INFLUENCE OF DRYING METHODS ON SPECIFIC ENERGY CONSUMPTION AND PHYSICAL QUALITY OF TOMATO SLICES (*Lycopersicon esculentum*)

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ABSTRACT: *The aim of this research was to study the effects of various drying methods on quality parameters of tomato slices and, and to compare the difference on these parameters by different drying methods. Energy and specific energy consumption under the different drying methods of the tomato slices were compared. Tomato slices were dried by three different methods viz. convection hot air drying, infrared radiation drying, and microwave drying. Rehydration ratio, shrinkage ratio and total colour change were determined in these differently dried samples. Among the various methods used, it was observed that samples dried microwave scored highest for rehydration. Best results were obtained by the microwave dehydration. Thus, it could be concluded that microwave dehydration resulted in better end products retaining natural colour and shrinkage ratio. Microwave drying of tomato slices proved to have the lowest specific energy consumption and drying time of tomato slices.*

Keywords: Drying methods, Tomato slices, Specific energy consumption, Physical quality

1. INTRODUCTION

Tomato (*Lycopersicon esculentum*) is a popular food for its culinary properties and their health benefits. It is a natural source of lycopene, a carotenoid that reduces the risk of cancer and coronary heart disease [1]. It is also the most commercially produced vegetable in the world. Major producers are China, the United States of America, India, Egypt, Turkey, and Italy and the yearly production was estimated as 145 751 507 Mt in 2010 [2]. Much of the total tomato production is consumed fresh or used to produce tomato paste.

Drying provides one of the oldest and most effective means of preserving foods from spoilage. Once dry, many foods can be stored successfully for years without refrigeration, if appropriately packaged [3]. In the Mediterranean countries the traditional technique of fruit and vegetable drying is by using the sun. This technique has the advantages of simplicity and the small capital investments, but it requires long drying times that may have adverse consequences to the product quality: the final product may be contaminated from dust and insects or suffer from enzyme and microbial activity [4,5]. In order to improve the quality, the traditional sun drying technique should be replaced with industrial drying methods such as hot-air and solar drying [6].

Infrared radiation heating offers many advantages over conventional hot air drying. When infrared radiation is used to heat or dry moist materials, the radiation impinges the exposed material and penetrates it and then the energy of radiation converts into heat [7]. Since a material is heated intensely, the temperature gradient is small. Therefore, energy consumption in infrared drying process is relatively low. Introduced energy is transferred from the heating element to the product surface without heating the surrounding air [8]. The use of infrared radiation technology in dehydrating foods has several advantages. These may include decreased drying time, high energy efficiency, high quality of finished products, uniform temperature in the product while drying, and a reduced necessity for air flow across the product [9,10,11,12]. The major influencing parameters in infrared radiation drying are air velocity and intensity of radiation [13].

Microwave energy is rapidly absorbed by water molecules which, consequently, results in rapid evaporation of water and thus higher drying rates, therefore microwave drying offers significant energy savings, with a potential reduction in drying times in addition to the inhibition of the surface temperature of the treated material [14]. Recently, microwave drying has attracted popularity as an alternative method for drying several food products such as fruits, vegetables, and dairy products were also studied. By researchers, potatoes [15], apples [16], mushrooms [17], ginseng roots [18], blueberries [19], pistachios [20], tomato pomace [21], kiwifruits [22], garlic [23], spinach [24], and green peas [25]. The literature survey revealed that very limited work has been published on the comparative study of tomato dehydration and specific energy consumption using various techniques. Therefore, the present investigation was undertaken to study the specific energy consumption and physical quality for tomato slices during drying by hot air convection (HA), Infrared radiation (IR) and microwave drying (MW).

2. MATERIALS AND METHODS

2.1. Experimental material

Fresh tomato were procured in bulk from the local market and stored in a refrigerator at 4 ^{o}C. The tomatoes were allowed to equilibrate their temperature to ambient environment prior to starting the experiments. The tomatoes were hand cut into slices of approximately 5 ±0.1 mm thick using a mechanical slicer (SS-250, SEP Machinery Company Ltd, Guangzhou, China). Dry matter content of tomato slices was determined by the oven drying method at an air temperature of 105 ^{o}C for 24 h [26]. These experiments were replicated thrice to obtain a reasonable average. The initial moisture content of the tomato sample varied between 19.80 and 14.79 g water/g dry matter.

