Mathematical modelling of the thin layer drying of banana blossoms

Abstract
In this study, the influence of air temperature on thin-layer drying of banana blossom was investigated. Drying characteristics of the flowers were determined using heated ambient air at temperature from 40°C to 60°C. The effects of air temperature and drying time were also determined. Results indicated that drying of the blossoms took place in the falling rate period. Moisture transfer from the blossoms was described by applying the Fick’s diffusion model. The effective diffusivity coefficient of moisture transfer varied from 5.45x10-9 to 8.09x10-9 m²/s over the temperature range. An Arrhenius relation with an activation energy value 50.06kJ/mol expressed the effect of temperature on the diffusivity. Mathematical models were fitted to the experimental data and by statistical comparison, it was concluded that the Logarithmic model represents drying characteristics better than the other equations. The results have shown that there was no significant difference between the fresh and dried samples.

Keywords: mathematical modelling, thin layer drying, banana blossom, diffusion coefficient, activation energy, nutritional properties

Introduction
Banana blossom, an agricultural by-product, is obtained from the subtropical Musa species originating from India. It is being consumed as a vegetable in the Asian countries like India, Malaysia, Indonesia, Sri Lanka and the Philippines. It has been appreciated for its nutritional content in dietary fibers, proteins, fatty acids, vitamin E, flavonoids and minerals such as magnesium, iron and copper. At ambient temperatures, the blossoms bloom continuously and drop the petals. At high temperatures the flowers start rotting and chilling turns the white heart of the flowers into black. Moreover, in spite of its high fiber content blossom consumption may be restricted due to the cumbersome preparation procedures. Convenience in preparation, promotion of the intake of fiber rich vegetables and increase in shelf life can be achieved by developing a preserved product from the banana blossom.

Drying is one of the techniques to develop a shelf stable and high quality products. The removal of moisture in the drying process prevents the growth of microorganisms and other deteriorative reactions. Drying induces a considerable reduction in weight and volume, minimizes packing, storage and transportation costs and as well as enables the product to be stored under ambient conditions. Sun drying is one of the traditional methods used to preserve agricultural commodities in the tropical and sub tropical regions. However, hot air dry drying is the most widely used industrial method due to its uniform and rapid drying process.

Numerous researches on the experimental studies and mathematical modelling of the drying characteristics of various fruits and vegetables such as apricot, garlic, green and red peppers, okra, egg plant, peach, carrot and tomato have been carried out. Many mathematical models have proposed to describe the drying process. Limited research has been performed on the drying of banana blossoms.

The objectives of this research are to:

a. Determine the effect of air temperature on drying time of banana blossoms
b. Fit the drying curves with ten mathematical models and investigate the goodness of fit
c. Calculate effective diffusivity and activation energy for the blossoms
d. Analyze the properties of the blossoms before and after the drying process

Materials and methods
Drying experiments
Freshly harvested banana blossoms were procured from the local market in Perundurai. They were washed thoroughly in running cold water to remove adhering extraneous matter. The purple petals and the stamen were removed. From each clusters of flowers, the yellow tipped fronds that are responsible for the bitter flavor were separated manually. The edible portion was then washed in water and chopped into small pieces of length 1cm. To prevent enzymatic browning and to remove the characteristic bitter and starchy flavor the blossoms were soaked in buttermilk. They were soaked in 500ml of buttermilk for about 15minutes. After pre-treatment the flowers were dehydrated using a tray-dryer. Blossoms of 500-1000g were taken for dry drying and spread over perforated aluminum trays and trays were kept in the drying chamber. Initial moisture content was determined by the standard AOAC method. The initial moisture content was found to be 87.3% (w.b.). Drying experiments were carried out at the temperature of 40°C, 50°C and 60°C. A constant air velocity of 1.0m/s was maintained. The relative humidity of air was found using dry and wet bulb temperatures acquired from a psychrometric chart. To achieve steady state conditions, the dryer was started 45minutes before commencing the experiments. The blossoms were evenly distributed inside the dryer. The moisture loss was recorded every 15minutes to obtain the drying curves. After the drying process, the
samples were cooled in desiccators and then packed in polyethylene bags. The experiments were replicated thrice at the above mentioned air temperatures and mean values were used for plotting the drying curve.

