Evaluate the drying of food waste using cabinet dryer

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Research Article

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Evaluate the drying of food waste using cabinet dryer

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Abstract

Purpose In order to reduce leachate from food waste; a food waste dryer with a conventional tray was built, and drying of food waste was investigated.

Methods Power of 2.7 kW was used as the heat source, and a centrifugal fan with an air volume of 1300 m^3/h, 2800 rpm, and 110 pa was used. The experiments were performed at three temperatures of 50, 60, and 70 °C and three air velocities of 1, 1.5, and 2 m/s with a thickness of 3 cm. A conventional tray was used for drying. The Drying kinetics, effective moisture diffusivity, activation energy, and dryer energy consumption during drying of food waste were obtained.

Result The minimum drying process was occurred in temperature of 70°C and air velocity of 2 m/s at the 120 min, and the maximum drying process was happened in temperature of 50°C and air velocity of 1 m/s at the 890 min. The energy consumption of drying process had the lowest value at 70°C of temperature and 2 m/s of inlet air velocity. The highest energy consumption value was related to temperature of 50°C and velocity of 1m/s. Effective moisture diffusivity of waste food during the drying process was in the range of 2.74×10^{-9}-3.65×10^{-8} m^2/s. The values of energy of activation were determined between 21.596 and 64 KJ/mol.

Conclusion Cabinet dryer with a conventional tray can be used for drying food waste in the shortest time with low energy consumption.

Keywords: Food waste, Activation Energy, Drying kinetics, Leachate of waste

Statement of Novelty

The main objective of this paper is to investigate a compact and economical dryer for food waste drying by using the advantages of high mass and heat transfer rates. Improving air distribution in the back of the tray and no passing air on the sides of the tray causes strong compaction and diffusivity of hot air into the food waste mass. This study concluded that, the cabinet dryer with a conventional tray can be used for drying food waste in the shortest time with low energy consumption.