2.2. Drying of tomato

2.2.1. Hot-air drying

Hot-air drying (HA) was performed in an electric thermal blast dryer (Type-101-3, Shanghai Ruda Experimental

Apparatus Co., Ltd., China) which could be regulated to any desired drying air temperature between 20 and 120 ^{o}C and velocity between 0.1 and 3.0 m /s with high accuracy. The dryer consisted of three basic units; a fan that provided the desired drying air velocity, a heating unit coupled with an air temperature control system, and the drying chamber. The trays were perforated at the bottom and samples were placed flat as disks so drying occurs from both sides. The dryers were run without the sample for about 30 minutes in order to reach set conditions before each drying experiment. Tomato slices were spread on perforated try and drying was carried out at 60 ^{o}C drying temperature with a constant air velocity 1 m/s.

2.2.2. Infrared drying

The experimental dryer with the infrared drying (IR) was developed for drying different agricultural products using infrared energy. A drying chamber of 50 × 40 × 50 cm was made from stainless steel sheet of 2 mm thickness. The inner sides of the drying chamber were covered with an aluminium foil. The dryer was equipped with two tube type incandescent heaters in a drying chamber. The distance between the heaters and drying surface was maintained constant at 15 cm throughout experiments. Infrared radiation intensity or output intensity of the heaters could be varied by regulating the voltage through a power regulator. Inlet air velocity was adjusted by changing the fan revolution using an air flow control valve. Desired experimenttal conditions inside the dryer were obtained for at least 30 min. The dryer was set at infrared radiation intensity of 0.27 W/cm^2 and air velocity of 0.5 m/s was used in drying of tomato slices.

2.2.3. Microwave drying

A laboratory digital microwave oven (M945, Samsung Electronics Ins, China) with amaximum output of 1000 W at 2450MHz was used for the drying experiments. The dimensions of the microwave cavity were 327×370×207 mm. and consisted of a rotating glass plate of 28 cm in diameter at the base of the oven. The glass plate rotates 5 times per min and the direction of rotation can be changed by pressing the on/off button. The microwave dryer was operated by a control terminal which could control both microwave power level and emission time. The drying processes were carried out at microwave powers of 200 W.

After dryer preparation and its adjustment for desired conditions according to the experimental plan, a 500 g mass of tomato slices was placed in the drying chamber in a single layer. Every 10 minutes throughout the drying period, the mass of the drying tomato was measured using a digital electronic balance (Sartorius BS2202S, Germany) having an accuracy of ± 0.01g. The drying was continued until the moisture content of tomato slices was reduced to approximately 0.17 g water/g dry matter. The dried product was cooled and packed in low-density polyethylene bags that were heat-sealed. Drying runs at each experimental setting of hot air drying, infrared drying, microwave drying were repeated three time and the average values were recorded.

2.3. Rehydration ratio

Rehydration ratio was determined to evaluate the reconstitution qualities of dehydrated samples. Pre-weighed samples were soaked in ample quantity of hot water (50 °C) for 30 minutes so as to make them soft [27]. The samples were drained with the help of tissue paper and stabilized at room temperature and reweighed. The rehydration ratio was calculated by dividing the mass of rehydrated samples with the mass of dehydrated samples using Eq. (1) as follow:

$$\text{Rehydration ratio} = \frac{\text{mass after rehydration}}{\text{mass before rehydration}} \quad (1)$$

2.4. Shrinkage ratio

The shrinkage ratio of the dried tomato was evaluated by a volumetric displacement method using n-heptane as the working liquid [28]. Ten slices were tested and the average values were reported. The shrinkage ratio was calculated as presented in Eq. 2.

$$\text{Shrinkage ratio} = 1 - \frac{V_d}{V_o} \quad (2)$$

where Vo and Vd is the average volume of slices before and after drying, respectively.