Mathematical modelling of drying curves

Moisture contents of the blossoms during the thin-layer drying experiments were expressed as moisture ratios MR with the following equation:

\[ D_{\text{eff}} = D_0 \exp \left( \frac{E_a}{R(T + 273.15)} \right) \]  

where \( M \) is the mean blossom moisture content (% w.b); \( M_i \) is the initial moisture content (% w.b); and \( M_j \) is the equilibrium moisture content (% w.b).

For mathematical modelling, the drying curves were fitted to ten well-known drying models given in Table 1. MATLAB R®11 tool was used for curve fitting.

The goodness of fit was deduced using the parameters, i.e. coefficient of determination \( R^2 \) and root mean square error \( \text{RMSE} \). These parameters can be described in equations from (2) and (3)

\[ \chi^2 = \sum_{x=1}^{n} \left( \frac{\text{MR}_{\text{exp},x} - \text{MR}_{\text{pre},x}}{n - z} \right)^2 \]  

\[ \text{RMSE} = \left[ \frac{1}{N} \sum_{x=1}^{n} \left( \frac{\text{MR}_{\text{pre},x} - \text{MR}_{\text{exp},x}}{n - z} \right)^2 \right]^{1/2} \]

Where, \( \text{MR}_{\text{exp}} \) is the experimental moisture ratio at observation \( x \), \( \text{MR}_{\text{pre}} \) is the predicted moisture ratio at this observation, \( N \) is number of experimental data points, and \( z \) is number of constants in model.

Table 1 Mathematical models applied to drying curves

| Model                  | Equation                      | References |
|------------------------|-------------------------------|------------|
| Newton                 | \( \text{MR} = \exp(-kt) \)   | 35-38      |
| Modified Page          | \( \text{MR} = \exp(-kt) n \) | 39         |
| Henderson and Pabis    | \( \text{MR} = \exp(-kt) \)   | 40-47      |
| Modified Henderson     | \( \text{MR} = \exp(-kt) + b \exp(-gt) + c \) | 48         |
| and Pabis              | \( \exp(hs) \)               |            |
| Logarithmic            | \( \text{MR} = \exp(-kt) + c \) | 9.21±9.30  |
| Two term               | \( \text{MR} = \exp(-kt) + b \exp(-kt) \) | 51/52      |
| Two term exponential   | \( \text{MR} = \exp(-kt) + (1-a) \exp(-kt) \) | 53         |
| Verma et al.           | \( \text{MR} = \exp(-kt) + (1-a) \exp(-gt) \) | 54         |
| Wang and Singh         | \( \text{MR} = \exp(-kt) + bt \) | 55-60      |
| Midilli et al.         | \( \text{MR} = \exp(-kt) + bt \) | 61/62      |

The \( R^2 \) value is the quotient of the variances of the fitted values and observed values of the dependent variable. The higher the value of the coefficient of determination, the greater is the success of the mathematical model. The RMSE gives the deviation between the predicted and experimental values and it is required to reach zero. The higher values of \( R^2 \) and the lower values RMSE are chosen as the criteria for goodness of fit and was followed in present study.

Nutritional properties

Samples of banana flower were analyzed for moisture, protein, fat, ash, total crude fiber, and total flavonoids following the standard methods published by Association of Official Analytical Chemists.15 Moisture content was estimated by gravimetric measurement of weight loss after drying the sample in an oven at 105°C until constant weight was obtained. Protein was determined by Kjeldahl method,16 and thereafter a conversion factor of 6.25 was used to calculate the total nitrogen to crude protein. The lipid content of the samples was done using Soxhlet type of the direct solvent extraction method. The solvent used was petroleum ether (boiling range 40-60°C).17 The content of ash was measured by gravimetric measurement of the sample in the furnace at 550°C until the constant weight was achieved.

