JOURNAL of THE TURKISH CHEMICAL SOCIETY
SECTION: B
CHEMICAL ENGINEERING
TURKISH CHEMICAL SOCIETY

A Study on Drying of Thin-Layer Pepino by Infrared and Microwave Methods and Their Color Analysis*

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Abstract: Pepino is an exotic fruit that contains high vitamin C and is known to have many beneficial effects on health. In this study, thin layer drying and color changes of pepino fruit by infrared (IR) and microwave (MW) methods were investigated. Effective moisture diffusions and activation energy were calculated from the drying data. Uniformly sliced pepino fruit was processed without peeling. While IR drying processes were performed at 60, 70, and 80 °C temperatures in 210, 165, and 120 minutes, respectively, MW drying processes were completed at 25, 16, and 6 minutes at 140, 210, and 350 W power levels. While the initial average moisture content was 18.5702 kg water/kg dry, the lowest moisture content was determined as 0.3250 at 80 °C in IR and 0.1263 water/kg dry matter×min at 350 W at MW. Effective moisture diffusions (D_{eff}) for IR were calculated between 6.69 × 10^{-10} - 1.23 × 10^{-9} m^2/s, while for MW it was found between 8.75 × 10^{-9} - 3.75 × 10^{-8} m^2/s. The activation energy (E_a) was 29.80 kJ/mol for IR and 33.30 kW/kg for MW. In addition, it was determined that color preservation was better in the IR method, and local burns were observed in the samples in the microwave method.

Keywords: Activation Energy, Drying Rate, Effective Moisture Diffusivity, Exotic Fruit, *Solanum maricatum.*

Submitted: October 03, 2022. **Accepted:** November 01, 2022.

Cite this: Ozyalcin ZO, Kipcak AS. A Study on Drying of Thin-Layer Pepino by Infrared and Microwave Methods and Their Color Analysis. JOTCSB. 2022;5(2):167–72.

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INTRODUCTION

Pepino (*Solanum maricatum*) is a thin-skinned and juicy tropical, semi-tropical fruit of the nightshades family. Pepino, whose taste is often likened to melon and cucumber, can also be called pepino melon, melon pear, or tree melon. It is produced in South America, Australia, New Zealand, and the USA. Studies have shown that pepino has protective effects against many health problems thanks to its high vitamin C content (1).

Preservation of foodstuffs and especially fruits are generally provided by drying processes. While thermal-based traditional methods have been used for years, numerous drying techniques have been developed as a result of the need for lower costs and higher final product quality. Microwave drying is a technique based on electromagnetic waves, independent of the product's thermal properties to be dried. The main benefit of choosing it is that it offers instant drying, which saves time and energy (2 - 4). In addition, infrared drying takes place by absorbing the energy provided by the source by the product to be dried without heating the air in the environment and drying the product by turning it into thermal energy. This method, which has a high-end product quality, is gaining popularity due to energy savings (4, 5).

Although there are studies on drying exotic fruits, there are relatively few studies on pepino, and those that exist are often based on conventional techniques. A few examples of studies on exotic fruits can be given as follows; Raaf et al. studied oven and sun drying kinetics and mathematical modelling of amla fruit (6), Ozgen and Celik evaluated the design parameters on convective dryer of kiwi slices (7), Raj and Dash investigated the microwave vacuum drying kinetics of dragon fruit slice (8). Izli et al. studied mango drying with freeze dryer, microwave, and hot air drying techniques (9), Luelue et al. investigated microwave vacuum drying of lychee fruit and the microstructure change due to drying (10). As an example of the few pepino drying studies, Uribe et al. examined the conventional drying and mathematical modeling of pepino at different temperatures (11). Di Scala et al. examined the traditional drying of pepino and the examination of its physicochemical properties (12). According to Izli et al. examined pepino drying using a combination of conventional methods and microwaves at different temperatures and power levels (13). Ozcan et al. studied the effect of microwave and oven drying on the bioactive compounds of pepino (14).

In this study, the behavior of Pepino fruit in thin layer drying with infrared and microwave processes was investigated and effective moisture diffusion, activation energy, and color changes were calculated.

