

Drying Characteristics of Agricultural Products under Different Drying Methods: A Review

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Abstract

Purpose: Drying is one of the most widely used methods for preserving agricultural products or food. The main purpose of drying agricultural products is to reduce their water content for minimizing microbial spoilage and deterioration reaction during storage. **Methods:** Although numerous drying methods are successfully applied to dehydrate various agricultural products with little drying time, the final quality of dried samples in terms of appearance and shape cannot be guaranteed. Therefore, based on published literature, this review was conducted to study the drying characteristics of various agricultural products when different drying methods were applied. **Results:** An increase in the drying power of sources-for example, increase in hot air temperature or velocity, infrared or microwave power-and the combination of drying power levels can reduce the drying time of various agricultural products. In addition, energy efficiency in drying significantly relies on the compositions of the dried samples and drying conditions. **Conclusions:** The drying power source is the key factor to control entire drying process of different samples and final product quality. In addition, an appropriate drying method should be selected depending on the compositions of the agricultural products.

Keywords: Agricultural product quality, Combination drying, Convective air drying, Infrared drying, Microwave drying

Introduction

Agricultural products constantly undergo physiological changes through respiration even after harvest. Such changes can result in serious quality problems such as decomposition, change in external appearance, and loss of nutritional properties. Therefore, various postharvest technologies are investigated to minimize the effect of the factors that influence product quality during storage and distribution.

Five major methods (fermentation, chemical treatment,

drying, heat treatment, and freezing) are used for preserving perishable foods and agricultural products without microbial contamination (WHO, 1988). Among these methods, drying is reliable and efficient for preserving agricultural products for further processing. The removal of moisture content from agricultural products during drying can reduce moisture-mediated degradation and chemical and enzymatic reactions (Baysal et al., 2003). Dried fruits and vegetables are popular owing to their longer shelf-life, produce diversity, and remarkable reduction in volume (Maskan, 2001). In addition, consumers prefer high-quality dried products that retain nutritional and health benefits. Because the majority of agricultural products are thermo-sensitive, their color and chemical and physical properties may change

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significantly because of excessive heat accumulation during drying. Therefore, temperature control during drying is crucial to obtain high-quality dried products.

Conventional drying methods (such as those involving the use of hot air, fluidized beds, and vacuum (VC) drying) are used for postharvest treatment of agricultural products; however, hot-air (HA) drying has its inherent limitations. For example, it causes case-hardening, which results in a thermal barrier that impedes heat transfer from the hot air to the product (Simal et al., 1997; Lin et al., 1998; Ratti, 1994).

In the past decades, new drying methods (such as those involving the application of microwave (MW) or infrared (IR) energy, freezing, and combination drying) were introduced as attractive alternatives to conventional drying methods. MW drying leads to a high vapor pressure inside the agricultural product, resulting in a more porous structure, less shrinkage, and lower energy consumption (Paengkanya et al., 2015). IR drying has the advantages of high heat transfer rates with a compact heater, easy operation control, and reduced drying time (Navari et al., 1992). Although MW and IR drying methods have outstanding merits over convective air drying, they can cause undesirable phenomena such as charring, non-uniform heat generation, and limited penetration depth depending on the components in agricultural products. Combination drying methods (MW/IR drying assisted with hot air/VC, MW and IR combination) were introduced to compensate for the aforementioned drawbacks of individual drying methods. Several studies reported that combination drying methods promote faster drying time with rapid moisture diffusion and less change in color than in HA drying (Koné et al., 2013; Zhao et al., 2013; Wojdyło et al., 2014; Wu et al., 2014; Salim et al., 2016). Freeze-drying was considered a novel drying method in which frozen food or agricultural products could be dried by the sublimation of ice (Oetjen, 2000). Products dried using freeze-drying retained their original high flavor content and high contents of organic volatile and aromatic acid compounds (Flink and Karel, 1970; Thijssen, 1971; Asami et al., 2003). However, freeze-drying incurs high maintenance costs for the high-performance compressor and VC pump because of the absence of a liquid phase (i.e., water) during the drying process.