The total phenol content of extracts was determined by the Folins-Ciocalteau colorimetric method.18 Briefly, 1ml of the extract solution was mixed with the Folins-Ciocalteau reagent (1ml) and 7.5% Na2CO3 (3ml). After 1h of incubation at room temperature, the absorbance was measured against water at 725nm (UV Spectrophotometer). Gallic acid was used for establishing the standard curve and the results were expressed asmg of gallic acid equivalents/g of extract. To quantify the total flavonoids content, quercetin was used as the reference,19 which was expressed as quercetin equivalent (QE). A standard curve of known concentrations of quercetin was generated by preparing and testing five concentrations of quercetin standard solution, which were 0, 25, 50, 75, and 100mg/L. A stock quercetin solution was prepared by dissolving 25mg of quercetin in 100mL of 80% ethanol. Then, the standard working solutions were made up by pipetting 0, 1, 2, 3, and 4mL aliquots of the stock solution (250mL/L) into 10mL-volumetric flasks and adjusting the volume with 80% ethanol. By using test tubes, 1mL of each standard solution was reacted with 3mL of 95% ethanol, 0.2mL, of a 10% aqueous solution of AlCl3 reagent, 0.2mL of 1M sodium hydroxide, and 5.6mL of distilled water. The mixture was mixed thoroughly by vortex mixer for about 30s and allowed to stand at room temperature for 30min. Absorbance readings were taken by a UV/Visible Spectrophotometer at 510nm.

Results and discussion

Drying kinetics of the banana blossoms

The effect of three temperatures on the drying curve of banana blossoms is shown in Figure 1. It is obvious from the chart that increasing the drying temperature resulted in an increase in the drying rate, therefore decreasing the drying time. The time required to decrease the moisture ratio to any given level was dependent on the drying condition, being highest at 40°C and lowest at 60°C. The time taken to reduce the moisture content of the blossoms from the initial 87.3 (%w.b) to 8.9±0.1 (%w.b) was 300, 240 and 195min at 40, 50 and 60°C respectively. It is observed that there is no constant rate drying period in the drying of banana blossoms. In case of these blossoms, the drying takes place in the falling rate period. This indicates that diffusion is the main physical mechanism governing moisture migration in the samples. Similar results were obtained by Togrul IT14 for apricots,20 for red chillies,21 for radish,22 for broccoli, and23 for okra. The effect of temperature used for the drying process was most remarkable with moisture ratio reducing rapidly with increased temperature. Several investigators have reported a significant increase in the drying rates when higher temperatures were used for drying various agricultural products such as red pepper,24 eggplant,25 okra,7 canola,26 pepino fruit27 and chilli.28

Citation: John SG, Sangamithra A, Veerapandian C, et al. Mathematical modelling of the thin layer drying of banana blossoms. J Nutr Health Food Eng. 2014;1(1):42-49. DOI: 10.15406/jnse.2014.01.00008
Mathematical modelling of the thin layer drying of banana blossoms

Evaluation of the mathematical models

In order to determine the moisture content as a function of drying time, Newton, Modified Page, Henderson and Pabis, Modified Henderson and Pabis, Logarithmic, Two term, Two term exponential, Verma et al., Wang and Singh and Midilli et al. empirical models were fitted. The statistical analysis values are summarized in Tables 2-4. All the models gave high coefficient of determination ($R^2$) values in the range 0.9697-0.9998 at 40°C, 0.9615-0.9998 at 50°C and 0.9474-0.9998 at 60°C. This indicates that all the models could satisfactorily describe the air-drying of the banana blossoms. Among the thin layer drying models, the Logarithmic model obtained the highest $R^2$ values of 0.9998, 0.9998 and 0.9997 at 40°C, 50°C and 60°C respectively. Similarly, the lowest RMSE values were obtained in the logarithmic model over the specified temperature range. Thus, this model may be assumed to present the thin-layer drying behavior of the blossoms.

Calculation of moisture diffusivity and activation energy

Fick’s second law gives the solution of the most widely studied theoretical model in thin layer drying of various foods. Considering a constant moisture diffusivity, infinite slab geometry and uniform initial moisture distribution, a simplified equation can be formed by taking the first term of series solution.

$$ MR = \frac{8}{\pi^2} \exp \left( -\frac{\pi^2 D_{eff} t}{4L^2} \right) $$

(4)

where $D_{eff}$ is the effective diffusivity (m$^2$/s), $L$ is the half thickness of the samples (m), and $n$ is a positive integer. The natural ln (MR) versus time was plotted and a straight line with a slope $k_0$ was obtained.

