were higher at high drying temperatures. Average drying rate increased by 16.87 %, 41.76 % and 71.60 % (Sun drying condition) for every 15 ºC rise in temperature from selected temperature range 50 to 70 ºC. These observations are concomitance with results reported by (Dimante and Munro, 1991) [5], Wang *et al*., (2006) [22] and Navneet *et al*., (2012) [14].

Effect of drying temperatures on drying time was found falling rate period. It can be seen that drying of water chestnut kernels at higher temperature resulted in quicker removal of water and shorter drying times Fig.3.

It can be seen that at higher moisture content, increase in temperature has more considerable effect on the drying rates than at lower moisture content, which was negligible at the end. The reduction in drying is mainly due to reduction in moisture content as drying advances. The rate of migration of moisture from inner surface to outer surface decreases at the final stage of drying and hence, lowers drying rates. Similar results were reported by Babalis *et al*., (2006) [3] for drying of figs, (Falade and Abbo, 2007) [7] and Rajkumar *et al*., (2007) [16].

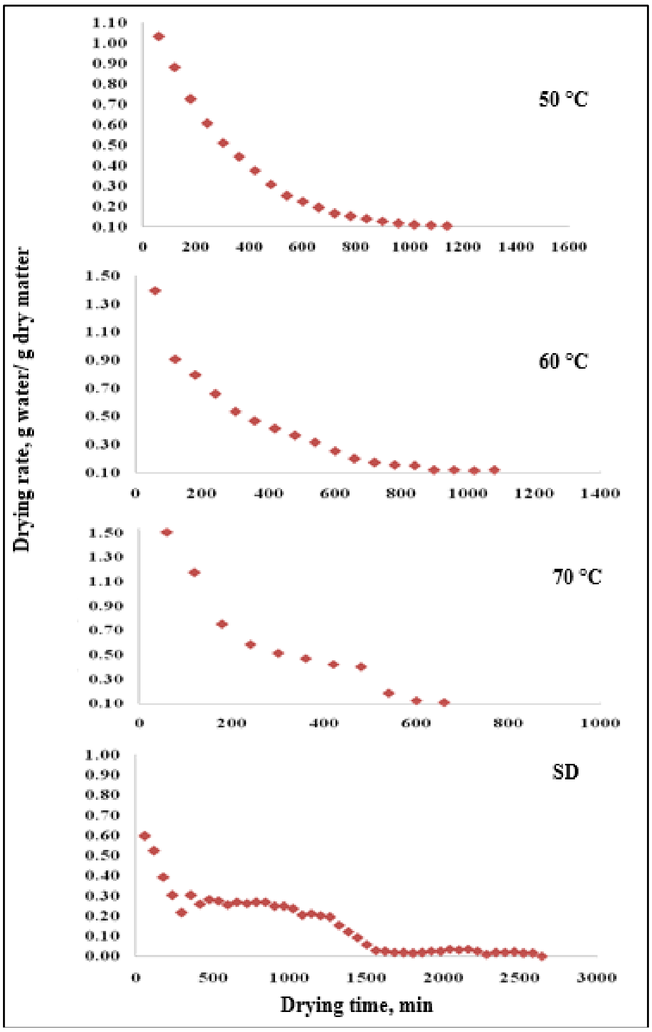



**Fig 3:** Drying curves of drying rate versus drying time of water chestnut kernels at 50, 60, 70 ºC and Sun drying

### Fitting of mathematical models to the drying curves

The moisture content data generated during drying experiments were converted into the moisture ratio (MR) and fitted to the 12 models listed in Table 1. The statistical results of the different models, including the drying model coefficients and the comparison criteria used to evaluate goodness of fit, namely $R^2$, $\chi^2$ and RSME, are listed in Table 2. Among these entire models, $R^2$ value was found as 0.99978 whereas $\chi^2$ and RSME values were found lower as 0.0000565 and 0.007057, respectively.

The values of $R^2$, $\chi^2$ and RSME for all the models were ranged from 0.961 to 0.99978, 0.0000162 to 0.0027 and 0.004029 to 0.05196 with average value of 0.971257 to 0.99927, 0.0000565 to 0.00208 and 0.007057 to 0.045349, respectively (Table 5.33).

The Midilli –Kucuk model fitted better than other models on the basis of higher $R^2$ value (0.99978) and lower value of $\chi^2$ and RSME as 0.0000162 and 0.004028784 at 60 °C, respectively. The residual of actual and predicted moisture ratio of Midilli –Kucuk model varied from 0.00118 to 0.00555 with an average value of 0.003587.

The selected model was established by comparing the experimental data with predicted values for each drying curve. The plotted responses (Fig.4) demonstrate the data points follow a straight line at 45 º angle signifying the suitability of model describing the thin layer drying of water chestnut kernels. Similar approach for selecting the model for thin layer drying of fresh figs was reported by Babalis *et al*.,

(2006) [3], Singh *et al*., (2008) [17] for water chestnut slices and Navneet *et al*., (2012) [14] for carrot pomace.