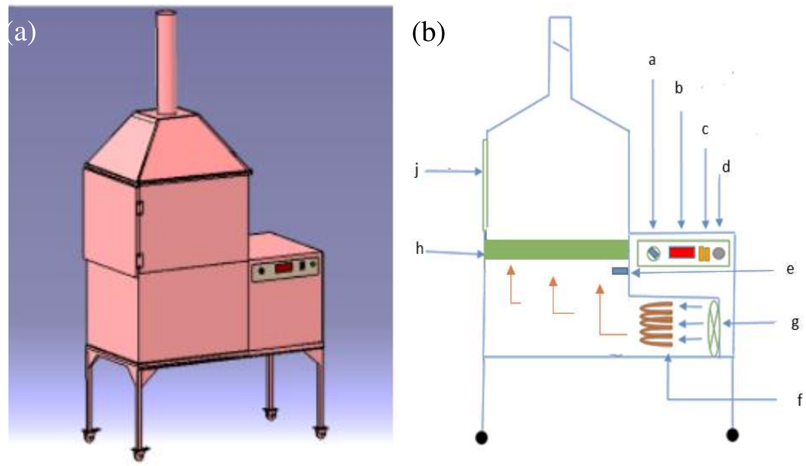
Introduction

Now the most important priorities of countries in the field of environment include prevention and recycling of waste. Decomposable organic matter, mainly kitchen waste and agriculture waste, is the major waste generated around the world. Encouraging homeowners and farmers to separate and dry organic waste is a promising project for food waste management to reduce significantly its volume. In general, dry biowaste is a fixed carbon source that can be used to produce green energy. Dry biowaste is very light because most of the water is removed. This means that the cost of transporting dry final products is very low. In addition, it is odorless and can be stored for a long time. Therefore, it reduces the amount of garbage collection. In addition, it helps reduce methane and toxic leachate from domestic landfills. Many kinds of drying systems have been developed for biomass drying such as the conveyor dryers, solar dryer, fluidized bed dryer, and rotary dryer, among which rotary dryers are the most common [1-6]. Lopez, et al [7] investigated the drying behavior of vegetable waste as a combination of cabbage and lettuce leaves at temperatures between 50 and 150°C. Air velocity 0.6 m/s and material thickness 1 to 2 cm were selected. They extracted the drying curves. The results showed that the drying process period at 150°C is seven times faster than at 50°C, and the drying rate is higher at high air humidity. In another study, the effect of sample sizes and different temperatures on the drying rate of municipal solid waste was investigated. The results showed that the drying rate increased with increasing temperature. Also, variation of food waste composition had no effect on drying rate [8]. Several studies on effective moisture diffusivity, energy of activation, and energy consumption were achieved in thin layer drying of vegetables and fruits [9-13]. However, there is little information on the drying of food waste in cabinet dryers, which makes the current research necessary. In this study, drying process of food waste in a cabinet dryer was investigated and the best drying conditions in order to decrease drying period and customize energy consumption were determined.

Materials and Methods

A cabinet dryer was developed for drying food waste in the research. Fig (1a) shows a schematic of the dryer. The dryer contained a centrifugal fan 2800 Rpm, electrical heating elements 2.7 kW, a drying chamber, a system controller, and a conventional tray. Hot air was flowed in cross through the horizontal sample tray and moved to the upper chamber after passing through the material. There is no passing air on the sides of the tray (Fig. 1b).

Fig. 1 a: Schematic of dryer food waste
b: Schematic representation of the food waste dryer: (a) on and off switch (b) Temperature controller (c) Selector key (d) Air velocity control,(e) Temperature selector (g) Centrifugal fan, (f) Heaters, (j) Door, (h) Place of tray,
b: Showing circuit representation of digital temperature controller



The dryer had an automatic temperature controller with an accuracy of ±0.1°C (G-Sense, Iran). The thermocouple was installed lower than the tray. The air velocity was adjusted at values 0.1, 1.5, and 2 m /s with an accuracy of ±0.1 m/s using an anemometer (UNIT UT363, China). Before starting each experiment, the dryer was turned on for 30 minutes in order to achieve desirable steady state conditions. Food, fruit and vegetables residues were prepared and the components such as glass, paper, plastic, and metals were separated from the wastes. After that, residues were crushed with a shredder in order to reduce their sizes to less than 20 mm (Fig. 2).

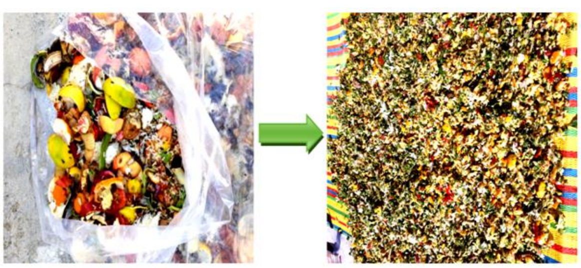


Fig. 3 Sample preparation

Drying kinetics

Initially, the wastes were exposed to ambient air and then were pressed with a Manual pressure press to take out the free water. Finally, the materials distributed on the tray with a thickness of 3cm. There were used three cylindrical containers in order to study the drying kinetics of waste samples in three replications during drying process (Fig.3a).

(a) (b)

Fig. 3 a: Conventional tray containing food waste, b: Dried product

Dried samples were manually weighed every 30 minutes using a digital balance, measuring to an accuracy of 0.01 g. The final moisture content should not be too close to its equilibrium value to avoid high energy and capital investment [14]. Therefore drying was continued until the final moisture content of the samples reached approximately 10% (wb). The moisture content (dry basis) at any time was then calculated from the sample weights obtained using initial and final moisture content values [7]. Then the samples were dried in an oven at temperature of 105±1ºC until to determine solid mass [15].
Experiments were conducted at three levels of temperature 50, 60, and 70ºC and three levels of hot air