The effective diffusivity is calculated from the slope.

$$ k_0 = \frac{\pi^2 D_{eff}}{4L^2} $$

(5)

The effective diffusivity values of dried samples at 40-60°C were varied in the range of 5.45-8.09 x 10^{-9} m$^2$/s. The determined values of $D_{eff}$ for different temperatures are given in Figure 2. The values lie within the range of 10^{-9} m$^2$/s to 10^{-8} m$^2$/s for food materials. It can be observed that the values of $D_{eff}$ increased significantly with increasing temperature. Drying at 60°C gave the highest $D_{eff}$ values. $D_{eff}$ values for the banana blossoms are similar to those estimated by different authors for vegetables: 1.3x 10^{-9} to 7.76x10^{-10} m$^2$/s for okra dried from 50°C to 70°C, 0.776x10^{-9}-9.335x10^{-9} m$^2$/s for carrot dried from 50°C to 70°C. These values are consistent with the present estimated $D_{eff}$ values for the blossoms.

To obtain the effect of temperature on the effective diffusivity, the values of ln ($D_{eff}$) versus 1/T, are plotted as shown in Figure 3. The plot was found to be a straight line over the temperature range investigated, thereby indicating Arrhenius dependence.

$$ D_{eff} = D_0 \exp \left( \frac{E_a}{R(T+273.15)} \right) $$

(6)

Where $D_0$ is the pre-exponential factor of Arrhenius equation (m$^2$/s), $E_a$ is the activation energy (kJ/mol), $T$ is the temperature of air (°C) and $R$ is the gas constant (kJ/mol K). The activation energy calculated from the slope of the straight line in Figure 3 and was found to be 50.06kJ/mol.

Table 2 Curve fitting criteria for the mathematical models and parameters at 40°C air temperature

| Model name          | Model constants | Determination of coefficient ($R^2$) | Root mean square error (RMSE) | Chi-square ($\chi^2$) |
|---------------------|-----------------|-------------------------------------|-------------------------------|-----------------------|
| Newton              | k=0.0107        | 0.9971                              | 0.0147                        | 0.000218              |
| Modified Page       | k=0.01035, n=0.01038 | 0.9971                              | 0.0151                        | 0.000229              |
| Henderson and Pabis | a=0.9758, k=0.0104, b=0.0104, c=0.0104 | 0.9979                              | 0.0129                        | 0.000166              |
| Modified Henderson and Pabis | c=0.0352, g=0.7681, h=0.8396, k=0.0102 | 0.9986                              | 0.0116                        | 0.000014              |
| Logarithmic         | a=0.9573, c=0.0358, k=0.0117 | 0.9998                              | 0.0037                        | 0.000119              |
Table 3 Curve fitting criteria for the mathematical models and parameters at 50°C air temperature

| Model name               | Model constants | Determination of coefficient (R^2) | Root mean square error (RMSE) | Chi-square (χ²) |
|--------------------------|-----------------|-----------------------------------|-------------------------------|-----------------|
| Newton                   | k=0.0123        | 0.9993                            | 0.0074                        | 0.000055        |
| Modified Page            | k=0.1106        | 0.9993                            | 0.0076                        | 0.000058        |
| Henderson and Pabis      | a=0.9864        | 0.9995                            | 0.0063                        | 0.000040        |
| Modified Henderson and Pabis | c=-0.0442   | 0.9998                            | 0.0050                        | 0.000017        |
| Logarithmic              | a=0.9804        | 0.9998                            | 0.0042                        | 0.000022        |
| Two term                 | a=0.0287        | 0.9998                            | 0.0047                        | 0.000019        |
| Two term exponential     | a=0.9714        | 0.9998                            | 0.0044                        | 0.000020        |
| Verma et al.             | a=0.9714        | 0.9998                            | 0.0045                        | 0.003175        |
| Wang and Singh           | a=0.0085        | 0.9615                            | 0.0563                        | 0.000022        |
| Midilli et al.           | a=0.9912        | 0.9997                            | 0.0047                        | 0.000022        |

Table 4 Curve fitting criteria for the mathematical models and parameters at 60°C air temperature

| Model name               | Model constants | Determination of coefficient (R^2) | Root mean square error (RMSE) | Chi-square (χ²) |
|--------------------------|-----------------|-----------------------------------|-------------------------------|-----------------|
| Newton                   | k=0.0144        | 0.9995                            | 0.0063                        | 0.001595        |
| Modified Page            | k=0.1433        | 0.9995                            | 0.0065                        | 0.001679        |
| Henderson and Pabis      | a=0.9969        | 0.9995                            | 0.0064                        | 0.001683        |
### Mathematical modelling of the thin layer drying of banana blossoms