2.5. Colour parameters

The colour of the fresh and dried tomato slices was measured in Hunter parameters with an automatic colour difference meter (DC-P3, Beijing, China). Six colour data were taken from different locations for each sample. Data were the average of three measurements. The total colour difference between fresh and dried tomato slices (δE) was defined in Eq. 3 as follows:

$$\delta E = \sqrt{(L_o - L)^2 + (a_o - a)^2 + (b_o - b)^2} \quad (3)$$

Where the subscript "o" refers to colour reading of fresh onion L, a and b colour parameters of dried tomato samples. A higher δE represents greater colour difference from the reference fresh material.

2.5. Specific energy consumption

The total energy consumption was defined as the sum of the electrical energy consumed during drying process and included the energy used to drive the fan, and energy for heating the air. In the infrared dryer, the total energy consumption is the sum of energy consumed by the infrared heater and the ventilator fan that is used in moving the air. This energy was measured using a digital electric counter (Kaan, type 101) with 0.01 kWh precision. The specific energy consumption was estimated, in all of the three dryers by considering the total energy supplied to dry tomato slices from initial moisture content of about 19.30 kg water/kg dry matter to the desired moisture content of approximately 0.17 kg water/kg dry matter. The specific energy consumption (SEC) of tomato slices during drying at different drying methods was expressed in MJ/kg of water evaporated, and calculated according to Eq.4 [29]:

$$SEC = \frac{\text{Total energy supplied in drying process, MJ}}{\text{Amount of water removed during drying, kg}} \quad (4)$$

3. RESULTS AND DISCUSSION

3.1. Effect of drying methods on drying behaviour

The effect of drying methods on drying time of tomato slices is shown in Fig. 1. As illustrated in Fig. 1, Microwave drying (MW) was so a much faster drying process that infrared (IR) and hot air drying (HA). Microwave drying took only 100 min to remove the moisture from 19.30 kg water/kg dry matter to the desired moisture content of approximately 0.17 kg water/kg dry matter, whereas, IR, and HA required 500 and 1200 min, respectively, for removing the same amount of moisture. During microwave heating, heat generated within the product results in rapid mass transfer, forming a high vapour pressure difference between the center and the surface of the product. This causes a shorter drying time. These results were in agreement with the study conducted on some various food products [30,31,32,33]

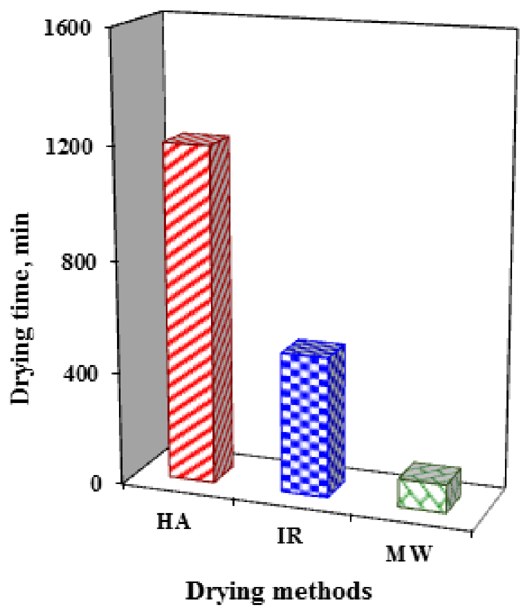

Figure. 1. Interaction effect of drying methods on the drying time for drying of tomato slices

3.2. Effect of drying methods on rehydration ratio

The rehydration ratio of dried tomato slices was 2.79, 4.69 and 6.38 for hot air (HA), infrared (IR) and microwave (MW) drying methods, respectively (Fig. 2). It can be seen that the highest value occurred in microwave drying (MW). Higher water absorption capacity was expected for the MW drying because of short drying duration which improves the rehydration capacity of dried products [34].

3.2. Effect of drying methods on Shrinkage ratio

The shrinkage ratio estimated for tomato dried under different drying methods is presented in Fig. 3. It is evident from Fig.3 that the shrinkage ratio of dried tomato slices was 0.25, 0.17 and 0.15 for HA, IR and MW drying methods, respectively. It can be seen that the least shrinkage occurred under microwave drying MW. The lower shrinkage of tomato slice sunder MW drying method can be attributed to higher drying air temperatures and the lower moisture content of the external surfaces and on both sides of the slice [35,36].