velocity 1, 1.5, and 2 m/s. Relative humidity and the temperature of the environment were 15– 25% and 18-21ºC, respectively. The moisture ratio (MR) was calculated applying the **Eq. (1).**

$$MR=\frac{M_d - M_e}{M_o - M_e} \quad (1)$$

Where, MR is moisture ratio (dimensionless), M_d is moisture content (gr_{water} /$gr_{dry\ solids}$). M_0 is initial moisture content (gr_{water}/$gr_{dry\ solids}$). M_e is equilibrium moisture content (gr_{water}/$gr_{dry\ solids}$). This was simplified to Md/M0 by some investigators, because of the continuous fluctuation of the relative humidity of the drying air during the drying processes [16-18]. Moisture content (X_w) of food waste was calculated according to dry basis (d.b.) by **Eq. (2).**

$$X_w = \frac{W_o - W_d}{W_d} \quad (2)$$

Where, w_o is sample weight at a specific time (Kg), w_d is dried sample weight (Kg). The drying rate (DR) is defined as the amount of the moisture which evaporated from the solid body over drying time. The drying rates of food waste were calculated by **Eq. (3)** [19].

$$DR = \frac{M_{t+dt} - M_t}{dt} \quad (3)$$

Where, M_t is solid moisture content at time t based on a dry solid basis (gr_{water} /$gr_{drysolid}$), M_{t+dt} is solid moisture content at time t+dt based on a dry solid basis (gr_{water}/$gr_{drysolid}$), t is drying time (min).

Effective Moisture Diffusivity

The diffusion rate for an infinite slab was calculated by **Eq. (4)[20]**.

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

Where, MR is moisture ratio (dimensionless), t is drying time (min), D_{eff} is effective moisture diffusivity (m^2 /s), L is half the thickness of the layer (m), Logarithmic simplification of above equation leads to the linear form of **Eq. (5)**

$$\ln(MR) = \ln\left(\frac{8}{\pi^2}\right) - \left(\frac{\pi^2 D_{eff} t}{4L^2}\right) \quad (5)$$

By plotting the measured data in a logarithmic scale, the effective moisture diffusivity was calculated from the slope of the line as presented in **Eq. (6):**

$$Slope = \left(\frac{\pi^2 D_{eff}}{4L^2}\right) \quad (6)$$

Activation Energy

Using Arrhenius equation, as a relationship between temperature and effective moisture diffusivity, energy of activation was calculated using **Eq. (7).**

$$D_{eff} = D_0 .\exp\left(\frac{E_a}{R_g} . \frac{1}{T}\right) \quad (7)$$

Where, E_a is energy of activation (KJ/mol), R_g is the universal gas constant as 8.3143 (J/mol. K), T is absolute temperature of the drying medium (K), and D_0 is the line intercept, which is always constant. Again, the logarithmic operation was carried out to obtain the linear form **Eq. (8).**

$$LnD_{eff} = \ln D_0 - \frac{E_a}{R_g} . \frac{1}{T} \quad (8)$$

$$K_0 = \frac{-E_a}{R_g} \quad (9)$$

Plotting ln D_{eff} versus (1/T) can give a line with slope K_0 during the test.

Energy Consumption

The energy consumption in each period was determined using **Eq. (10)** [9,10,20,21].

$$E_t = A \times \upsilon \times \rho_a \times C_a \times \Delta T \times Dt \quad (10)$$

Where, E_t is total energy in each drying phase (kWh), A is cross sectional area (m^2), ρ_a is air density (Kg/ m^3), ΔT is temperature differences (°C), Dt is time for drying each sample (h), C_a is the specific heat of air (KJ/ Kg. °C).