**Table 5** shows the effective diffusivity of the present study as well as information available in the literature. The activation energy for water diffusion in banana blossom is higher than activation energies of dill leaves, parsley leaf, pistachio nuts and bean drying but lower than okra and mint leaves. The values of the energy of activation lie within the general range of 12.7-110 kJ/mol for food materials.\(^3\)

#### Table 5 Activation energies of banana blossom and other agricultural products

| Agricultural products          | \(E_a\) (kJ/mol) | References |
|-------------------------------|-------------------|------------|
| Okra                          | 51.26             | 7          |
| Dill and Parsley leaves       | 35.05 and 43.92   | 63         |
| Mint leaves                   | 82.93 and 62.96   | 64,65      |
| Pistachio nuts                | 30.79             | 66         |
| Beans                         | 35.43             | 67         |

### Effect of drying on the nutritional properties of banana blossoms

The chemical composition of fresh and dried banana blossom at temperatures of 40, 50 and 60°C are shown in Table 6. During the drying process, moisture loss occurs due to the difference in water vapor pressure between the product and the air surrounding it. This process increases the shelf life due to the lower availability of water for activity of microorganisms and enzymes, also resulting in fewer nutritional and sensorial alterations.\(^3\) The initial moisture content of the banana blossoms were 87.3g/100g. Approximately similar values have been reported for the blossoms (89.42-90.58g/100g).\(^1\) All these flowers had high moisture levels, implying they have very short shelf life. The time taken to reduce the moisture content of the blossoms

---

Citation: John SG, Sangamithra A, Veerapandian C, et al. Mathematical modelling of the thin layer drying of banana blossoms. *J Nutr Health Food Eng.* 2014;1(1):42–49. DOI: 10.15406/jnsk.2014.01.00008
from the initial 87.3 (% w.b) to 8.9±0.1 (%w.b) was 300, 240 and 195min at 40, 50 and 60°C respectively. The protein content of the dried sample was between 1.78 to 1.93g/100g, over the temperature range. Though there was a slight variation in the protein content, selected range of temperature does not significantly affect the protein content. Heating generally improves the digestibility of foods, making some nutrients more available as in the case of proteins in legumes.33

The fat content was low in banana blossoms and ranged from 0.31 to 0.58g/100g when dried at temperatures between 40 and 60°C, similar reduction in fat content during increasing air temperature during drying has been reported in previous literature. The ash content in fresh banana blossoms differed significantly from blossom subjected to drying. The ash content across the temperature range varied from 1.35 to 1.42g/100g. This might have resulted from the temperatures applied which degrade the micronutrients represented in the analysis of ashes. Regarding the total crude fiber content, there was no difference between the treatments. The fresh sample contains 20.97±0.02g/100g of total crude fiber. A considerable decrease in the crude fiber content was observed during the drying process. The higher crude fiber content of the banana blossoms usually leads to increase in absorption and adsorption of water. Therefore, the samples dried over the temperature range can easily rehydrate during consumption.

Usually, thermal treatments have destructive effect on the flavonoids and phenolic compounds as they are highly unstable compounds.34 With respect to fresh samples, the dried ones presented lower total phenolic contents. There was no statistical difference when analyzing the effect of different temperatures in relation to the content of phenolic compounds. Therefore, the highest temperature can be considered to be the most viable, since it reduces the time and consequently the costs of processing, resulting in amounts of phenols statistically equal to the other temperatures. The content of total flavonoids expressed as quercetin equivalence varied from 281.81 to 335.85mg QE/100g from 40 to 60°C.

### Table 6 Nutritional composition of fresh and dried banana blossoms

| Analysis                             | Fresh sample | 40°C   | 50°C   | 60°C   |
|--------------------------------------|--------------|--------|--------|--------|
| Moisture content, g/100g             | 87.3±0.11    | 8.9±0.16 | 8.9±0.04 | 9.0±0.01 |
| Protein, g/100g                      | 2.1±0.03     | 1.9±0.03 | 1.8±0.06 | 1.7±0.08 |
| Fat, g/100g                          | 0.6±0.01     | 0.5±0.08 | 0.5±0.03 | 0.4±0.09 |
| Ash, g/100g                          | 5.4±0.04     | 1.41±0.01 | 1.39±0.01 | 1.37±0.02 |
| Total crude fiber, mg/100g           | 20.97±0.02   | 19.76±0.03 | 18.55±0.01 | 17.63±0.01 |
| Total polyphenols, mg GAE/100g       | 5481.48±0.29 | 5470.16±0.52 | 5409.75±0.86 | 5373.58±0.75 |
| Total flavonoids, mg QE/100g         | 359.26±0.10  | 335.59±0.26 | 304.94±0.52 | 281.32±0.49 |