MATERIALS AND METHODS

Apparatus

Pepinos purchased from a local grocery chain in Istanbul, Turkey in April 2021 were sliced unpeeled with a thickness of 5 ± 0.01 mm and weight of 10 ± 0.15 grams. Dimensions were measured with manual calipers and weights were measured with a Radwag AS 220.R2 digital balance (Radwag Balances and Scales, Radom, Poland). The sliced samples were processed in the oven Nüve EV-018 (Nüve, Ankara, Turkey) for 3 hours at 105 °C to determine the moisture content according to the Association of Official Analytical Chemists (AOAC, 2005) procedure (15). In drying processes using unpeeled pepinos with a thickness of 5 ± 0.01 mm and 10 ± 0.15 grams, MA 50.R model infrared moisture analyzer (Radwag Balances and Scales, Radom, Poland) at 60, 70 and 80 °C and Delonghi MW205S microwave dryer (Delonghi, Treviso, Italy) at power levels of 140, 210 and 350 W were used. Color changes of the samples before and after drying were determined with a PCE-CSM 1 model (PCE Instruments UK Ltd., Southampton Hampshire, UK) color analyzer.

Drying Kinetics Calculations

The moisture content was calculated to be 94.89% on a wet basis and 18.5702 kg water/kg dry matter by moisture determination. During the drying process, weight measurements were made at intervals of 15 minutes for IR and 1 minute for MW, and drying was continued until the moisture content of the samples fell below 10%. After drying, the samples are shown in Figures 1 and 2 for IR and MW, respectively.

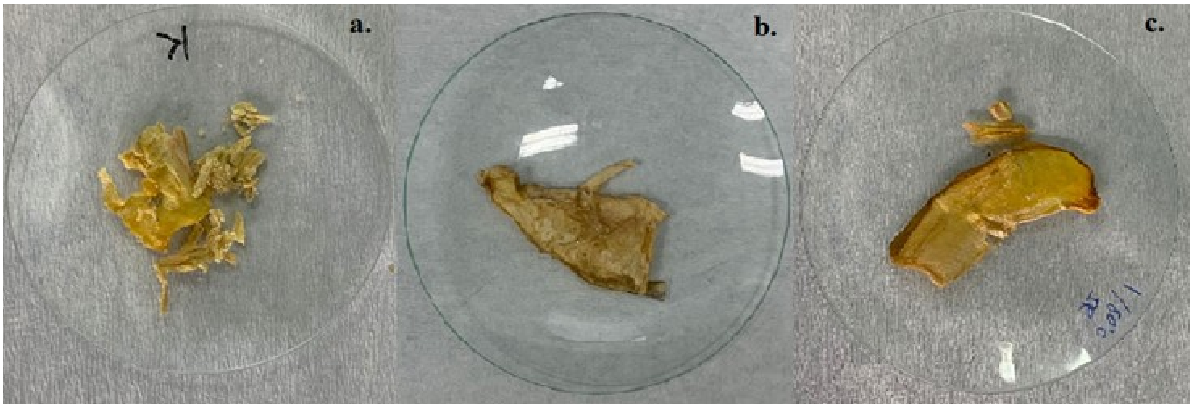


Figure 1: IR dried samples at a. 60 ºC, b. 70 ºC, and c. 80 ºC.

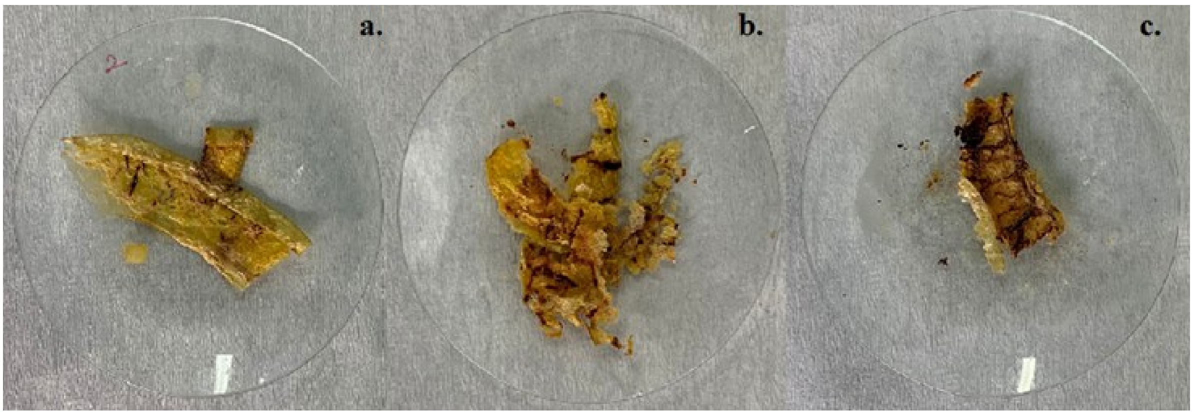


Figure 2: MW dried samples at a. 140 W, b. 210 W, and c. 350 W.

