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Drying Food Waste Using a Conventional Tray Cabinet Dryer

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ABSTRACT

In order to reduce leachate from food waste a conventional tray cabinet dryer was designed and built, and the drying process of these wastes was investigated. A 2.7 kW heater equipped with an axial fan was used as the heating source. 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 and activation energy during drying of food waste were obtained. Results showed that improving air distribution in the back of the tray and no passing air on the sides of the tray causes that increase the drying rate significantly. The minimum drying process was occurred in temperature of 70°C and air velocity of 2 m/s at the 120 min. 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 for activation energy have ranged from a minimum of 21.6 kJ/mol in 1.5 m/s air velocity up to a maximum of 64.0 kJ/mol in 2m/s air velocity.

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INTRODUCTION

Decomposable organic matter, mainly kitchen waste and agriculture waste, is the major waste generated worldwide. Encouraging homeowners and farmers to separate and dry organic waste is a promising project for food waste management to reduce significantly its volume. 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 (Shirinbakhsh & Amidpour, 2017), solar dryer (Ikem et al., 2016; Nijmeh et al., 1998), fluidized bed dryer (Liu et al., 2014), and rotary dryer (Kim et al., 2014), among which rotary dryers are the most common.

Lopez et al (2000) investigated the drying behavior of vegetable waste as a combination of cabbage and lettuce leaves. They extracted the drying curves. The results showed 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 (Nzioka et al., 2016). Several studies on effective moisture diffusivity and energy of activation were achieved in thin layer drying of vegetables and fruits included pomegranate Quercus (Tahmasebi et al., 2011), potato (Darvishi, 2012), Apple (Ghasemkhani et al., 2018; Hosseini et al., 2023).

However, there is little information on the drying of food waste in cabinet dryers, which makes the current research necessary. 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. In this study, drying process of food waste in a cabinet dryer with a conventional tray was investigated and drying kinetics, effective moisture diffusivity and activation energy during drying of food waste were investigated.

MATERIALS AND METHODS

A cabinet dryer was developed for drying food waste in the research. Figure 1 (a) shows a schematic of the dryer. The dryer contained a axial 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 (Figure 1b).

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 (Figure 2).

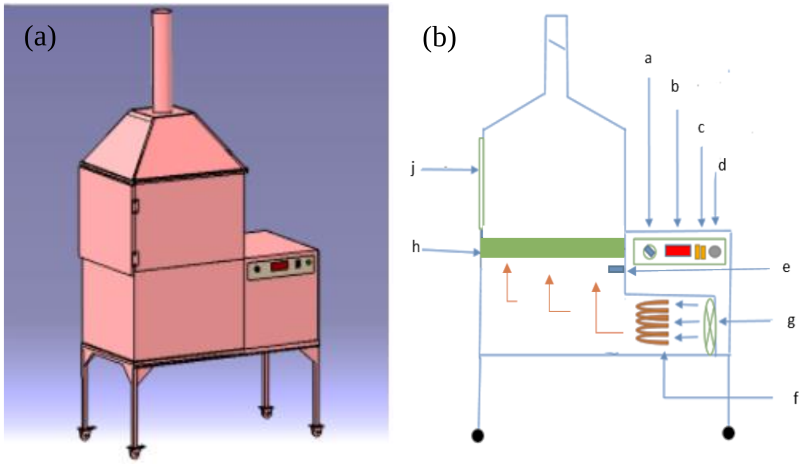

Figure 1. a: Schematic of dryer food waste**,** b: Schematic representation of the food waste dryer: (a) on and off switch, (b) Temperature controller, (c) Selector key, (d) Air velocity control, (e) Temperature selector, (g) Centrifugal fan, (f) Heaters, (j) Door, (h) Place of tray.

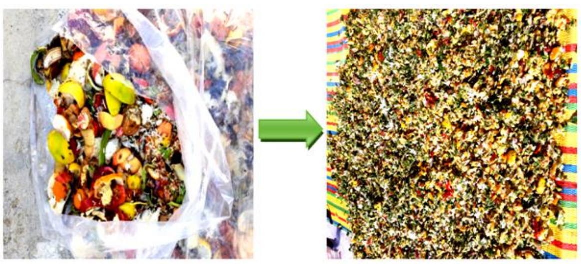

Figure 2. Sample preparation

Drying kinetics

Initially, the wastes were exposed to ambient air and then were pressed with a manual 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 (Figure 3a).

Figure 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. Drying was continued until the final moisture content of the samples reached approximately 10% (d.b). The moisture content (dry basis) at any time was then calculated from the sample weights obtained using initial and final moisture content values (Lopez et al., 2000).Then the samples were dried in an oven at temperature of 105±1ºC until to determine solid mass (AOAC, 1990).

