Research Article

Influence of Different Drying Techniques on Drying Characteristics and Quality Aspects of Pink Lotus (*Nelumbo nucifera*) Flowers

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ABSTRACT

The present study investigated the effect of different drying methods on the drying kinetics and antioxidant activity of pink lotus flowers to identify the suitable drying models describe the dehydration as well as drying conditions giving minimum loss of antioxidant compounds and antioxidant properties of product. Samples were dried by Freeze Drying (FD), Oven Drying (OD) at 40, 50 and 60°C, Microwave Drying (MWD) with the powers of 140, 420 and 700 W. Drying kinetics from OD and MWD were analyzed mathematically and the dehydration data was statistically analyzed to obtain best fit among all available models basing on coefficient of determinations ($R^2$), reduced chi-square ($\chi^2$) and Root Mean Square Error (RMSE). The dried lotus flowers were analyzed Total Polyphenol Contents (TPC), Total Flavonoid Contents (TFC) and Antioxidant Activity (AA). It was found that the Midilli et al. model is the most appropriate model for drying behavior of samples by both OD and MWD. The activation energies of drying were 56.29 kJ/mol and 6.48 W/g for OD and MWD, respectively. FD was found to be the best method to give the highest antioxidant activity for lotus flowers and the next one was the OD at 50°C.

Keywords: Antioxidant Activity, Drying Methods, Kinetic, Lotus Flowers, Phenolic Compounds

Introduction

Lotus (*Nelumbo nucifera*) is an aquatic plant that is grown in wetlands or ponds which are widely distributed and commonly used in Asian.¹ Lotus flowers are not only beautiful, radiating fragrance, but also symbolizing the purity and nobility. Therefore, it is no coincidence that the lotus was chosen as the symbolic flower for Vietnam.

Lotus is one of the most popular edible plants, almost every part of it can be used, especially, its seed and rhizome are the most consumed partsdue to physiologically activity.³ They are used as food products, for example, dessert, porridge and soup.⁴ In Vietnam, lotus flowers are used for decoration, worshiping or processing tea. Importantly, these flowers have been published to be useful in the treatment
of diarrhea, cholera, fever and gastric ulcers. They showed the hypoglycemic, antioxidant, antipyretic, antibacterial, aphrodisiac and antiplatelet activities. The bioactivities of the lotus flowers have been attributed its chemical constituents, such as the flavonoids, phenolic acids and numerous groups of phenolic compounds.

However, the freshness of flowers can be retained only for few days even by using the best post-harvest technology. Drying of flowers to prolong this shelf life is very importance in using them as functional food ingredients. Various drying methods like sun drying, OD, MWD and FD can be used for various purposes, beside, the quality of the final products depends on the drying method. However, it is not so much information about the changes of bioactive compounds during drying process for lotus flowers by different drying methods, so this study was conducted to predict the drying curves of lotus flowers by the way fitting of the mathematical models at different drying temperatures as well as supplied MWD power. In addition to find out the ways for remaining the antioxidant activity as well as sensory value of pink lotus flowers in Vietnam.

Materials and Methods

Lotus Flower Preparation and Drying Methods

Pink lotus flowers were collected from Dong Thap Province and shipped to laboratory of Food Technology Department, CanthoUniversity, Vietnam. Flowers were cleaned by clean water and drained. Drying methods applied for flowers included:

- FD
- OD by hot air at 40, 50 and 60°C
- MWD with the powers of 140, 420 and 700 W.

The flower moisture contents were determined after time intervals and drying process finished when the moisture content of the flowers reached about 5%.

Drying Kinetic for Lotus Flowers

Many researchers have developed various empirical models to describe the relationship between non-dimensional parameter Moisture Ratio (MR) and drying time. These models are still widely used in describing the drying characteristic of food and agricultural products. The MR related to the gradient of the sample moisture in real time (M) with initial Moisture (M₀) and equilibrium moisture (Mₑ) and was calculated according to Equation (1). The variation of the MR with time is fitted to different models as listed in Table 1.

\[
MR = \frac{(M_t - M_0)}{(M_e - M_0)}
\]

In order to observe the influence of drying temperature on the kinetic parameters k, an Arrhenius type equation was applied (Equation 2 and 3).