The values of the selected model coefficients (a, k, n, c and g) for thin layer drying at 50, 60 and 70 ºC were estimated. Regression analysis was performed to set up the relations between these parameters and temperatures. Thus, the second order polynomial regression equations of these constants against drying temperature T (ºC) for accepted model are given below.

$$a = -160.4T^2 + 94.81T - 12.98 \qquad R^2 = 1$$

$$k = 7E^{-06}T^2 - 0.000T + 0.028 \qquad R^2 = 1$$

$$n = -6E^{-05}T^2 + 0.009T + 0.586 \qquad R^2 = 1$$

$$b = -1E^{-08}T^2 - 9E^{-07}T + 5E^{-05} \qquad R^2 = 1$$

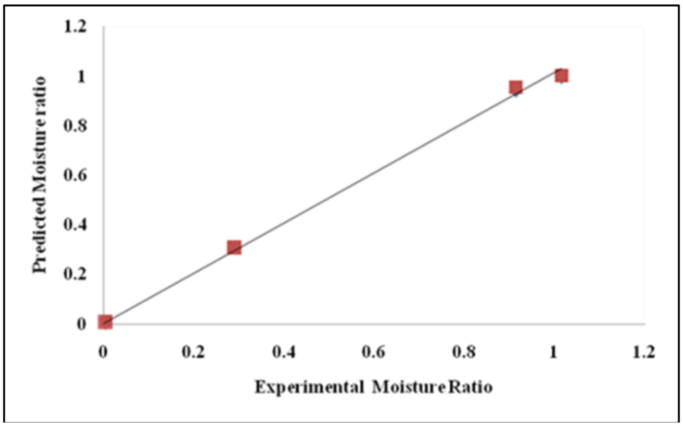



**Fig 4:** Predicted versus experimental moisture ratio of WCK using Midilli-Kucuk model at different drying temperatures

**Table 1:** Proposed thin layer drying models for water chestnut kernels ( $a, b, c, g, h, k, k_0, k_1$ and $n$ : empirical constants and coefficient in drying models)

| Model Name | | Model Name |
|---|---|---|
| Page | $MR = \exp(-kt^n)$ | Page (1949) [15] |
| Hendersons and Pabis | $MR = a\exp(-kt)$ | Hendersons and Pabis [9] (1961) |
| Two-Term | $MR = a\exp(k_0 t) + b\exp(k_1 t)$ | Henderson (1974) [8] |
| Wang and Singh | $MR = 1 + at + bt^2$ | Wang and Singh (1978) [21] |
| Lewis | $MR = \exp(-kt)$ | Bruce (1985) [4] |
| Verma | $MR = a\exp(-kt) + (1-a)\exp(-gt)$ | Verma *et al*.(1985) [20] |
| Simplified Fick's | $MR = a\exp(-c(t/L^2))$ | Dimante and Munro (1991) [5] |
| Modified Page-II | $MR = \exp(-c(t/L^2)^n)$ | Dimante and Munro (1991) [5] |
| Approximation of diffusion | $MR = a\exp(-kt) + (1-a)\exp(-k\,at)$ | Yaldiz *et al*., (2001) [23] |
| Logarithmic | $MR = a\exp(-kt) + c$ | Togrul and Pehlivan (2002) [19] |
| Midilli-Kucuk | $MR = a\exp(-kt^n) + bt$ | Midilli *et al*., (2002) [12] |
| Hii, Law & Cloke | $MR = a\exp(-kt^n) + c\exp(-gt^n)$ | Hii *et al*., (2009) [10] |