Although numerous drying methods were successfully employed for the dehydration of various agricultural products, controlling the unsteady heat and moisture transfer during drying was practically not achieved. Therefore, investigating the drying characteristics of agricultural products for different

drying methods is essential. The aim of this review is to study the drying characteristics of various agricultural products under different drying methods such as HA, IR, MW, and combination drying methods based on mainly the literature published in the past five years.

Drying methods for agricultural products

Hot-air (convective air) drying

HA drying is the most commonly used commercial method for drying vegetables and fruits (Mazza and LeMaguer, 1980). During HA drying, convective air flow passes over the surface of the product, not through the products; thus, heat transfer from the surrounding environment to the internal section of agricultural products significantly relies on the thermal conductivities of the products (Wang and Sheng, 2006). Moreover, HA drying frequently causes loss in quality and requires a long drying time with low energy efficiency during the falling rate period (Maskan, 2001).

In a study, thin-layer drying characteristics of blanched and unblanched eggplant slices were determined for different sample thickness (0.5 and 1 cm) and by changing the air temperature from 50°C to 80°C in steps of 10°C (Doymaz and GÖL, 2011). High HA temperature, low sample thickness, and pretreatment were effective for shortening the drying time. In this experiment, Fick's diffusion model was used to determine moisture transfer from eggplant slices, and different mathematical models were used for predicting drying characteristics. Effective diffusivity values were varied depending on the experimental condition, and Page's model was in good agreement with the experimental drying curves of eggplant slices.

Sweet potato cubes of three different thicknesses were dried under five different temperatures and velocities (Singh and Pandey, 2012). The drying time of the cubes increased proportionally with the increase in thickness and the decrease in HA temperature and velocity. Page's model was used to describe the drying curves of the sweet potato cubes.

Tulek et al. (2011) investigated theoretical models for the HA drying of oyster mushroom. Drying was carried out at different HA temperatures. Among the different drying models studied, the highest R^2 , the lowest root mean square error (RMSE), and chi-square (χ^2) values for all drying temperatures were obtained using the model proposed by Midilli et al. (2002). Motevali et al. (2011) determined the amount of energy and specific energy

consumption for drying button mushroom using different drying methods. In the case of HA drying, the energy consumption decreased with an increase in HA temperature but increased with an increase in HA velocity.

HA drying characteristics of various fruits (namely, sweet cherry, apple, and peach) were recently determined by a number of researchers (Doymaze and İsmail et al., 2011; Zlatanović et al., 2013; Zhu and Shen, 2014). Similar to the HA drying of vegetables, in the case of fruits too, the HA temperature and velocity play an important role in decreasing the drying time and deteriorating the quality index such as color values. Page's model was considered the best for describing the drying characteristics of sweet cherry and peach, while the Henderson and Pabis model fitted the drying curves of apple well.

Infrared drying

IR radiation, which is the part of the electromagnetic spectrum in the wavelength range 0.78-1000 μm , is employed for thermal processes involving food such as drying and pasteurization and for determining the quality and safety of agricultural products (Sakai and Hanazawa, 1994; Cho et al., 2011). IR drying is a good alternative for conventional drying methods (sun, HA, or VC drying). As compared to conventional drying methods, IR drying is effective for increasing the drying rate of agricultural products with higher energy efficiency and is suitable for dehydrating thin layers of fruits and vegetables by exposing large surfaces to IR radiation (Nasiroglu and Kocabiyik, 2009; Nowak and Lewicki, 2004). However, the rate of absorption of IR energy by agricultural products significantly depends on their moisture content and composition (Lampinen et al., 1991). Aboltins and Palabinskis (2016) investigated the effect of an IR film dryer on the dehydration of three different fruit products (namely, grape halves and apple and banana slices with a thickness of 1 cm) at relatively low temperatures (between 40 and 45°C). The drying rates of the apple and banana slices were higher than the drying rate of the grape halves; grape skin may obstruct penetration. In spite of the distinct merits and demerits of IR drying, the method is applied for drying different types of agricultural products.