Statistical Analysis

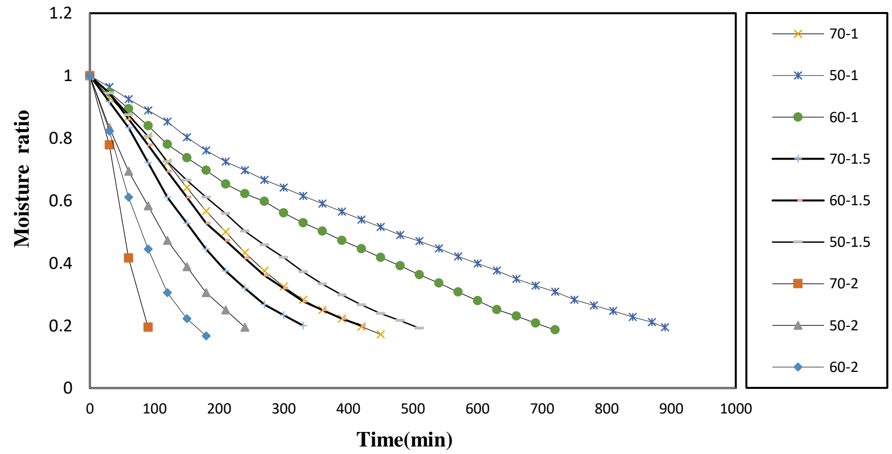
Statistical analysis was performed using a completely randomized factorial design, and used the SPSS Statistics 26.0 software. The data was analyzed by two way-ANOVA. The chosen significance level was $p < 0.05$.

Results and Discussion

Drying Kinetics

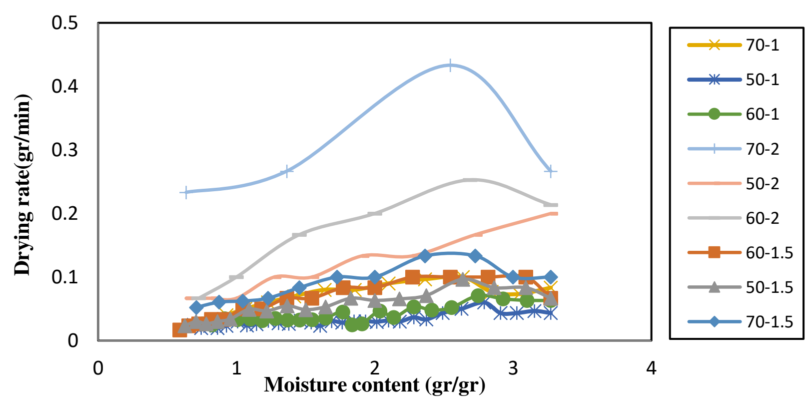
The food waste was dried as a thin layer with thickness of 3 cm at the cabinet dryer. The variations of moisture ratio of the food waste as a function of drying time at different inlet air velocity are presented in Fig.4. It was concluded that increasing drying temperature and inlet air velocity decreased the drying time.

Fig. 4 Drying curves of moisture ratio



In Fig. 5 the behavior of the drying rate curves for the food waste shows that, as the drying air velocity increases, the drying rate of the food waste increase.
The drying rate is high at the inlet air velocity of 2 m/s. Because at the air velocity of 2m/s, the air has a better contact with the surface of food waste, which results in a greater absorption of moisture. But at air velocities 1 and 1.5 m/s, reduced the air velocity pass through the sample, therefore reduced drying of food waste. Results from the drying rate in this research show that increasing the air velocity from 1.5 to 2 m/s could enhance the drying rate significantly. This is in line with the report of Liu et al [5]. They investigated a fluidized bed dryer for biomass drying, and concluded that increasing the air velocity could enhance the drying rate significantly. Also, the drying rate increased with increase in the temperature of the drying air, and the highest values of drying rate were obtained in the experiments at drying air temperature of 70°C. A similar increase was reported in the convection hot air dryer, industrial fruit and vegetable dryer and cabinet tray dryer [27-29]. Of course, in them, hot air circulates by the fan throughout the dryer chamber, and drying curves, existed in the falling rate period.