For Equation (2), Eᵢ is the activation energy (kJ/mol). Activation energy shows sensitivity to drying temperature (T) and can be determined by the graphic representation between ln(k) versus T⁻¹ (K).

Equation (3) is found as modified from the revised Arrhenius equation. It is assumed that the air temperature was replaced by the ratio of sample weight to MWD power (m/P) in the relation with drying kinetic constant rate (k, min⁻¹). So, activation energy Eᵢ (W/g) can be determined by the graphic representation between ln(k) versus m/P²,²²,²³

\[
k = k_0 \exp\left(-\frac{E_i}{RT}\right)
\]

\[
k = k_0 \exp\left(-\frac{E_i \times m}{P}\right)
\]

Analysis of TPC, TFC and AA

The dried flowers were finely ground and 2.0 g of the this sample was suspended and extracted by refluxing with 50 ml boiling distilled water for 30 min. After cooling, the extracts were filtered through a filter paper and aqueous extracts were analyzed in triplicate.²⁴

Determination of TPC: TPC of the lotus flower extract was analyzed according to the procedures previously reported by Wu et al. (2011)²⁵ with slight modifications. Briefly, 0.5 ml extract was mixed with 2.5 ml of 10 fold diluted Folin-Ciocalteau reagent, and 2.0 ml of 7.5% sodium carbonate (Na₂CO₃) followed by incubation for 30 min. Consequently, TPC in the reaction mixture was determined colorimetrically at 760 nm and the result was expressed as mg of gallic acid equivalents per gram of lotus in dry weight (mgGAE/g).

Determination of TFC: TFC of the lotus flower extract was estimated as per the aluminum chloride method described by Yamini et al., (2019)²⁶ with slight modifications. Briefly, 0.5 ml extract was mixed into 0.2 ml of sodium nitrate (5%), 3.0 ml of distilled water and 0.3 ml of 10% aluminum chloride. It was mixed thoroughly and incubated at room temperature for 30 min in dark and the absorbance was measured at 415 nm using UV-visible spectrophotometer.

### Table 1. Mathematical models for drying curve fitting of food and agricultural products

| Model Name               | Model                                      | References |
|--------------------------|--------------------------------------------|------------|
| Lewis                    | MR = exp (-kt)                             | [15]       |
| Page                     | MR = exp (-kt)                             | [16]       |
| Modified Page            | MR = exp (-kt n)                           | [17]       |
| Henderson and Pabis      | MR = a x exp (-kt)                         | [18]       |
| Logarithmic              | MR = a x exp (-kt) + b                     | [19]       |
| Wang and Singh           | MR = 1 + bt + at2                          | [20]       |
| Midilli et al.           | MR = a x exp (-kt²) + bt                   | [21]       |

Where k is kinetic parameters; t is drying time; a, b and n are constants.
The standard curve was prepared using quercetin and the results are expressed in milligram per gram of lotus in dry weight quercetin equivalent (mQE/g).

**Determination of AA:** AA of the extracts from lotus flowers was assessed by measuring their radical scavenging activities. It was measured basing on the bleaching of the purple-colored solution of 2,2-diphenyl-1-picrylhydrazyl (DPPH) in methanol. The DPPH radical scavenging activity was evaluated from the difference in peak area decrease of the DPPH radical detected at 517 nm between a blank and a sample.\(^7\)

**Data Analysis**

**Curve fitting:** Non-linear regression analyses were carried out using Curve Expert Professional 2.4.0 software. The statistical parameters used to determine the best model are the coefficient of determination \((R^2)\), chi-square \((\chi^2)\), and Root Mean Square Error (RMSE). The higher the \(R^2\) and lower the \(\chi^2\) and RMSE values, the better is the fitting procedure.\(^28,30,22\)

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

Where: \(MR_{\text{exp},i}\), \(MR_{\text{pre},i}\) are experimental and predicted dimensionless moisture ratios, respectively; \(N\) is number of observations and \(z\) is number of constants.

**Comparison of the means:** The sample means of TPC, TFC and the DPPH radical scavenging activity were expressed as means ± SD and compared by Analysis of Variance (ANOVA) using LSD test. All the analyses were performed in Microsoft Excel 2013, the p–value less than 0.05 has been considered significant.