The IR drying characteristics of carrot and sweet potato slices with changes in IR power levels were investigated, and different thin-layer drying models were used for both vegetable slices (Doymaz, 2012 and 2015). As the IR power increased, the drying time of the carrot and sweet potato slices decreased significantly, and the drying rate increased; however, the color values (namely, L (brightness), a (redness),

and b (yellowness)) of the carrot slices decreased consistently. The logarithmic model fitted the experimental data for the drying of sweet potato slices well. The thin-layer drying model established by Midilli et al. (2002) appropriately depicted the drying curves of carrot slices regardless of the IR power levels. In addition, the model proposed by Midilli et al. (2002) was successfully applied to model the drying characteristics of carrot (Toğrul, 2006).

Microwave drying

MW heating technology has contributed to changes in thermal processing operations, saving processing time in the food industry. In addition, the development of an inexpensive and practical MW power generator known as the magnetron has made domestic microwave ovens popular in real life (Zarein et al., 2015). MWs cause internal heat generation in food materials by the rotation of the dipolar water molecule and the conduction of ions resulting by altering the electromagnetic field (Paengkanya et al., 2015). Therefore, when MW heating is applied for drying agricultural products, the two heating mechanisms can cause rapid evaporation of water in the products. MW drying can improve the energy efficiency and quality of the dried products (Dev et al., 2011).

Energy efficiency during the MW drying of apple slices (thickness: 5 mm) was investigated (Zarein et al., 2015). As the MW power levels increased, energy efficiency increased from 17.42% to 54.34%. Furthermore, the increase in MW power levels affected moisture diffusivity. In addition, MW drying was employed in orange juice processing to make use of orange peel waste as valuable feedstock (Erdem et al., 2014). Five MW power levels (180, 360, 540, 720, and 900 W) were applied in the drying experiments, and nine drying models were established based on the results of the experiments. Drying time and moisture ratio of orange peel waste significantly decreased with an increase in MW power levels. Furthermore, among the models, the model proposed by Midilli et al. (2002) showed good agreement with experimental data. The results of the studies by Zarein et al. (2015) and Erdem et al. (2014) clearly showed that more MW energy could be absorbed by the water molecules in apple slices and orange peel waste, resulting in higher drying rates.

The major problem in MW drying is the nonuniform drying rate of samples. Moreover, temperature and quality control of samples is a tedious task at a fixed MW power level during the overall MW drying process. To

overcome this limitation, Li et al. (2010) proposed a new concept involving an MW drying system with automatic adjustment of MW power level and control of sample temperature. For evaluating the new MW drying system, four drying modes (mode 1:fixed power levels without temperature control, mode 2:fixed power levels with preset temperatures, mode 3:continuous adjustment of power level with feedback temperature control, and mode 4:continuous power adjustment by power-time (on/off ratio) and power-moisture content relationship) were applied for drying apple cube samples that were pretreated in hot water (80°C) for 1 min. In drying modes 1 and 2, samples were charred because of high MW power levels and large temperature fluctuations under the preset high temperature. In drying mode 3, as compared to mode 2, smaller temperature fluctuations and better final product quality were achieved; however, the drying rates of the apple samples varied depending on their initial moisture contents. Power adjustment depending on time and the moisture content of samples in mode 4 caused samples to overheat. Thus, drying mode 3 improved temperature control, final product quality, and drying rate.

The effectiveness of MW drying for various vegetables (celery, carrot, pumpkin, spinach, and pepper) was determined by many researchers (Alibas, 2014; Darvishi et al., 2014; Ozkan et al., 2007; Wang and Xi, 2005; Wang et al., 2007). Alibas (2014) utilized the domestic MW oven without any modification for drying approximately 50 g of celery leaves and applied 20 mathematical thin-layer-drying models for predicting the drying curves. The drying time of celery leaf samples decreased with an increase in MW power levels. In addition, among the developed models, the Weibull model fitted the entire drying curves of celery leaves well; the R^2 values ranged from 0.9992 to 0.9998.

When MW drying was applied to dehydrate carrot and pumpkin slice samples, the required time to achieve the target moisture contents of dried samples was affected by the thickness of the slice, MW power levels, and mass load (Wang and Xi, 2005; Wang et al., 2007). The effectiveness of the two-stage drying process (change in MW power levels) on changes in the β -carotene content and rehydration ratio of dried carrot samples was investigated (Wang and Xi, 2005). The rehydration ratio and β -carotene content of dried carrot samples decreased significantly with an increase in the thickness of slices. The main factors influencing the rehydration ratio of dried carrot samples were slice thickness, first-stage and

second-stage MW power levels, and slice thickness and the second-stage MW power level.