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).

$$MR=\frac{M_d - M_e}{M_o - M_e} \tag{1}$$

Where, MR is moisture ratio (dimensionless), M_d is moisture content (g_{water} /$g_{dry\ solids}$). M_0 is initial moisture content (g_{water}/$g_{dry\ solids}$). M_e is equilibrium moisture content (g_{water}/$g_{dry\ solids}$). This was simplified to M_d/M_0 by some investigators, because of the continuous fluctuation of the relative humidity of the drying air during the drying processes (A. El-Sebaii et al., 2002; Togrul & Pehlivan, 2002; Yaldiz et al., 2001). 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). (Meziane, 2011).

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

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

Effective moisture diffusivity

The diffusion rate for an infinite slab was calculated by Eq (4) (Aghbashlo et al., 2008).

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

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 by Eq (6), using the method of slopes.

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

Activation energy

Using Arrhenius equation which is shown in Eq (7), activation energy can be calculated.

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

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. Then the logarithmic operation was performed to obtain the linear form Eq (8).

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

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

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

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. 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. The variations of moisture ratio of the food waste as a function of drying time at different inlet air velocity are presented in Figure 4. It was concluded that increasing drying temperature and inlet air velocity decreased the drying time.

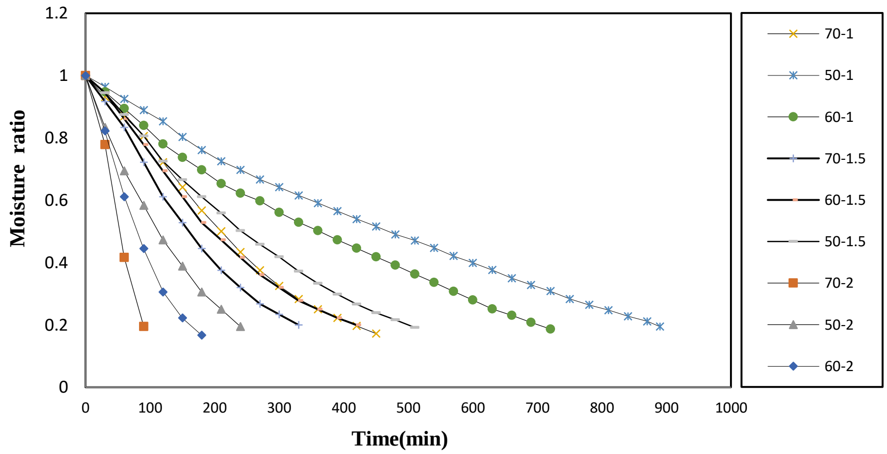

Figure 4. Drying curves of moisture ratio

In Figure 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 hot air has better contact with the surface of food waste, which results in greater evaporation 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 show that increasing the air velocity from 1.5 to 2 m/s could increase the drying rate significantly. This is in line with the report of Liu et al (2014). They investigated a fluidized bed dryer for biomass drying, and concluded that increasing the air velocity could enhance the drying rate significantly. Of course, this is different to proceeding of the drying in the convection hot air dryer (Ojediran et al., 2020), industrial fruit and vegetable dryer (Ehiem et al., 2009), and cabinet tray dryer (Akpan et al., 2016). Of course, in their investigation, hot air circulates by the fan throughout the dryer chamber, and drying curves, existed in the falling rate period.

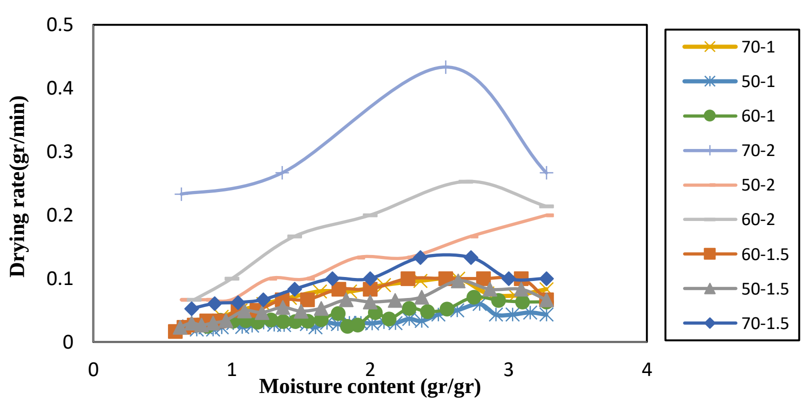

Figure 5. Drying rate curves

The required total drying time to achieve the suitable moisture content, 10% (d.b.) of the dried food waste should be observed in Figure. 6 and Table 1. Drying time reduction by increasing drying temperature was reported for many foodstuffs such as nettle leaves (Alibas, 2007), tomato pomace (Al-Harahsheh et al., 2009), onions (Arslan & Özcan, 2010), carrot (Rostami Baroji et al., 2017).