During the falling rate period, in which the drying occurs substantially, moisture is transported from the center to the surface by diffusion. It then evaporates into the surrounding environment of the product, resulting in the mass transfer of moisture. The diffusion mechanism of drying is explained by Fick's second law equation. Moisture content (M) and moisture content (MR) required for the application of this law are calculated by Equations 1 and 2 (16):

$$M=\frac{m_w}{m_d} \quad \text{(Eq. 1)}$$

$$MR=\frac{M_t-M_e}{M_0-M_e} \quad \text{(Eq. 2)}$$

where M is the moisture content (kg water/kg dry matter), mw is the water content (kg) and, md is the dry matter content (kg). MR stands for the moisture ratio, M_0, M_t, and M_e are moisture content at initial, at any time, and at equilibrium in kg water/kg dry matter. Effective moisture diffusivity can be calculated using MR value as in Equation 3, by taking its logarithm as in Equation 4 to linearize the equation;

$$\mathrm{MR}=\frac{8}{\pi^2}\exp\left(-\frac{\pi^2 D_{eff}\, t}{4L^2}\right) \quad \text{(Eq. 3)}$$

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

The activation energy was calculated based on the temperature and power provided by the drying devices. Arrhenius-type equations for temperature-based IR and power-based MW operations are given in Equations 5 and 6 (17):

$$D_{eff}=D_0\exp\left(\frac{E_a}{RT}\right) \quad \text{(Eq. 5)}$$

$$D_{eff}=D_0\exp\left(-\frac{E_a m}{P}\right) \quad \text{(Eq. 6)}$$

where E_a is the activation energy value (kJ/mol), D_0 is the pro-exponential factor of the Arrhenius equation (m^2/s), R is the universal gas constant (8.314 kJ/mol.K), P is the microwave power (W) and m is the sample weight (kg). When the graph of ln(D_{eff}) versus 1/T for IR and ln(D_{eff}) versus m/P for MW is plotted. For MW the activation energy is the slope of its graph, for IR E_a can be calculated as shown in Equation 7:

$$E_a=-slope\times R \quad \text{(Eq. 7)}$$

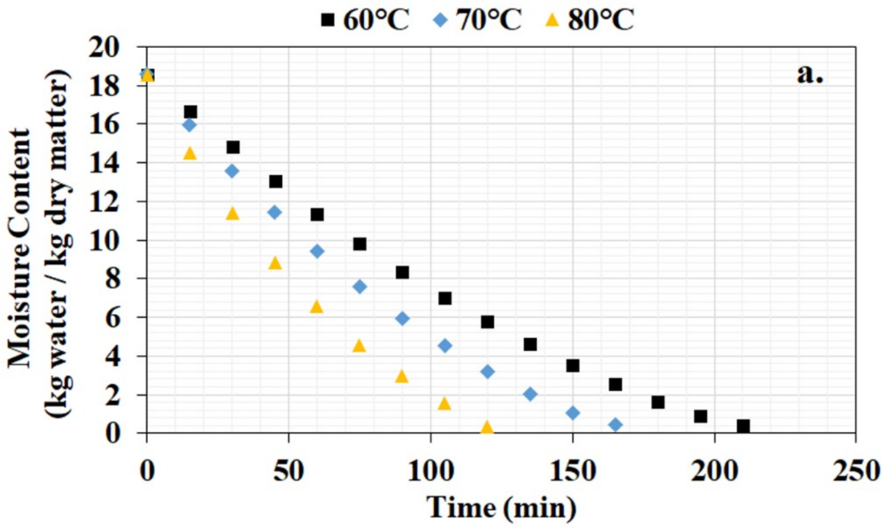
To audit the quality standards of the dried products, color analysis was performed on each sample from 5 different regions, before and after the experiment. In the color analysis, the lightness/darkness value L^*, the redness/greenness value a^*, and the yellowness/blueness value b^* were measured and the ΔE (color change) values of the dried samples, which were the difference with the untreated sample, were calculated by Equation 8 (16):

$$\Delta E=\sqrt{(L_0-L)^*+(a_0-a)^*+(b_0-b)^*} \quad \text{(Eq. 8)}$$

where, L_0^*, a_0^*, and b_0^* values are the L^*, a^*, and b^* values of the raw samples, respectively.