### Conclusion

Drying kinetics of banana blossoms was investigated in a laboratory scale hot-air dryer, at a temperature range 40-60°C. Based on this study, the following conclusions can be stated:

1. Drying air temperature is a significant factor in drying of banana blossoms.
2. Higher drying air temperature resulted in a shorter drying time.
3. Drying of the blossoms takes place in the falling rate period.
4. The effective diffusivity was calculated from the data and varied from 5.45 x 10^-9 to 8.09 x 10^-9 m²/s with the data temperature dependence represented by a simple Arrhenius-type relationship. The activation energy for moisture diffusion was found to be 50.06kJ/mol.
5. The Logarithmic model with the generalized k and n fits the thin-layer drying characteristics of the blossoms well.
6. Drying at the selected temperature range did not significantly affect the nutritional properties of banana blossoms.
7. The quality of the dried product was found to be best when the blossom was dried at 60°C. The dried blossoms can be rehydrated and used in ready to eat foods.

### Acknowledgments

None.

### Conflict of interest

Author declares that there is no conflict of interest.

### References

1. Zhan-Wu S, Wei-Hong M, Zhi-Qiang J, et al. Investigation of dietary fiber, protein, vitamin E and other nutritional compounds of banana flower of two cultivars grown in China. African Journal of Biotechnology. 2010;9(25):3888–3895.
2. Ongen G, Gargin S, Tetik D, et al. Hot air drying of green table olives. Food Technol Biotechnol. 2005;43(2):181–187.
3. I Doymaz. Drying of leek slices using heated air. Journal of food process engineering. 2008;31(5):721–737.
4. Abdelhaq EH, Labuza TP. Air drying characteristics of apricots. Journal of Food Science. 1987;52(2):342–345.
5. Madamba PS, Driscoll RH, Buckle KA. The thin-layer drying characteristics of garlic slices. Journal of Food Engineering. 1996;29(1):75–97.
6. Kaymak-Ertekin F. Drying and rehydrating kinetics of green and red peppers. Journal of Food Science. 2002;67(1):168–175.
7. Doymaz I. Drying characteristics and kinetics of okra. Journal of Food Engineering. 2005;69(3):275–279.
8. Akpinar EK, Bicer Y. Modelling of the drying of eggplants in thin-layers. International Journal of Food Science & Technology. 2005;40(3):273–281.
9. Kingsly RP, Goyal RK, Manikanant MR, et al. Effects of pretreatments and drying air temperature on drying behaviour of peach slice. International Journal of Food Science & Technology. 2007;42(1):65–69.
10. Xiao HW, Gao ZJ, Lin H, et al. Air impingement drying characteristics and quality of carrot cubes. Journal of Process Engineering. 2010;33(5):899–918.
11. Doymaz I, Ozdemir O. Effect of air temperature, slice thickness and pretreatment on drying and rehydration of tomato. International Journal of Food Science & Technology. 2013;49(2):558–564.
12. Helrich K. Official methods of Analysis of the AOAC. 15th ed. Virginia: Association of Official Analytical Chemists, Inc.; 1990.
13. Doymaz I. The kinetics of forced convective air-drying of pumpkin slices. Journal of Food Engineering. 2007;79(1):243–248.
14. Togrut IU, Pehlivan D. Modelling of drying kinetics of single apricot. Journal of Food Engineering. 2003;58(1):23–32.
15. Cumming P, AOAC. Official methods of analysis of AOAC International. 16th ed. Virginia: Association of Official Analytical Chemists, Inc; 1995.
16. Kjeldahl J. A new method for the determination of nitrogen in organic matter. Z Anal Chem. 1883;22:366.
17. Hassain J, Rehman NU, Khan AL, et al. Determination of macro and micronutrients and nutritional prospects of six vegetable species of Mardan, Pakistan. Pak J Bot. 2011;43(6):2829–2833.
18. Socha R, Juszczyk L, Pietrzyk S, et al. Antioxidant activity and phenolic composition of herbhoneys. Food Chemistry. 2009;113(2):568–574.
19. Misan KH, Mohamed S, Flavonoid (myricetin, quercetin, kaempferol, luteolin, and apigenin) content of edible tropical plants. J Agric Food Chem. 2002;49(6):3106–3112.
20. Kaleermullah S, Kailappan R. Modelling of thin-layer drying kinetics of red chillies. Journal of Food Engineering. 2006;76(4):531–537.
21. Lee JH, Kim HJ. Vacuum drying kinetics of Asian white radish (Raphanus sativus L.) slices. LWT-Food Science and Technology. 2009;42(1):180–186.
22. Doymaz I. Effect of blanching temperature and dipping time on drying time of broccoli. Food Sci Technol Int. 2013;20(2):149–157.