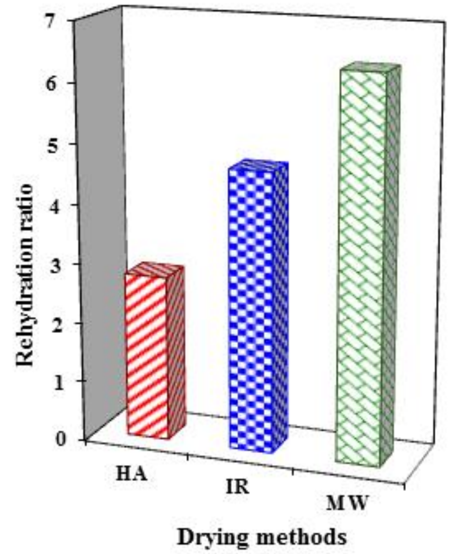

Figure. 2. Rehydration ratio as related to drying methods of tomato slices.

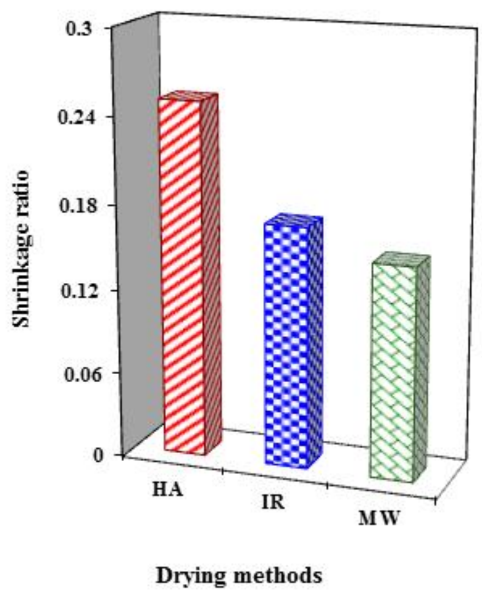

Figure. 3. The influence of different drying methods on shrinkage ratio of dried tomato slices

3.3. Effect of drying methods Colour parameters

The colour difference of dried tomato slices at different drying methods is presented in Fig. 4. It is clear that the microwave drying (MW) produced a dried product that had the least change in colour and that the HA drying had the highest change in colour.

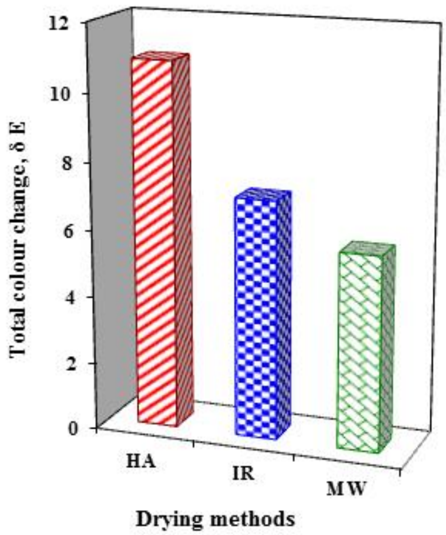

Figure. 4. Interaction effect of drying methods on colour difference change of dried tomato slices.

The higher value of (δE) for the HA drying setting could be attributed to the longer period of drying and case hardening of product [37,38].

3.4. Effect of drying methods on specific energy consumption

The specific energy consumption under different drying methods of drying tomato slices are presented in Fig. 5. It is evident from Fig. 5 that the lowest amounts of specific energy were observed in the microwave drying (MW) dryer while the highest amount was recorded while drying in the (HA) drying [39].

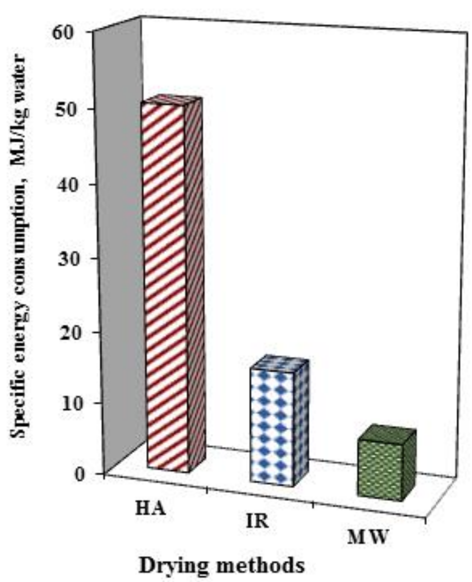

Figure. 5. Specific energy consumption during the drying of tomato slices under different drying methods.