Fig. 5 Drying rate curves



The required total drying time to achieve the suitable moisture content, 10% (d.b.) of the dried food waste should be observed in Fig. 6 and Table 1. Drying time reduction by increasing drying temperature was reported for many foodstuffs [22-26]. The drying time is very important for dryer efficiency. This parameter in this study is different as compared to other developed dryers that reported for solar dryer [2,4]. The drying time in the cabinet dryer is much less than solar dryer.

Fig. 6 Drying time of food waste

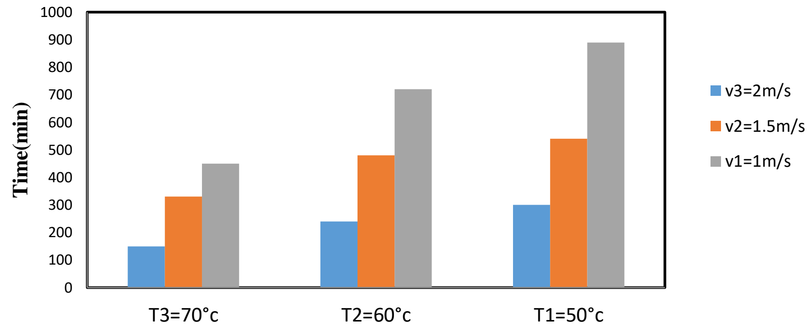


Table. 1 Drying time of food waste(min)

Velocity	Temperature		
	70° C	60°C	50°C
1 m/s	450	720	890
1.5 m/s	330	480	540
2 m/s	120	240	300

The period times to reach to 10% moisture content from the initial moisture content of the food waste at various drying air temperature were found between 120 and 890 min. The minimum drying period time was occurred at temperature of 70°C and inlet air velocity of 2m/s and the maximum drying time was happened at temperature of 50°C and inlet air velocity of 1m/s.

Statistical Analysis

Table 2 shows the results of the analysis of variance at the level of 95 % ($p < 0.05$). Results show that inlet air velocity, temperature, and the interaction (air velocity × temperature) have a significant effect on drying. All three factors affect the drying of food waste.

Table 2 Results of analysis of variance the effect of temperature and velocity on drying time of food waste

Source	Sum of Squares	Degree of Freedom	Mean Squares	F
Velocity	2	0.868	0.434	8.491**
Temperature	2	7.642	3.821	74.758**
Temperature× velocity	4	10.768	2.692	55.669**
Error	18	0.920	2.692	
Total	26	20.198		

significant differences at probability level of 95 % (p<0.05)

Effective Moisture Diffusivity

Table 3 demonstrates the calculated values of effective moisture diffusivity in different temperatures and velocities. Effective moisture diffusivity increased with the increase in temperature and air velocity. As seen, the maximum value of D_{eff} was found at the maximum air temperature and air velocity. Because at a high air velocity of 2m/s, the air has a better contact with the food waste which results in a greater absorption of moisture. Effective moisture diffusivities of food waste during the drying process were in the range of 2.74×10^{-9} -3.65×10^{-8} m^2/s. Effective moisture diffusivity is in agreement with the results that reported for vegetable wastes. Generally, effective diffusivity values found for different foods are in the range 10^{-11}-10^{-9} m^2/s [10,30]. This value was higher at the velocity of 2 m/s and 70˚C, which is due to the increase in drying intensity.

Table 3 Effective moisture diffusivity m^2/s in different temperatures and velocities

Velocity m/s	Temperature		
	70˚C	60˚C	50˚C
2	3.65×10^{-8}	1.83×10^{-8}	9.13×10^{-9}
1.5	7.3×10^{-9}	6.39×10^{-9}	4.56×10^{-9}
1	6.39×10^{-9}	3.65×10^{-9}	2.74×10^{-9}

Activation Energy

Variation of ln (D_{eff}) versus 1/T in different inlet air velocity is observed in Fig. 7. The activation energy for food waste was calculated by means of linear regression, and the values are shown in Table 4. The values for activation energy have ranged from a minimum of 21.59 KJ/mol in 1.5 m/s air velocity up to a maximum of 64.00 KJ/mol in 2m/s air velocity. Values obtained for activation energy is in the ranges of food waste activation energy [31]. The activation energy at the velocity of air 1m/s is more than the velocity of air 1.5 m/s. This is attributed to the difference in the chemical composition of the food waste.