23. Wankhade P, Sapkal R, Sapkal V. Drying characteristics of okra slices on drying in hot air dryer. Procedia Engineering. 2013;51:371–374.
24. Doymaz I, Pala M. Hot-air drying characteristics of red pepper. Journal of Food Engineering. 2002;55(4):331–335.
25. Ertekin C, Yaldiz O. Drying of eggplant and selection of a suitable thin layer drying model. Journal of Food Engineering. 2004;63(3):149–156.
26. Gazor HR, Mohsenimamash A. Modelling drying kinetics of canola in fluidized bed dryer. Czech J Food Sci. 2010;28:531–537.
27. Uribé E, Vega-Galvez A, Di Scala K, et al. Characteristics of convective drying of pepino fruit (Solanum muricatum Ait.): application of weibull distribution. Food and Bioprocess Technology. 2011;4(8):1349–1356.
28. Zhao D, Zhao C, Tao H, et al. The effect of osmosis pretreatment on hot-air drying and microwave drying characteristics of chilli (Capsicum annuum L.) flesh. International Journal of Food Science & Technology. 2013;48(8):1589–1595.
29. Crank J. The mathematics of diffusion. 2nd ed. Oxford University Press, New York: 1975.
30. Doymaz I. Convective air drying characteristics of thin layer carrots. Journal of Food Engineering. 2004;61(3):359–364.
31. Zogzas NP, Maroulis ZB, Marinos-Kouris D. Moisture diffusivity data compilation in foodstuff. Drying Technology. 1996;14(10):2225–2253.
32. Reis RC, Castro VC, Devilla IA, et al. Effect of drying temperature on the nutritional and antioxidant qualities of cumari peppers from Para (Capsicum chinense Jacqui). Brazilian Journal of Chemical Engineering. 2013;30(2):337–343.
33. Morris A, Barnett A, Burrows O. Effect of processing on nutrient content of foods. Cajarticles. 2004;37(3):160–164.
34. Ismail A, Marjan ZM, Foong CW. Total antioxidant activity and phenolic content in selected vegetables. Food Chemistry. 2004;87(4):581–586.
35. Midilli A, Kacuk H. Mathematical modeling of thin layer drying of pistachio by using solar energy. Energy Conversion and Management. 2003;44(7):1111–1122.
36. Kaya A, Aydin O, Demirtas C. Drying kinetics of red delicious apple. Biosystems Engineering. 2007;96(4):517–524.
37. Fudholi A, Othman MY, Ruslan MH, et al. Design and testing of solar dryer for drying kinetics of seaweed in Malaysia. Recent Researches in Geography, Geology, Energy, Environment and Biomedicine. 2011:119–124.
38. Faustino JMF, Barroca MJ, Guine RP. Study of the drying kinetics of green bell pepper and chemical characterization. Food and Bioproducts Processing. 2007;85(3):163–170.
39. Suherman, Fajar B, Satriadi H, et al. Thin Layer Drying Kinetics of of Roselle. Journal of Food Science and Technology. 2012;4(1):51–55.
40. Doymaz I. Air-drying characteristics of tomatoes. Journal of Food Engineering. 2007;78(4):1291–1297.
41. Doymaz I. Effect of pre-treatments using potassium metabisulphide and alkaline ethyl oleate on the drying kinetics of apricots. Biosystems Engineering. 2004;89(3):281–287.
42. Abalone R, Gaston A, Cassinera A, et al. Thin layer drying of amaranth seeds. Biosystems Engineering. 2006;93(2):179–188.
43. Panchuriya PC, Popovic D, Sharma AL. Thin-layer modelling of black tea drying process. Journal of Food Engineering. 2002;52(4):349–357.
44. Doymaz I. Drying kinetics of black grapes treated with different solutions. Journal of Food Engineering. 2006;76(2):212–217.
45. Akgun NA, Doymaz I. Modelling of olive cake thin-layer drying process. Journal of Food Engineering. 2005;68(4):455–461.
46. Ghodake HM, Goswami TK, Chakraverty A. Mathematical modeling of withering characteristics of tea leaves. Drying Technology. 2006;24(2):159–164.
47. Doymaz I, Gorel O, Akgun NA. Drying characteristics of the solid by-product of olive oil extraction. Biosystems Engineering. 2004;88(2):213–219.
48. Sobukola OP, Dairo OU, Odanewu AV. Convective hot air drying of blanched yam slices. International Journal of Food Science & Technology. 2008;43(7):1233–1238.
49. Doymaz I. Drying kinetics of white mulberry. Journal of Food Engineering. 61(3):341–346.
50. Sogi DS, Shivhare US, Gang SK, et al. Water sorption isotherm and drying characteristics of tomato seeds. Biosystems Engineering. 2003;84(3):297–301.
51. Dandamrongrag R, Young G, Mason R. Evaluation of various pre-treatments for the dehydration of banana and selection of suitable drying models. Journal of Food Engineering. 2002;55(2):139–146.
Mathematical modelling of the thin layer drying of banana blossoms