3. CONCLUSION

The influences of each drying method hot-air, (HA) infrared radiation (IR) and microwave drying (MW) on the physical quality properties such as colour, shrinkage and rehydration ratio and specific energy consumption of dried tomato slices were investigated in this study. Drying of the tomato slices was found to be optimised under microwave drying whereby comparatively highest rehydration ratio and lowest shrinkage and colour change were recorded. Microwave drying of tomato slices proved to have the lowest drying time and specific energy consumption.

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4. REFERENCE

[1] Brooks M.S., Abou El-Hana N.H., Ghaly A.E. Effects of tomato geometries and air temperature on the drying behavior of plum tomato. American Journal of Applied Sciences, 5: 1369–1375. (2008).

[2] FAO Agriculture data. Food and Agriculture Organization of the United Nations. Available at http:// faostat.fao.org.(2012_.

[3] Durance TD, Wang JH. Energy consumption, density and rehydration rate of vacuum microwave and hot-air convection dehydrated tomatoes. J Food Sci 67:2212–2216.(2002).

[4] Doymaz I. Air drying characteristics of tomatoes. J Food Eng 78:1291–1297.(2007).

[5] Andritsos N, Dalampakis P, Kolios N. Use of geothermal energy for tomato drying. GHC Bull 24:9–13 (March). (2003).

[6] Ertekin C, Yaldiz O. Drying of eggplant and selection of a suitable thin layer drying model. J Food Eng 63:349–359.2004.

[7] Hebbar, H.U. and N.K. Rostagi,. Mass transfer during infrared drying of cashew kernel. Journal of Food Engineering, 47: 1-5. (2001).

[8] Jones, P.,. Electromagnetic wave energy in drying processes. In A. S. Mujumdar (Ed.), Drying '92 (pp: 114-136). Amsterdam: Elsevier Science. (1992).

[9] Celma, A.R., F.L. Rodriguez and F.C. Blazquez,. Experimental modelling of infrared drying of industrial grape by-products. Food and Bioproducts Processing, 87: 247-253. (2009).

[10] Nowak, D. and P.P. Lewicki,. Infrared drying of apple slices. Innovative Food Science and Emerging Technologies, 5: 353-360. (200)4.