Fig. 7 Plot of ln(D_{eff}) plotted against 1/T at the different air velocities

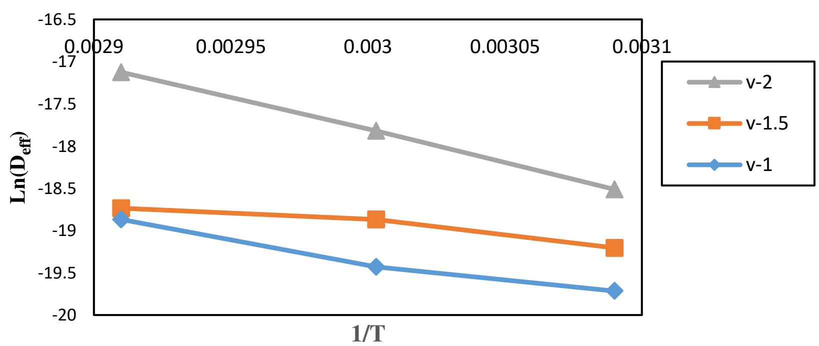


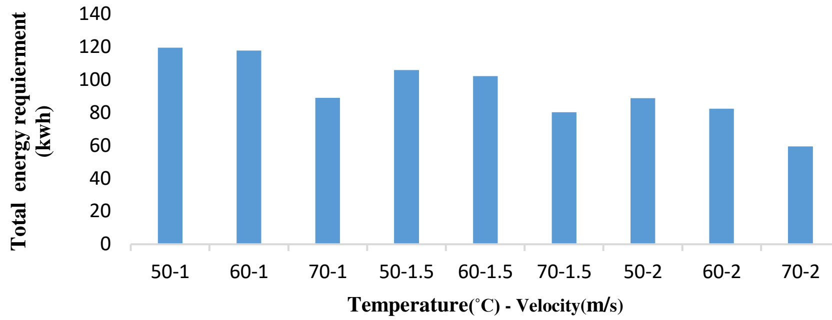
Table 4 Activation energy in different velocities

Velocity (m/s)	k	Ea (KJ/mol)
2	7698.8	64.00
1.5	2597.6	21.59
1	4722.2	39.26

Energy Consumption

The energy consumption in different temperatures and inlet air velocities are demonstrated in Fig. 8. The energy consumption was reduced by increasing the drying temperature and air velocity. The lowest energy consumption was at 70°C and 2m/s and the highest energy consumption was at 50°C and 1m/s. considering the results, the values obtained for total energy required for drying of food waste was in ranges of 119.62-59.41 Kwh.

Fig. 8 Energy consumption of food waste dryer at different levels of air temperature and velocity



Conclusions

Cabinet dryer with a conventional tray can be used for drying food waste to reduce leachate, and prevented the release of pollutants into the environment. The minimum drying time was obtained in temperature of 70°C and inlet air velocity of 2m/s at the 120 min. Also, the lowest energy consumption was occurred at 70°C and 2m/s. Reduction energy consumption by increasing the temperature and increasing the air velocity was the important advantages of the cabinet dryer by conventional tray.

Declarations

Conflict of interest The authors have no financial or proprietary interests in any material discussed in this article.

Data availability The data that support the findings of this are available from the corresponding and lead authors, upon reasonable request.

Code availability The code is available from the corresponding and lead authors, upon reasonable request.