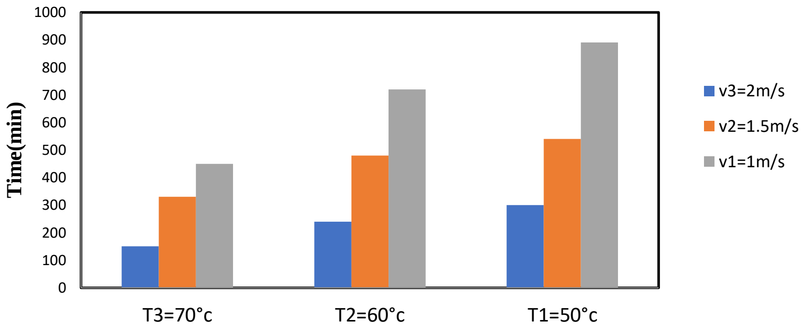

Figure 6. Drying time of food waste

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 better contact with the food wastes which results in greater evaporation 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. Effective diffusivity values for different foods have been reported in the range 10-11-10-9 m^2/s (Motevali et al., 2012). 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 Figure 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 (Jo et al., 2017). 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.

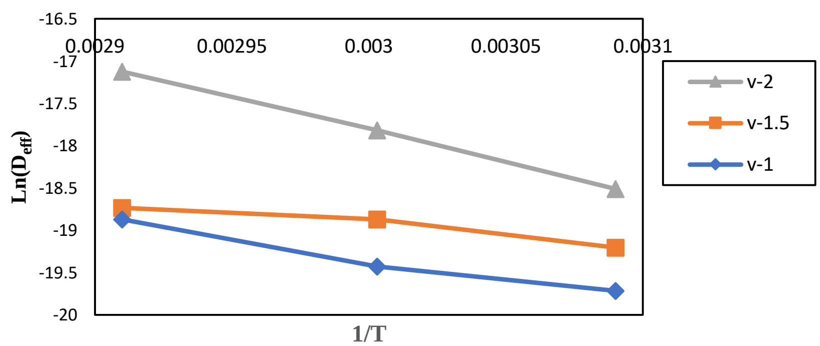

Figure 7. Plot of ln(D_{eff}) plotted against 1/T at the different air velocities

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

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. Improving air distribution in the back of the tray and no passing air on the sides of the tray causes that increase the drying rate significantly. The minimum drying time was obtained in temperature of 70°C and inlet air velocity of 2m/s at the 120 min. 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. 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.

REFRENCES

Aghbashlo, M., Kianmehr, M., & Samimi-Akhijahani, H. (2008). 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. https://doi.org/10.1016/j.enconman.2008.03.009

Akpan, G. E., Onwe, D. N., Fakayode, O. A., & Offiong, U. D. (2016). Design and Development of an Agricultural and Bio-materials Cabinet Tray dryer. *Science Research*, *4*(6), 174-182. https://doi.org/10.11648/j.ijfet.20160201.14

Al-Harahsheh, M., Ala'a, H., & Magee, T. (2009). Microwave drying kinetics of tomato pomace: Effect of osmotic dehydration. *Chemical Engineering and Processing: Process Intensification*, *48*(1), 524-531. https://doi.org/10.1016/j.cep.2008.06.010

Alibas, I. (2007). Energy consumption and colour characteristics of nettle leaves during microwave, vacuum and convective drying. *Biosystems Engineering*, *96*(4), 495-502. https://doi.org/10.1016/j.biosystemseng.2006.12.011

AOAC. (1990). Official methods of analysis (15th Edn). *Association of Official Analytical Chemists.Washington DC, USA.*

Arslan, D., & Özcan, M. M. (2010). Study the effect of sun, oven and microwave drying on quality of onion slices. *LWT-Food Science and Technology*, *43*(7), 1121-1127. https://doi.org/10.1016/j.lwt.2010.02.019

Darvishi, H. (2012). Energy consumption and mathematical modeling of microwave drying of potato slices. *Agricultural Engineering International: CIGR Journal*, *14*(1), 94-102.

Ehiem, J., Irtwange, S., & Obetta, S. (2009). Design and development of an industrial fruit and vegetable dryer. *Research Journal of Applied Sciences, Engineering and Technology*, *1*(2), 44-53.

El-Sebaii, A., Aboul-Enein, S., Ramadan, M., & El-Gohary, H. (2002). Empirical correlations for drying kinetics of some fruits and vegetables. *Energy*, *27*(9), 845-859. https://doi.org/10.1016/S0360-5442(02)00021-X

Ghasemkhani, H., Rafiei, S., Kayhani, A., & Dalvand, M. (2018). Evaluation of drying apple slices using a rotary dryer equipped with a heat exchanger. *Journal of Agricultural Machinery Mechanical Research*, *7*(2), 9-19.