Spinach samples (50 g) were dehydrated by MW drying at different power levels, and the changes in ascorbic acid content and color parameters of dried spinach samples were investigated (Ozkan et al., 2007). Increase in MW power levels considerably shortened the drying times of spinach samples and led to high drying rates. The ascorbic acid content and color parameters (L , a , and b values) of dried spinach leaves decreased significantly with increase in MW power levels. The drying time of green pepper samples under MW drying also decreased with an increase in MW power levels, and the model of Midilli et al. (2002) accurately described the MW drying characteristics of green pepper (Darvishi et al., 2014).

Combination drying

As mentioned earlier, individual MW and IR drying are effective in reducing the drying time at high power levels, but they often cause quality deterioration in the final products. To minimize damage to the final products, several combination drying methods such as IR and HA, MW and VC, and MW and HA were developed.

Heat and mass transfer characteristics during combined IR and HA drying of apple slices (thickness:approximately 5.5 mm) were examined and compared with those of HA drying (Nowak and Lewicki, 2004). The distance between the IR lamps and apple samples was 10, 20, and 30 cm, and the applied air velocity for IR-HA drying was 0.5, 1.0, and 1.5 m/s. To compare the effects of IR and HA drying and HA drying alone on the drying time of apple slices, HA drying at temperatures of 65 and 75°C and at an air velocity of 1.5 m/s was conducted in the same dryer. For a fixed distance, an increase in air velocity significantly affected the drop in evaporation temperature. The fastest drying time of apple slices was achieved for an air velocity of 0.5 m/s and a distance of 10 cm. The drying time of the samples under IR and HA drying under the fixed condition (distance:30 cm, and air velocity:1 m/s) was lesser than that accomplished under HA drying at a velocity of 1.5 m/s and temperatures of 65 and 75°C by 50% and 13 to 40%, respectively. It was also reported that far infrared (FIR) drying combined with HA drying can lead to higher heat and mass transfer over individual HA drying (Jaturonglumert and Kiatsiriroat, 2010). Continuous IR and HA drying was designed to determine the drying and quality characteristics of radish (Park et al., 2015). An FIR heater was used to control HA

temperatures in the dryer. The drying experiment was conducted at four HA temperatures and three air velocity settings, provided using blast fans. An increase in HA temperature and velocity reduced the drying time of radish. Depending on HA temperature and velocity, the color values of dried radish varied significantly. In particular, the total color difference values of dried radish ($\Delta E = \sqrt{\Delta L^2 + \Delta a^2 + \Delta b^2}$) increased as the temperature increased and velocity decreased. Specifically, the a and b values of dried radish increased, and the L value decreased at high temperatures. Arikian et al. (2012) compared the performance of MW and HA drying of grated carrots with the results of HA drying alone. MW and HA drying yielded better performance than HA drying alone in terms of drying time, energy efficiency, and physical and sensory attributes. Instant rice samples were dehydrated by MW and HA drying and HA drying and MW drying alone (Jiao et al., 2014). An increase in MW power levels and HA temperature significantly reduced the drying time, and MW and HA combination drying produced dried instant rice of a better quality (little change in color values).

The drying kinetics and quality of durian chips dried by MW and VC drying were compared with those dried by MW and HA drying and by HA drying alone (Paengkanya et al., 2015). MW power levels from 150 to 250 W and VC pressure range from 10 to 30 kPa were applied in MW and VC drying. Identical MW power levels and a HA velocity of 0.3 m/s were used in MW and HA drying. The drying time of durian chips in MW and VC drying was lesser than the time required for MW and HA drying. As the MW power level increased and VC pressure decreased, the drying time decreased further. MW combination drying was better than HA drying alone in terms of color values. The effectiveness of MW and VC drying on the osmotic dehydration of papaya was evaluated by Nimmanpipug and Therdtai (2013). The hardness of papaya samples dried by MW and VC was lower than that of the samples dried by HA alone. MW and VC drying was effective for increasing the internal vapor pressure inside the papaya sample, consequently producing a more fine and porous structure in the dried papaya sample.