References

1. Shirinbakhsh, M., Amidpour, M.: Design and optimization of solar- assisted conveyer-belt dryer for biomass. Energy Equipment and Systems. **5**(2), 10-15 (2017)
2. Nijmeh, M. N., Ragab, A. S., Emish, M. S., Jubran, B. A.: Design and testing of solar dryers for processing food wastes. Applied Thermal Engineering. **18**, 1337-1346 (1998)
3. Ferreira, A. G., Gonçalves, L. M., Maia, C. B.: Experimental analysis of industrial solid waste solar drying. 22nd International Congress of Mechanical Engineering, Brazil. (2013).
4. Ikem, I. A., Osim, A. D., Nyong, O. E., Takim, S. A.: Determination of loading capacity of a direct solar boiler dryer. International Journal of Engineering andTechnology. **8**(2), 1386-1396 (2016)
5. Liu, Y., Peng, J., Kansha, Y., Ishizuka, M., Tsutsumi, A., Jia, D., Sokhansanj, S.: Novel fluidized bed dryer for biomass drying. Fuel Processing Technology. 122, 170–175 (2014) https://doi.org/10.1016/j.fuproc.2014.01.036.
6. Kim, B. S., Kang, C. N., Jeong, H. J.: A study on a high efficiency dryer for food waste. Journal of the Korean Society for Power System Engineering. **18**(6), 153-158 (2014) https://doi.org/10.9726/kspse.2014.18.6.153
7. López, A., Iguaz, A., Esnoz, A., Vírseda, P.: Thin-layer drying behavior of vegetable waste from wholesale market. Drying Technology. **18**(4), 995-1001 (2000) https://doi.org/10.1080/07373930008917749
8. Nzioka, M. A., Hwang, U. H., Kim, M. G., Troshin, A. G., Caozheng, Y., Kim, Y. J.: Experimental investigation of drying processing for mixed municipal solid waste: case study of waste generated in nairobi, kenya. Int'l Journal of Advances in Agricultural & Environmental Engg. **3**(1), 87-91(2016) http://dx.doi.org/10.15242/IJAAEE.ER01160039
9. Motevali, A., Minaei, S., Khoshtaghaza, M. H., Kazemi, M., Nikbakht, A. M.: Drying of pomegranate arils: comparison of predictions from mathematical models and neural networks. Int. J.Food Eng. **6**(3), 1-20 (2010)
10. Motevali, A., Abbaszadeh, A., Minaei, M., Khoshtaghaza, M. H., Ghobadian, B.: Effective moisture diffusivity, activation energy and energy consumption in thin-layer drying of jujube (Zizyphus jujube Mill). J. Agr. Sci. Tech.**14**, 523-532 (2012).
11. Tahmasebi, M., Tavakoli Hashjin, T., Khoshtaghaza, M. H., Nikbakht, A. M.: Evaluation of thin-layer drying models for simulation of drying kinetics of quercus (quercus persica and quercus libani). J. Agri. Sci. Tech. **13**, 155-163 (2011)
12. Darvishi, H.: Energy consumption and mathematical modeling of microwave drying of potato slices. Agric Eng Int: CIGR Journal. **14**(1), (2012)
13. Ghasemkhani, H., Rafiei, S., Kayhani, A., Dalvand, M. B.: Evaluation of drying apple slices using a rotary dryer equipped with a heat exchanger. Journal of Agricultural Machinery Mechanical Research. **7**(2), 9-19 (2018)