**Result and Discussion**

**Drying Kinetic and Curve Fitting for Lotus Flowers**

The results of non-linear regression analysis and the model constants of 7 models from the drying process of lotus flowers by OD and MWD were presented in Table 1 and 2, respectively. Data given in Table 1 and 2 are considered to assess the fitting ability of drying models. For OD method, according to Li et al. (2019)\(^25\) the temperature is the key factor in drying kinetics. Table 1 showed the value of the drying coefficient \((k)\) that decreased with the increase in drying temperature for all models. For MWD method, it is difficult to measure temperature directly in the system, thus the supplied power is the main factor that replaces the drying temperature.\(^22,23\) Thus, for all models Table 2 also showed the value of the drying coefficient \((k)\) that decreased with the increase in MW power.

| Model Name          | T (°C) | Constants and coefficients | \(R^2\) | \(\chi^2\) | RMSE   |
|---------------------|--------|----------------------------|---------|------------|--------|
| 1. Lewis             | 40     | \(k = 0.0055\)             | 0.9974  | 0.00023    | 0.0148 |
|                     | 50     | \(k = 0.0089\)             | 0.9968  | 0.00037    | 0.0187 |
|                     | 60     | \(k = 0.0205\)             | 0.9979  | 0.00016    | 0.0124 |
| 2. Page              | 40     | \(k = 0.0077, n = 0.9383\) | 0.9980  | 0.00015    | 0.0119 |
|                     | 50     | \(k = 0.0096, n = 0.9854\) | 0.9988  | 0.00038    | 0.0183 |
|                     | 60     | \(k = 0.0273, n = 0.9324\) | 0.9986  | 0.00019    | 0.0103 |
| 3. Modified Page     | 40     | \(k = 0.0056, n = 0.9383\) | 0.9979  | 0.00015    | 0.0119 |
|                     | 50     | \(k = 0.0096, n = 0.9854\) | 0.9988  | 0.00069    | 0.0247 |
|                     | 60     | \(k = 0.0210, n = 0.9324\) | 0.9986  | 0.00019    | 0.0139 |
| 4. Henderson and Pabis| 40   | \(k = 0.0053, a = 0.9679\) | 0.9978  | 0.00016    | 0.0123 |
|                     | 50     | \(k = 0.0088, a = 0.9893\) | 0.9989  | 0.00036    | 0.0173 |
|                     | 60     | \(k = 0.0222, a = 0.9812\) | 0.9977  | 0.00046    | 0.0206 |
| 5. Logarithmic       | 40     | \(k = 0.0053, a = 0.9693, b = -0.0036\) | 0.9978  | 0.00035    | 0.0169 |
|                     | 50     | \(k = 0.0086, a = 0.9943, b = -0.0096\) | 0.9981  | 0.00037    | 0.0170 |
|                     | 60     | \(k = 0.0202, a = 0.9742, b = -0.1217\) | 0.9980  | 0.00013    | 0.0108 |
| 6. Wang and Singh    | 40     | \(a = 2.55×10^6, b = -0.00327\) | 0.9611  | 0.00642    | 0.0775 |
|                     | 50     | \(a = 7.43×10^6, b = -0.00555\) | 0.9718  | 0.00506    | 0.0671 |
|                     | 60     | \(a = 2.76×10^5, b = -0.01083\) | 0.9625  | 0.00860    | 0.0891 |
| 7. Midili et al.     | 40     | \(a = 0.9903, b = -1.18×10^5, k = 0.0004, n = 0.9180\) | 0.9985  | 0.00011    | 0.0100 |
|                     | 50     | \(a = 0.9945, b = -3.4×10^5, k = 0.0108, n = 0.9563\) | 0.9993  | 0.00029    | 0.0107 |
|                     | 60     | \(a = 0.9931, b = -2.1×10^5, k = 0.0277, n = 1.0436\) | 0.9987  | 0.00028    | 0.0124 |
In both cases of OD and MWD, except Wang and Singh model, the others showed good fitting to describe the change of MR with drying temperature or MW power due to $R^2$ values greater than 0.990, Chi square ($\chi^2$) and RMSE values close to 0. However, $R^2$ values for Midilli et al. model are considerably higher than that of the other models, beside, $\chi^2$ and RMSE values for Midilli et al. model were nearly lowest. For this reason, the Middili et al. model was selected as the most suitable model representing the thin layer OD and MWD of lotus flowers.