**Table 2:** Statistical results of the thin layer drying model coefficients at different drying temperature

| Sr. No. | Model Name | Temperature °C | Constants | | | | | $R^2$ | $\chi^2$ | RMSE |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1st | 2nd | 3rd | 4th | 5th | | | |
| 1 | Lewis model | 50 | k=0.0261 | | | | | 0.9986 | 9.581E-05 | 0.009788069 |
| 2 | | 60 | k=0.00299 | | | | | 0.99776 | 1.600E-04 | 0.012648913 |
| 3 | | 70 | k=0.00424 | | | | | 0.99536 | 3.542E-04 | 0.01881991 |
| 4 | Page model | 50 | k=0.00293 | n=0.98157 | | | | 0.9987 | 8.788E-05 | 0.009374359 |
| 5 | | 60 | k=0.00269 | n=1.01719 | | | | 0.99787 | 1.545E-04 | 0.012430326 |
| 6 | | 70 | k=0.00313 | n=1.05355 | | | | 0.9963 | 2.883E-04 | 0.016979812 |
| 7 | Henderson Pabis | 50 | a=0.99118 | k=0.00259 | | | | 0.99869 | 9.094E-05 | 0.009536084 |
| 8 | | 60 | a=0.99502 | k=0.00297 | | | | 0.99779 | 1.601E-04 | 0.012653379 |
| 9 | | 70 | a=1.01228 | k=0.0429 | | | | 0.99553 | 3.482E-04 | 0.018661082 |
| 10 | Logarithmic | 50 | a=0.99389 | k=0.00253 | c= - 0.0069 | | | 0.99876 | 8.667E-05 | 0.009309726 |
| 11 | | 60 | a=1.01274 | k=0.00266 | c= -0.03689 | | | 0.99951 | 3.620E-05 | 0.006016494 |
| 12 | | 70 | a=1.03582 | k=0.00373 | c=-0.04792 | | | 0.99854 | 1.159E-04 | 0.010766383 |
| 13 | Two term | 50 | a=0.01032 | $k_0$=484.7215 | b=0.98967 | $k_1$= 0.00259 | | 0.9987 | 9.198E-05 | 0.009590766 |
| 14 | | 60 | a=0.006 | $k_0$= 57.57414 | b=0.994 | $k_1$= 0.00297 | | 0.99779 | 1.641E-04 | 0.012809723 |
| 15 | | 70 | a=0.03711 | $k_0$= 0.00428 | b=0.97515 | $k_1$= 0.0429 | | 0.99553 | 3.616E-04 | 0.019016572 |
| 16 | Wang and Singh | 50 | a= - 0.00184 | b=8.73795E-7 | | | | 0.961 | 2.700E-03 | 0.051961524 |
| 17 | | 60 | a= -0.00212 | b=1.15914E-6 | | | | 0.97378 | 1.900E-03 | 0.043588989 |
| 18 | | 70 | a=-0.00297 | b=2.24177E-6 | | | | 0.97899 | 1.640E-03 | 0.040496913 |
| 19 | Simple Ficks | 50 | a=0.99118 | c=6.47461E-4 | | | | 0.99869 | 9.094E-05 | 0.009536084 |
| 20 | | 60 | a=0.99498 | c=7.42818E-4 | | | | 0.99779 | 1.601E-04 | 0.012653379 |
| 21 | | 70 | a=1.01228 | c=0.00107 | | | | 0.99553 | 3.482E-04 | 0.018661082 |
| 22 | Approx Diffusion | 50 | a=0.01053 | k=0.24544 | | | | 0.9987 | 8.987E-05 | 0.009479979 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 23 | | 60 | a=0.00596 | k=0.49825 | | | | 0.99779 | 1.597E-04 | 0.012637761 |
| 24 | | 70 | a=2.40203E-4 | k=17.63459 | | | | 0.99536 | 3.61E-04 | 0.019006394 |
| 25 | Modified Page II | 50 | c=7.55697E-4 | n=0.9807 | | | | 0.99873 | 8.790E-05 | 0.009375452 |
| 26 | | 60 | c=6.81529E-4 | n=1.01233 | | | | 0.99786 | 1.55E-04 | 0.012454598 |
| 27 | | 70 | c=7.61407E-4 | n=1.04672 | | | | 0.99628 | 2.89E-04 | 0.017012966 |
| 28 | Verma | 50 | a= - 1665.3097 | k=0.00261 | g=0.00261 | | | 0.9986 | 9.798E-05 | 0.009898672 |
| 29 | | 60 | a= -208.63715 | k=0.00369 | g=0.00368 | | | 0.99814 | 1.37E-04 | 0.011696367 |
| 30 | | 70 | a=-210.50036 | k=0.00568 | g=0.00568 | | | 0.99675 | 2.58E-04 | 0.01606269 |
| 31 | Midilli-Kucuk | 50 | a=1.01533 | n=0.91447 | b= -2.09285E-5 | k= 0.0043 | | 0.99935 | 4.633E-05 | 0.006806805 |
| 32 | | 60 | a=0.99572 | n=0.94204 | b=-4.12398E-5 | k=0.00391 | | 0.99978 | 1.62E-05 | 0.004028784 |
| 33 | | 70 | a=1.00385 | n=0.9569 | b=-6.35173E-5 | k=0.00501 | | 0.99868 | 1.07E-04 | 0.01033436 |
| 34 | Hii, Law and Cloke | 50 | a=0.71787 | k=0.00293 | c=0.28183 | g=0.00293 | n=0.98118 | 0.99873 | 9.094E-05 | 0.009536383 |
| 35 | | 60 | a=0.67981 | k=0.002 | c=0.28958 | g=0.00199 | n=1.06182 | 0.99831 | 1.27E-04 | 0.011285788 |
| 36 | | 70 | a=0.64133 | k=0.00251 | c=0.33569 | g=0.00251 | n=1.08808 | 0.99655 | 2.84E-04 | 0.016866446 |

## Conclusions

Drying rates for drying of water chestnut kernels were found 1.1880, 1.6181, 2.6688 and 0.7249 g water/ g dry matter-min at temperatures of 50, 60, 70 ºC and sun drying temperature (38 ± 5 ºC), respectively. The average drying 0.3225, 0.3769, 0.5343 and 0.1517 g water/ g dry matter-min were observed at temperature 50, 60 & 70 ºC and sun drying condition, respectively. The Midilli–Kucuk model was fitted better than other models on the basis of higher $R^2$ value (0.99978) and lower value of $\chi^2$ and RSME value as 0.0000162 and 0.004028784 at 60 °C.