[11] Shi, J., Z. Pan, T.H. McHugh, D. Wood, E. Hirschberg and D. Olson,. Drying and quality characteristics of fresh and sugar-infused blueberries dries with infrared radiation heating.LWT - Food Science and Technology, 41: 1962-1972. (2008).
[12] Baysal, T., F. Icier, S. Ersus and H. Yildiz,.Effects of microwave and infrared drying on the quality of carrot and garlic.European Food Research and Technology, 218: 68-73. (2003).
[13] Wang, J.,. A single-layer model for far-infrared radiation drying of onion slices. Drying Technology, 20(10): 1941-1953. (2002).
[14] McLoughlin C.M., McMinn W.A.M., Magee T.R.A. Microwave drying of multicomponent powder systems. Drying Technology, 21: 293–309. (2003).
[15] Bondaruk J., Markowski M., Błaszczak W. Effect of dry¬ing conditions on the quality of vacuum-microwave dried potato cubes. Journal of Food Engineering, 81: 306–312. (2007).
[16] Bilbao-Sáinz C., Andrés A., Chiralt A., Fito P. Mi¬crowaves phenomena during drying of apple cylinders. Journal of Food Engineering, 74: 160–167. (2006).
[17] Giri S.K., Prasad S. Drying kinetics and rehydration characteristics of microwave-vacuum and convective hot-air dried mushrooms. Journal of Food Engineering, 78: 512–521. (1998).
[18] Ren G., Chen F. Drying of American ginseng panax quinquefolium roots by microwave-hot air combination. Journal of Food Engineering, 35: 433–443. (1998).
[19] Feng H., Tang J., Mattinson D.S., Fellman J.K. Micro¬wave and spouted bed drying of frozen blueberries: the effect of drying and pretreatment methods on physical properties and retention of flavor volatiles. Journal of Food Processing and Preservation, 23: 463–479. (1999).
[20] Kouchakzadeh A., Shafeei S. Modeling of microwave-convective drying of pistachios. Energy Conversion and Management, 51: 2012–2015. (2010).
[21] Al-Harahsheh M., Al-Muhtaseb A.H., Magee T.R.A. Microwave drying kinetics of tomato pomace: Effect of osmotic dehydration. Chemical Engineering and Process¬ing, 48: 524–531. (2009).
[22] Maskan M. Drying, shrinkage and rehydration char¬acteristics of kiwifruits during hot air and microwave drying. Journal of Food Engineering, 48: 177–182. (2001).
[23] Sharma G.P., Prasad S. Optimization of process parameters for microwave drying of garlic cloves. Journal of Food Engineering, 75: 441–446. (2006).
[24] Alibas Ozkan I., Akbudak B., Akbudak N. Micro¬wave drying characteristics of spinach. Journal of Food Engineering, 78: 577–583. (2007).
[25] Zielinska M., Zapotoczny P., Alves-Filho O., Eikevik T.M., Blaszczak W. A multi-stage combined heat pump and microwave vacuum drying of green peas. Journal of Food Engineering, 115: 347–356. (2013).
[26] AOAC. Official methods of analysis (12th ed.), Association of Official Analytical Chemists. Washington, DC, (2000).
[27] Saxena S. Process development for making tomato powder by multistage dehydration. Unpublished ME Thesis, CTAE, Udaipur (Raj.), India. (2000).
[28] Duan X, Liu W, Ren G Y, Liu W C, Liu Y H. Comparative study on the effects and efficiencies of three sublimation drying methods for mushrooms. Int J Agric & Biol Eng,; 8(1): 91－97. (2015).
[29] Jindarat W., P. Rattanadecho , S. Vongpradubchai. Analysis of energy consumption in microwave and convective drying process of multi-layered porous material inside a rectangular wave guide. Experimental Thermal and Fluid Science. 35: 728–737. (2011).
[30] Chong, C. H., Figiel, A., Law, C. L., & Wojdyło, A.. Combined drying of apple cubes by using of heat pump, vacuum-microwave, and intermittent techniques. Food and Bioprocess Technology, 7, 975–989. (2014).
[31] Alibas I. Energy consumption and colour characteristics of nettle leaves during microwave, vacuum and convective drying. Biosyst Eng;96:495–502. (2007)
[32] Queiroz R, Gabas AL, Telis VRN. Drying kinetics of tomato by using electric resistance and heat pump dryers. Drying Technol;22:1603–20. (2004).
[33] Lin, T.M.; Durance, T.D.; Scaman, C.H. Characterization of vacuum microwave, air and freeze dried carrot slices. Food Research International, 31, 111–117. (1998).
[34] Dev, S. R., Geetha, P., Orsat, V., Gariepy, Y., & Raghavan, G. S.. 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, 1452–1458. (2011).
[35] Drouzas A E, Tsami E, Saravacos G D. Microwave/vacuum drying of model fruit gels. Journal of Food Engineering,; 39(2): 117–122. (1999).
[36] Mayor, L., and A. M. Sereno, Modelling shrinkage during convective drying of food materials: a review. Journal of Food Engineering, 61, 373–386, (2004).
[37] Mongpraneet, S.,T.Abe, and T. Tsurusaki, “Far infrared-vacuumand -convection drying of Welsh onion”. Transaction of the American Society of Agricultural Engineers, 45, 1529–1535, (2002).
[38] Reyes, A., Vega, R., Bustos, R. And C.Araneda, Effect of Processing Conditions on Drying Kinetics and Particle Microstructure of Carrot. Drying Technology, 26, 1272-1285. (2008).
[39] Samad, S.H and Loghmanieh, L. Evaluation of energy aspects of apple drying in the hot-air and infrared dryers. Energy Research Journal 4 (1): 30-38, (2013).