All applied drying methods were able to dry the lotus flowers from 86.72% (w.b.) to around 5% (w.b.). For OD, the higher drying temperature is the shorter drying time. The required drying time of lotus flowers were 900, 510 and 280 minutes corresponding to drying temperatures of 40, 50 and 60°C. For MWD, the drying time of lotus flowers when the supplied MW of 140, 420 and 700 W was 24, 9.5 and 8 minutes respectively.

| Model R       | P (W) | Constants and coefficients | $R^2$ | $\chi^2$ | RMSE |
|---------------|-------|----------------------------|-------|---------|------|
| 1. Lewis      | 140   | k = 0.0036                 | 0.9981| 0.00021 | 0.0144|
|               | 280   | k = 0.0079                 | 0.9974| 0.00036 | 0.0186|
|               | 420   | k = 0.0126                 | 0.9984| 0.00013 | 0.0112|
| 2. Henderson and Pabis | 140   | k = 0.0038, a = 1.0410     | 0.9985| 0.00011 | 0.0105|
|               | 280   | k = 0.0076, a = 1.0266     | 0.9970| 0.00032 | 0.0169|
|               | 420   | k = 0.0126, a = 1.0030     | 0.9984| 0.00014 | 0.0112|
| 3. Logarithmic | 140   | k = 0.0038, a = 1.0405, b = 0.0018 | 0.9985| 0.00012 | 0.0104|
|               | 280   | k = 0.0072, a = 1.0372, b = 0.0200 | 0.9977| 0.00023 | 0.0139|
|               | 420   | k = 0.0127, a = 1.0019, b = 0.0019 | 0.9984| 0.00015 | 0.0111|
| 4. Modified Page | 140   | k = 0.0036, n = 1.0650     | 0.9983| 0.00014 | 0.0116|
|               | 280   | k = 0.0073, n = 1.1104     | 0.9985| 0.00014 | 0.0113|
|               | 420   | k = 0.0125, n = 1.0227     | 0.9986| 0.00014 | 0.0109|
| 5. Page       | 140   | k = 0.0025, n = 1.0648     | 0.9983| 0.00014 | 0.0116|
|               | 280   | k = 0.0042, n = 1.1104     | 0.9985| 0.00011 | 0.0113|
|               | 420   | k = 0.0113, n = 1.0226     | 0.9986| 0.00014 | 0.0109|
| 6. Wang and Singh | 140   | a = 1.09×10^{-6}, b = -0.0021 | 0.9650| 0.00067 | 0.0788|
|               | 280   | a = 5.37×10^{-6}, b = -0.0047 | 0.9815| 0.00304 | 0.0552|
|               | 420   | a = 1.10×10^{-6}, b = -0.0069 | 0.9505| 0.00957 | 0.0915|
| 7. Midili et al. | 140   | a = 1.0139, b = -3.8×10^{-6}, k = 0.0029, n = 1.0450 | 0.9993| 0.00006 | 0.0071|
|               | 280   | a = 0.9957, b = -3.7×10^{-6}, k = 0.0039, n = 1.1232 | 0.9990| 0.00010 | 0.0090|
|               | 420   | a = 0.9978, b = -1.5×10^{-6}, k = 0.0109, n = 1.0336 | 0.9989| 0.00011 | 0.0091|

Many previous studies have selected Midilli et al. model as the best one in their researches. For example, studying on modeling air convective drying kinetic of tomato, apple slices, debittered apricot kernels, studying on modeling MWD kinetic of green bean slices, parsley, white mulberry, black pepper. The Midilli et al. model has also been suggested by many authors to describe the other drying techniques, such as studying on modeling natural convection solar cabinet dryer and natural sun drying of banana blossom sun drying kinetic of green bean and okra, studying on oven, MWD and sun drying of pomegranate fruit, studying on fluidized bed drying of olive pomace, studying on infrared drying of carrot slices.

The changes with time of the MR from lotus flowers dehydrated by OD and MWD fitted by Midilli et al. model were displayed in Figures 1 and 2.