## References


1. Adedeji A, Tanya G, Ngadi M, Raghavan VGS. Effect of pretreatments on drying characteristics of okra. Drying Technology 2008;26(10):1251-1256.
2. Attanasio G, Cinquanta L, Lbanese A, Matteo D, MD. Effect of drying temperature on Physical-chemical properties of dried and rehydrated chestnuts (*Castanea sativa*), Food Chemistry 2004;88(4):583-590.
3. Babalis SJ, Papanicolaou E, Kyriakis N, Belessiotis VG. Evaluation of thin layer drying model for describing drying kinetics of figs. Journal of Food Engineering, 2006;75:205-214.
4. Bruce DM. Exposed-layer barley drying, three models fitted to new data up to 150 °C. Journal of Agricultural Engineering Research 1985;32:337-347.
5. Diamante LM, Munro PA. Mathematical modelling of hot air drying of sweet potato slices. International Journal of Food Science and Technology 1991;26:99-109.
6. Diamante LM, Munro PA. Mathematical modelling of the thin layer solar drying of sweet potato slices. Solar Energy 1993;51(4):271-276.
7. Falade KO, Abbo ES. Air-drying and rehydration characteristics of date palm (*Phoenix dactylifera* L.) fruits. Journal of Food Engineering 2007;79:224-230.
8. Henderson SM. Progress in developing the thin layer drying equation. Transactions of the ASAE 1974;17:1167-1172.
9. Henderson SM, Pabis S. Grain drying theory. II. Temperature effects on drying coefficients. Journal of Agricultural Engineering Research 1961;6:169 -174.
10. Hii CL, Law CL, Cloke M. Modelling using a new thin layer drying model and product quality of cocoa. Journal of Food Engineering 2009;90:191-198.
11. Hummel M, Kiviat E. Review of world literature on water chestnut with implications for management in North America. Journal of Aquatic Plant Management 2004;42:17-28.
12. Midilli A, Kucuk H, Yapar ZA. New model for single-layer drying. Drying Technology 2002;20(7):1503-1513.
13. Moreira R, Chenlo F, Chaguri L, Vazquez G. Mathematical modelling of the drying kinetics of chestnut (*Castanea Sativa* Mill.): Influence of the Natural Shells, Food and by product Processing 2004;83(4):306-314.
14. Navneet K, Sarkar BC, Sharma HK. Mathematical modelling of thin layer hot air drying of carrot pomace. Journal of Food Science and Technology 2012;49(1):33-41.
15. Page GE. Factors influencing the maximum rates of air drying shelled corn in thin layers. M.S. thesis: Department of Mechanical Engineering Purdue University, Purdue, USA 1949.
16. Rajkumar P, Kaailappan R, Viswanathan R, Raghavan GSV. Drying characteristics of foamed alphonso mango pulp in a continuous type foam mat dryer. Journal of Food Engineering 2007;79:1452-1459.
17. Singh GD, Sharma R, Bawa AS, Saxena DC. Drying and rehydration characteristics of water chestnut (*Trapa natans*) as a function of drying air temperature, Journal of Food Engineering 2008;87:213-221.
18. Singh S, Raina CS, Bawa AS, Saxena DC. Effect of pretreatments on drying and rehydration kinetics of sweet potato slices. Drying Technology 2006;24:1-8.
19. Togrul IT, Pehlivan D. Mathematical modelling of solar drying of apricots in thin layers. Journal of Food Engineering 2002;55:209-216.
20. Verma LR, Bucklin RA, Endan JB, Wratten FT. Effect of drying air parameters on rice drying models. Transactions of the ASAE 1985;28:296-301.
21. Wang CY, Singh RP. Use of variable equilibrium moisture content in modelling rice drying. Transactions of the ASAE 1978;11:668-672.
22. Wang Z, Sun J, Liao X, Chen F, Zhao G, Wu J *et al*. Mathematical modelling on hot air drying of thin layer apple pomace. Food Research International 2006;40(1):39-46.
23. Yaldiz O, Ertekin C, Uzun HI. Mathematical modelling of thin layer solar drying of sultana grapes. Energy 2001;26:457-465.