14. Gebreegziabher, T., Oyedun , A. O., Hui, C. W.: Optimum biomass drying for combustion - a modeling approach. Energy. **53**, 67-73 (2013) https://doi.org/10.1016/j.energy.2013.03.004
15. AOAC. Official methods of analysis (15th Edn). Association of official analytical chemists.Washington DC, USA. (1990)
16. El-Sebaii, A. A., Aboul-Enein, S., Ramadan, M. R. I., El-Gohary, H. G.: Empirical correlations for drying kinetics of some fruits and vegetables. Energy. **27**, 845–859 (2002)
17. Togrul, I. T., Pehlivan, D.: Mathematical modelling of solar drying of apricots in thin layers. Journal Food Eng. **55**, 209–216 (2002) https://doi.org/10.1016/S02608774 (02)00065-1
18. Yaldiz, O., Ertekin, C., Uzun, H. I.: Mathematical modeling of thin layer solar drying of sultana grapes. Energy. **26**(5), 457-464 (2001) https://doi.org/10.1016/S0360-5442(01)00018-4
19. Meziane, S.: Drying kinetics of olive pomace in a fluidized bed dryer. Energ. Convers. Manage. **52**, 1644-1649 (2011) https://doi.org/10.1016/j.enconman.2010.10.027
20. Aghbashlo, M., Kianmehr, M., Samimi-Akhijahani, H., Influence of drying conditions on the effective moisture diffusivity, energy of activation and energy consumption during the thin-layer drying of berberis fruit (berberidaceae). Energy Con Manag. **49**, 2865-2871(2008)
21. Koyuncu, T., Tossun, I., pinar, Y., Drying characteristic and heat energy riqurment of cornelian cherry fruits. Journal OF Food Engineering, **78**, 735-739 (2007). https://doi.org/10.1016/j.jfoodeng.2005.09.035
22. Alibas, I.: Energy consumption and colour characteristics of nettle leaves during microwave, vacuum and convective drying. Biosystems Engineering. **96**(4), 495–502 (2007) https://doi.org/10.1016/j.biosystemseng.2006.12.011
23. Al-Harahsheh, M., AL-Muhtaseb, A., Magee, T. R. A: Microwave drying kinetics of tomato pomace: Effect of osmotic dehydration. Chemical Engineering and Processing. **48**(1), 524-531(2009) https://doi.org/10.1016/j.cep.2008.06.010
24. Arslan, D., Ozcan, M. M.: Study the effect of sun, oven and microwave drying on quality of onion slices. LWT-Food Science and Technology. **43**(7), 1121-1128(2010)
25. RostamiBaroji, R., SeiiedlouHeris, S. S., Dehghannya, J.: Mathematical simulation of heat and mass transfer in convectional drying of carrot, pretreated by ultrasound and microwave. Journal of Agricultural Machinery. **7**(1), 97-113(2017)
26. Mazandarani, Z., Aghajani, N., Daraei, G. A., Bani ardalan, M. J., Nouri, M.: Mathematical modeling of thin layer drying of pomegranate (punica granatum L.) arils: various drying methods. J. Agr. Sci. Tech. **19**, 1527-1537 (2017)
27. Ojediran, J. O., Clinton, E. O., Adeyi, A. J., Adeyi, O., Olaniran, A. F., George, N. E., Olayanju, A., T.: Drying characteristics of yam slices (dioscorea rotundata) in a convective hot air dryer: Application of ANFIS in the prediction of drying kinetics. Heliyon. **6**, (2020) https://doi.org/10.1016/j.heliyon.2020.e03555
28. Ehiem, J. C.: Design and development of an industrial fruit and vegetable dryer. Research Journal of Applied Sciences, Engineering and Technology. **1**(2), 44-53 (2009)
29. Akpan, G.E., Onwe, D.N., Fakayode, O.A., Offiong, U., D.:Design and development of an agricultural and bio-materials cabinet tray dryer. Science Research. **4**, 174-182 (2016)
30. Babalis, S.J., Belessiotis, V.G: Influence of drying conditions on the drying constants and moisture diffusivity during the thin-layer drying of figs. J. Food Eng. **65**, 449-458 (2004)
31. Jo, J. H., Kim, S. S., Shin, J. W., Lee.Y.E., Yoo, Y. S.: Pyrolysis characteristics and kinetics of food wastes. Energies. **10**(10), (2017) https://doi.org/10.3390/en10081191

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