52. Akpinar E, Midilli A, Bicer Y. Single layer drying behaviour of potato slices in a convective cyclone dryer and mathematical modeling. Energy Conversion and Management. 2003;44(10):1689–1705.

53. Karaaslan SN, Tuncer IK. Development of a drying model for combined microwave-fan-assisted convection drying of spinach. Biosystems Engineering. 2008;100(1):44–52.

54. Vega-Galvez A, Lemus-Mondaca R, Bilbao-Sainz C, et al. Mass transfer kinetics during convective drying of red pepper var. Hungarian (Capsicum annuum L.). Mathematical modeling and evaluation of kinetic parameters. Journal of Food Process Engineering. 2008;31(1):120–137.

55. Doymaz I. Effect of dipping treatment on air drying of plums. Journal of Food Engineering. 2004;64(4):465–470.

56. McMinn WAM. Thin-layer modelling of the convective, microwave, microwave-convective and microwave-vacuum drying of lactose powder. Journal of Food Engineering. 2006;72(2):113–123.

57. Jain D, Pathare PB. Selection and evaluation of thin layer drying models for infrared radiative and convective drying of onion slices. Biosystems Engineering. 2004;89(3):289–296.

58. Hii CL, Law CL, Cloke M. Modeling using a new thin layer drying model and product quality of cocoa. Journal of Food Engineering. 2009;90(2):191–198.

59. Xanthopoulos G, Oikonomou N, Lambrinos G. Applicability of a single-layer drying model to predict the drying rate of whole figs. Journal of Food Engineering. 2007;81(3):553–559.

60. Liu X, Qiu Z, Wang L, et al. Mathematical modeling for thin layer vacuum belt drying of Panax notoginseng extract. Energy Conversion and Management. 2009;50(4):928–932.

61. Karaaslan S, Erdem T, Oztekin S. Mathematical modelling and color characteristics of Purslane (Portulaca oleracea L.) leaves using different drying methods. The Philipp Agric Scientist. 2013;96(3):267–274.

62. Schessler K, Jager H, Knorr D. Effect of continuous and intermittent ultrasound on drying time and effective diffusivity during convective drying of apple and red bell pepper. Journal of Food Engineering. 2010;108(1):103–110.

63. Doymaz I, Tugrul N, Pala M. Drying characteristics of dill and parsley leaves. Journal of Food Engineering. 2006;77(3):559–565.

64. Park KJ, Vohnikova Z, Brod FPR. Evaluation of drying parameters and desorption isotherms of garden mint leaves (Mentha crispa L.). Journal of Food Engineering. 2002;51(3):193–199.

65. Doymaz I. Thin-layer drying behaviour of mint leaves. Journal of Food Engineering. 2006;74(3):370–375.

66. Kashaninejad M, Mortazavi A, Safekordi A, et al. Thin-layer drying characteristics and modeling of pistachio nuts. Journal of Food Engineering. 2007;78(1):98–108.

67. Doymaz I. Drying behaviour of green beans. Journal of Food Engineering. 2005;69(2):161–165.