Figure 1. Changes in MR during OD and curve fitting by Midilli et al. model.
may be resulted from the difference in the moisture content of fresh and dried samples effecting to extraction yield for analysis. This result is agreed with the finding of the sprouts and leaves of white and red quinoa dried using oven,\textsuperscript{52} of Borassus aethiopum mart ripe fruits’ pulp,\textsuperscript{53} of Stroblanthes crispus leaves dried by OD and MWD.\textsuperscript{53} However, some opposite results have been published.\textsuperscript{54,55} According to Coklar et al. (2018),\textsuperscript{55} differences in the results of researches about the effect of drying on phenolic content have attributed factors such as drying method, extraction and analysis procedure.

TPC and AA of lotus flowers dried by FD are 93.18±1.10 (mgGAE/g) and 85.01±1.01(%) respectively, that are significant higher than other samples (Table 3). An increase have been reported in TPC of papaya,\textsuperscript{56} jujubes,\textsuperscript{57} sweet potato\textsuperscript{58} after FD. Many authors found out that using FD sampleshad the higher TPC, TFC and AA than that dried by sun drying, MWD, OD.\textsuperscript{59,60,55} The increasing heat treatment lead to oxidative and thermal degradation of phenolic compounds in dried products.\textsuperscript{55} The variations in drying temperatures of OD have shown a significant effect on all TPC, TFC and AA of dried lotus flowers (Table 3). Sample dried at 50°C had the significant higher TPC, TFC and AA than that of other samples dried by OD. Sample dried at 60°C showed the decrease in TPC, TFC and AA as compared to dried sample at 50°C. This might be attributed to the higher temperature that leads to the decomposition of the heat sensitive compounds as bioactive compounds.\textsuperscript{61} This result is agreed with the finding of the persimmon fruit,\textsuperscript{62} Moringa stenopetala leaves.\textsuperscript{61}

Table 4. Effectiveness of drying methods on TPC, TFC and AA of dried lotus flowers

| Flower samples | TPC (mgGAE/g) | TFC (mgQE/g) | Radical DPPH scavenging (%) |
|----------------|--------------|--------------|----------------------------|
| Fresh flowers  | 11.78±0.99g  | 10.38±0.64d  | 66.88±0.79f                |
| FD             | 93.18±1.10a  | 22.39±1.74a  | 85.01±1.01a                |
| 40ºC OD        | 67.06±1.66f  | 16.74±1.22c  | 78.52±0.82de               |
| 50ºC OD        | 89.17±2.08b  | 21.74±0.61a  | 83.39±0.96b                |
| 60ºC OD        | 69.91±1.82e  | 19.01±0.68b  | 80.48±0.53c                |
| MWD 140 W      | 75.62±1.52d  | 17.70±0.59bc | 76.99±0.94e                |
| MWD 420 W      | 84.38±2.15c  | 18.15±0.95bc | 79.68±0.57cd               |
| MWD 700 W      | 76.03±0.89d  | 18.29±0.10bc | 79.40±1.27cd               |

(Data were expressed in mean ±SD, values in a column with different letters were significantly different (p< 0.05)

Effect of Drying Methods on TPC, TFC and AA of Dried Lotus Flowers

The TPC, TFC and AA of lotus flowers dried by different methods are summarized in Table 4. It can be inferred that values of TPC, TFC and AA of all dried lotus flower samples were higher when compared with fresh lotus flower. This was shown in Table 4 that the degradation of TPC significantly varied according to the different MWD powers (140–700 W). MWD with the power of 420 W resulted in higher in the retention of TPC and AA compared to the power of 140 and 700 W. This result is probably related to drying time and the amount of heat heating samples.
Similar results have been obtained from other authors.\textsuperscript{40,63} However, TPC of dried banana increased with the increase of MWD power.\textsuperscript{64} The increase in microwave output power not significantly increased the TFC of dried lotus flower (Table 4). Similar results have been obtained from other author.\textsuperscript{50}

**Conclusion**

All studied models were used to describe well the OD and MWD kinetics of the lotus flowers except Wang and Singh model. The Midilli et al. model provided the best fit for both drying methods. Among the drying techniques tested, FD method was found to give the most functional quality for lotus flowers. However, economically, the most effective drying method for lotus flowers can be selected as drying by oven at 50°C. This is recommend for drying lotus flowers as a cheap and profitable a source of antioxidant constituents and antioxidant activity.

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