MW-assisted fluidized bed (FB) drying was applied for dehydrating soybeans (Ranjbaran and Zare, 2013). FB drying is a type of HA drying and is employed for drying of granular materials because it realizes high heat and mass transfer between the HA and granular materials; however, when FB drying is used for drying porous materials, longer drying times with lower energy efficiency are observed

during the falling rate period (Chen et al., 2001; Dondee et al., 2011). The performance of MW and FB drying was evaluated based on the first and second laws of thermodynamics, and the energy and exergy efficiencies during MW and FB drying were determined. The energy efficiency when drying soybeans improved with a decrease in exergy destruction when the inlet temperature of the HA and the MW power levels were increased. However, exergy efficiency improved when MW power was not applied in the first stage of FB drying.

Conclusions

In this work, the drying characteristics of different agricultural produce samples under convective air, infrared, microwave, and combination drying methods were reviewed. Studies on drying identical samples using different drying methods show that the drying characteristics and numerical models that can describe the drying data of the samples vary with the drying methods. For convective air-drying methods, the HA temperature and velocity play important roles in reducing the drying time and enhancing the quality of dried samples. Dehydration time, drying rate of samples, and energy efficiency are significantly affected by an increase in the MW and IR power levels during MW and IR drying of samples. For combination drying methods, it is necessary to determine the optimum condition for combination drying, such as MW/IR power levels, VC pressure, and HA temperature and velocity, for producing high-quality dried samples. Drying methods influence the quality index of dried agricultural products, such as color values, rehydration rate, and hardness. Therefore, the entire drying process should be monitored and controlled by determining the moisture content in the products. The composition of samples and the combination drying conditions in different drying methods should be evaluated for developing combination-drying equipment.

Conflict of Interest

The authors have no conflicting financial or other interests.