Hosseini, F., Shakiba, R., Rezvani, Z., & Arslan, S. (2023). Investigating the Kinetics, Energy and Exergy of Drying Apple slices Using Infrared Radiation. *Biomechanism and Bioenergy Research*, *2*(1), 1-10. https://doi.org/10.22103/BBR.2023.21678.1043

Ikem, I., Osim, A., Nyong, O., & Takim, S. (2016). Determination of loading capacity of a direct solar boiler dryer. *International Journal of Engineering and Technology*, *8*, 1386-1396.

Jo, J.-H., Kim, S.-S., Shim, J.-W., Lee, Y.-E., & Yoo, Y.-S. (2017). Pyrolysis characteristics and kinetics of food wastes. *Energies*, *10*(8), 1191. https://doi.org/10.3390/en10081191

Kim, B.-S., Kang, C.-N., & Jeong, J.-H. (2014). A study on a high efficiency dryer for food waste. *Korean Society for Power System Engineering*, *18*(6), 153-158. https://doi.org/10.9726/kspse.2014.18.6.153

Liu, Y., Peng, J., Kansha, Y., Ishizuka, M., Tsutsumi, A., Jia, D., . . . Sokhansanj, S. (2014). Novel fluidized bed dryer for biomass drying. *Fuel*

Processing Technology, *122*, 170-175. https://doi.org/10.1016/j.fuproc.2014.01.036

Lopez, A., Iguaz, A., Esnoz, A., & Virseda, P. (2000). Thin-layer drying behaviour of vegetable wastes from wholesale market. *Drying technology*, *18*(4-5), 995-1006. https://doi.org/10.1080/07373930008917749

Meziane, S. (2011). Drying kinetics of olive pomace in a fluidized bed dryer. *Energ. Convers. Manage*, *52*, 1644-1649.

Motevali, A., Abbaszadeh, A., Minaei, S., Khoshtaghaza, M., & Ghobadian, B. (2012). Effective moisture diffusivity, activation energy and energy consumption in thin-layer drying of Jujube (Zizyphus jujube Mill). *Journal of Agricultural Science and Technology*, *14*(3), 523-532. https://doi.org/20.1001.1.16807073.2012.14.3.10.4

Nijmeh, M., Ragab, A., Emeish, M., & Jubran, B. (1998). Design and testing of solar dryers for processing food wastes. *Applied thermal engineering*, *18*(12), 1337-1346. https://doi.org/10.1016/S1359-4311(98)00002-7

Nzioka, A. M., Hwang, H. U., Kim, M. G., Troshin, A. G., CaoZheng, Y., & Kim, Y. J. (2016). Experimental investigation of drying process for mixed municipal solid waste: Case study of wastes generated in Nairobi, Kenya. *Int'l Journal of Advances in Agricultural & Environmental Engg.(IJAAEE) Vol*, *3*(1), 2349-1523. https://doi.org/10.15242/IJAAEE.ER01160039

Ojediran, J. O., Okonkwo, C. E., Adeyi, A. J., Adeyi, O., Olaniran, A. F., George, N. E., & Olayanju, A. T. (2020). Drying characteristics of yam slices (Dioscorea rotundata) in a convective hot air dryer: Application of ANFIS in the prediction of drying kinetics. *Heliyon*, *6*(3). https://doi.org/10.1016/j.heliyon.2020.e03555

Rostami Baroji, R., Seiiedlou Heris, S., & Dehghannya, J. (2017). 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. https://doi.org/10.22067/jam.v7i1.38881

Shirinbakhsh, M., & Amidpour, M. (2017). Design and optimization of solar-assisted conveyer-belt dryer for biomass. *Energy Equipment and Systems*, *5*(2), 85-94. https://doi.org/10.1016/j.fuproc.2014.01.036

Tahmasebi, M., Tavakkoli Hashjin, T., Khoshtaghaza, M., & Nikbakht, A. (2011). Evaluation of thin-layer drying models for simulation of drying kinetics of quercus (Quercus persica and Quercus libani). *Journal of Agricultural Science and Technology*, *13*(2), 155-163. https://doi.org/20.1001.1.16807073.2011.13.2.1.6

Togrul, I. T., & Pehlivan, D. (2002). Mathematical modelling of solar drying of apricots in thin layers. *Journal Food Eng*, *55*, 209–216.

Yaldiz, O., Ertekin, C., & Uzun, H. I. (2001). Mathematical modeling of thin layer solar drying of Sultana grapes. *Energy*, *26*(5), 457-464.