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References

- Aboltins, A. and J. Palabinskis. 2016. Fruit drying process investigation in infrared film dryer. *Agronomy Research* 14(1):5-13.
- Alibas, I. 2014. Mathematical modeling of microwave dried celery leaves and determination of the effective moisture diffusivities and activation energy. *Food Science and Technology (Campinas)* 34(2):394-401.
- Arikan, M. F., Z. Ayhan, Y. Soysal and O. Esturk. 2012. Drying characteristics and quality parameters of microwave-dried grated carrots. *Food and Bioprocess Technology* 5(8):3217-3229.
- Asami, D. K., Y. J. Hong, D. M. Barrett and A. E. Mitchell. 2003. Comparison of the total phenolic and ascorbic acid content of freeze-dried and air-dried marionberry, strawberry, and corn grown using conventional, organic, and sustainable agricultural practices. *Journal of Agricultural and Food Chemistry* 51(5):1237-1241.
- Baysal, T., F. Icier, S. Ersus and H. Yildiz. 2003. Effects of microwave and infrared drying on the quality of carrot and garlic. *European Food Research and Technology* 218(1):68-73.
- Chen, G., W. Wang and A. S. Mujumdar. 2001. Theoretical study of microwave heating patterns on batch fluidized bed drying of porous material. *Chemical Engineering Science* 56(24):6823-6835.
- Cho, B. K., I. S. Beak, N. G. Lee and C. H. Mo. 2011. Study on bruise detection of ‘Fuji’ apple using hyperspectral reflectance imagery. *Journal of Biosystems Engineering* 36(6):484-490.
- Darvishi, H., A. R. Asl, A. Asghari, M. Azadbakht, G. Najafi and J. Khodaei. 2014. Study of the drying kinetics of pepper. *Journal of the Saudi Society of Agricultural Sciences* 13(2):130-138.
- Dev, S. R. S., P. Geetha, V. Orsat, Y. Gariépy and G. S. V. Raghavan. 2011. Effects of microwave-assisted hot air drying and conventional hot air drying on the drying kinetics, color, rehydration, and volatiles of *Moringa oleifera*. *Drying Technology* 29(12):1452-1458.
- Dondee, S., N. Meeso, S. Soponronnarit and S. Siriamornpun. 2011. Reducing cracking and breakage of soybean grains under combined near-infrared radiation and fluidized-bed drying. *Journal of Food Engineering* 104(1):6-13.
- Doymaz, İ. 2012. Infrared drying of sweet potato (*Ipomoea batatas* L.) slices. *Journal of Food Science and Technology* 49(6):760-766.
- Doymaz, İ. 2015. Infrared drying kinetics and quality characteristics of carrot slices. *Journal of Food Processing and Preservation* 39(6):2738-2745.
- Doymaz, İ. and E. GÖL. 2011. Convective drying characteristics of eggplant slices. *Journal of Food Process Engineering* 34(4):1234-1252.
- Doymaz, İ. and O. İsmail. 2011. Drying characteristics of sweet cherry. *Food and Bioprocess Processing* 89(1):31-38.
- Erdem, T., S. Karaaslan, S. Öztekin, Z. Şahan and H. Çiftçi. 2014. Microwave drying of orange peels and its mathematical models. *Tarım Makinaları Bilimi Dergisi* 10(4):392-333.
- Flink, J. and M. Karel. 1970. Retention of organic volatiles in freeze-dried solutions of carbohydrates. *Journal of Agricultural and Food Chemistry* 18(2):295-297.
- Jaturonglumlert, S. and T. Kiatsiriroat. 2010. Heat and mass transfer in combined convective and far-infrared drying of fruit leather. *Journal of Food Engineering* 100(2):254-260.
- Jiao, A., X. Xu and Z. Jin. 2014. Modelling of dehydration-rehydration of instant rice in combined microwave-hot air drying. *Food and Bioprocess Processing* 92(3):259-265.
- Koné, K. Y., C. Druon, E. Z. Gnimpieba, M. Delmotte, A. Duquenoy and J. C. Laguerre. 2013. Power density control in microwave assisted air drying to improve quality of food. *Journal of Food Engineering* 119(4):750-757.
- Lampinen, M. J., K. T. Ojala and E. Koski. 1991. Modeling and measurements of infrared dryers for coated paper. *Drying Technology* 9(4):973-1017.
- Li, Z., G. S. V. Raghavan and V. Orsat. 2010. Temperature and power control in microwave drying. *Journal of Food Engineering* 97(4):478-483.
- Lin, T. M., T. D. Durance and C. H. Scaman. 1998. Characterization of vacuum microwave, air and freeze dried carrot slices. *Food Research International* 31(2):111-117.
- Maskan, M. 2001. Kinetics of colour change of kiwifruits during hot air and microwave drying. *Journal of Food Engineering* 48(2):169-175.
- Mazza, G. and M. LeMaguer. 1980. Dehydration of onion: some theoretical and practical considerations. *International Journal of Food Science and Technology* 15(2):181-194.

- Midilli, A., H. Kucuk and Z. Yapar 2002. A new model for single-layer drying. *Drying Technology* 20(7):1503-1513.
- Motevali, A., S. Minaei, M. H. Khoshtaghaza and H. Amirnejat, 2011. Comparison of energy consumption and specific energy requirements of different methods for drying mushroom slices. *Energy* 36(11):6433-6441.
- Nasiroglu, S. and H. Kocabiyik 2009. Thin-layer infrared radiation drying of red pepper slices. *Journal of Food Process Engineering* 32(1):1-16.
- Navari, P., J. Andrieu and A. Gevaudan 1992. Studies on infrared and convective drying of non hygroscopic solids. *Drying* 92:685-694.
- Nimmanpipug, N. and N. Therdthai 2013. Effect of osmotic dehydration time on hot air drying and microwave vacuum drying of papaya. *Food and Applied Bioscience Journal* 1(1):1-10.
- Nowak, D. and P. P. Lewicki 2004. Infrared drying of apple slices. *Innovative Food Science and Emerging Technologies* 5(3):353-360.
- Oetjen, G. W. 2000. Freeze-drying. *Encyclopedia of Separation Science*. London, UK:Elsevier Science, 1023-1034.
- Ozkan, I. A., B. Akbudak and N. Akbudak 2007. Microwave drying characteristics of spinach. *Journal of Food Engineering* 78 (2):577-583.
- Paengkanya, S., S. Soponronnarit and A. Nathakaranakule 2015. Application of microwaves for drying of durian chips. *Food and Bioproducts Processing* 96:1-11.
- Park, B. S., T. H. Kang, J. H. Lee, J. M. Choi and C. S. Han 2015. Drying characteristics of radishes using far infrared ray dryer. *Journal of Biosystems Engineering* 40(1):61-66.
- Ranjbaran, M. and D. Zare, 2013. Simulation of energetic-and exergetic performance of microwave-assisted fluidized bed drying of soybeans. *Energy* 59:484-493.
- Ratti, C. 1994. Shrinkage during drying of foodstuffs. *Journal of Food Engineering* 23(1):91-105.
- Sakai, N. and T. Hanzawa 1994. Applications and advances in far-infrared heating in Japan. *Trends in Food Science and Technology* 5(11):357-362.
- Salim, M., N. Salina, Y. Gariépy and V. Raghavan 2016. Hot air drying and microwave-assisted hot air drying of broccoli stalk slices (*Brassica oleracea* L. Var. *Italica*). *Journal of Food Processing and Preservation*. Version of Record online : 15 JUN 2016. Doi:10.1111/jfpp.12905.
- Simal, S., E. Deya, M. Frau and C. Rossello 1997. Simple modelling of air drying curves of fresh and osmotically pre-dehydrated apple cubes. *Journal of Food Engineering* 33(1):139-150.
- Singh, N. J. and R. K. Pandey 2012. Convective air drying characteristics of sweet potato cube (*Ipomoea batatas* L.). *Food and Bioproducts Processing* 90(2):317-322.
- Thijssen, H. A. C. 1971. Flavour retention in drying pre-concentrated food liquids. *Journal of Applied Chemistry and Biotechnology*, 21(12):372-377.
- Toğrul, H. 2006. Suitable drying model for infrared drying of carrot. *Journal of Food Engineering* 77(3):610-619.
- Tulek, Y. 2011. Drying kinetics of oyster mushroom (*Pleurotus ostreatus*) in a convective hot air dryer. *Journal of Agricultural Science and Technology* 13:655-664.
- Wang, J. and K. Sheng, 2006. Far-infrared and microwave drying of peach. *LWT-Food Science and Technology* 39(3):247-255.
- Wang, J. and Y. S. Xi, 2005. Drying characteristics and drying quality of carrot using a two-stage microwave process. *Journal of Food Engineering* 68(4):505-511.
- Wang, J., J. S. Wang and Y. Yu 2007. Microwave drying characteristics and dried quality of pumpkin. *International Journal of Food Science and Technology* 42(2):148-156.
- Wojdyło, A., A. Figiel, K. Lech, P. Nowicka and J. Oszmiański 2014. Effect of convective and vacuum-microwave drying on the bioactive compounds, color, and antioxidant capacity of sour cherries. *Food and Bioprocess Technology* 7(3):829-841.
- World Health Organization. 1988. Food irradiation: a technique for preserving and improving the safety of food. World Health Organization, p.11.
- Wu, B., H. Ma, W. Qu, B. Wang, X. Zhang, P. Wang, J. Wang, G. G. Atungulu and Z. Pan 2014. Catalytic infrared and hot air dehydration of carrot slices. *Journal of Food Process Engineering* 37(2):111-121.
- Zarein, M., S. H. Samadi and B. Ghobadian 2015. Investigation of microwave dryer effect on energy efficiency during drying of apple slices. *Journal of the Saudi Society of Agricultural Sciences* 14(1):41-47.
- Zhao, D., C. Zhao, H. Tao, K. An, S. Ding and Z. Wang 2013. The effect of osmosis pretreatment on hot-air drying and microwave drying characteristics of chili (*Capsicum annuum* L.) flesh. *International Journal of Food Science and Technology* 48(8): 1589-1595.
- Zhu, A. and X. Shen 2014. The model and mass transfer characteristics of convection drying of peach slices. *International Journal of Heat and Mass Transfer* 72: 345-351.
- Zlatanović, I., M. Komatina and D. Antonijević 2013. Low-temperature convective drying of apple cubes. *Applied Thermal Engineering* 53(1):114-123.