RESULTS AND DISCUSSION

The drying curves of the samples whose initial average moisture content was determined as 18.5702 kg water/kg dry matter are given in Figure 3. The final moisture values of the samples dried at IR 60, 70, and 80 °C for 210, 165, and 120 minutes, respectively, were found as 0.4306, 0.4218, and 0.3250 kg water/kg dry matter. In addition, the final moisture values of the samples dried for 25, 16, and 6 minutes at MW 140, 210, and 350 W, respectively, were found to be 0.1322, 0.1286, and 0.1263 kg water/kg dry matter. These results indicate that a decrease in drying times and final moisture contents is brought about by an increase in temperature and power levels. Comparing MW and IR techniques, it can be said that MW offers instant drying.



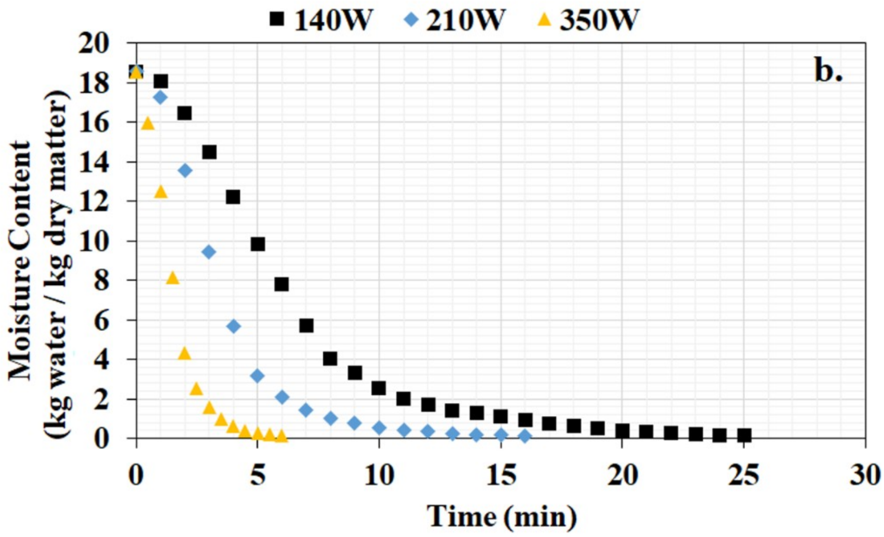


Figure 3: Drying curves for a. IR- and b. MW-dried pepino.

Effective moisture diffusion values were calculated using the slope from the logarithmic moisture content-time plot shown in Figure 4. The slope values for IR at 60, 70 and 80 °C can be read in the graphs as -0.000264, -0.000343, and -0.000486 and as -0.003454, -0.005561, and -0.014812 for MW. The effective moisture diffusion values calculated from here are; 6.69×10^{-10}, 8.69×10^{-10}, and 1.23×10^{-9} m^2/s for IR at 60, 70 and 80 °C, respectively, 8.75×10^{-9}, 1.41×10^{-8}, and 3.75×10^{-8} m^2/s for MW at 140, 210 and 350 W.

The results show that effective moisture diffusion increases with increasing temperature levels and energy levels. This situation can be interpreted as the increase in diffusion as a result of the acceleration of the molecules with the increase in the energy taken by the unit cell.

Activation energies calculated using Figure 4 and equations 5 and 6 are 29.80 kJ/mol for IR and 33.30 kW/kg for MW. Using data from the color analysis, total color change values were calculated and were found as 9.89, 10.67, and 12.43 for IR at 60, 70, and 80 °C, respectively, and as 11.14, 12.36, and 19.91 for MW at 140, 210 and 350 W, respectively.

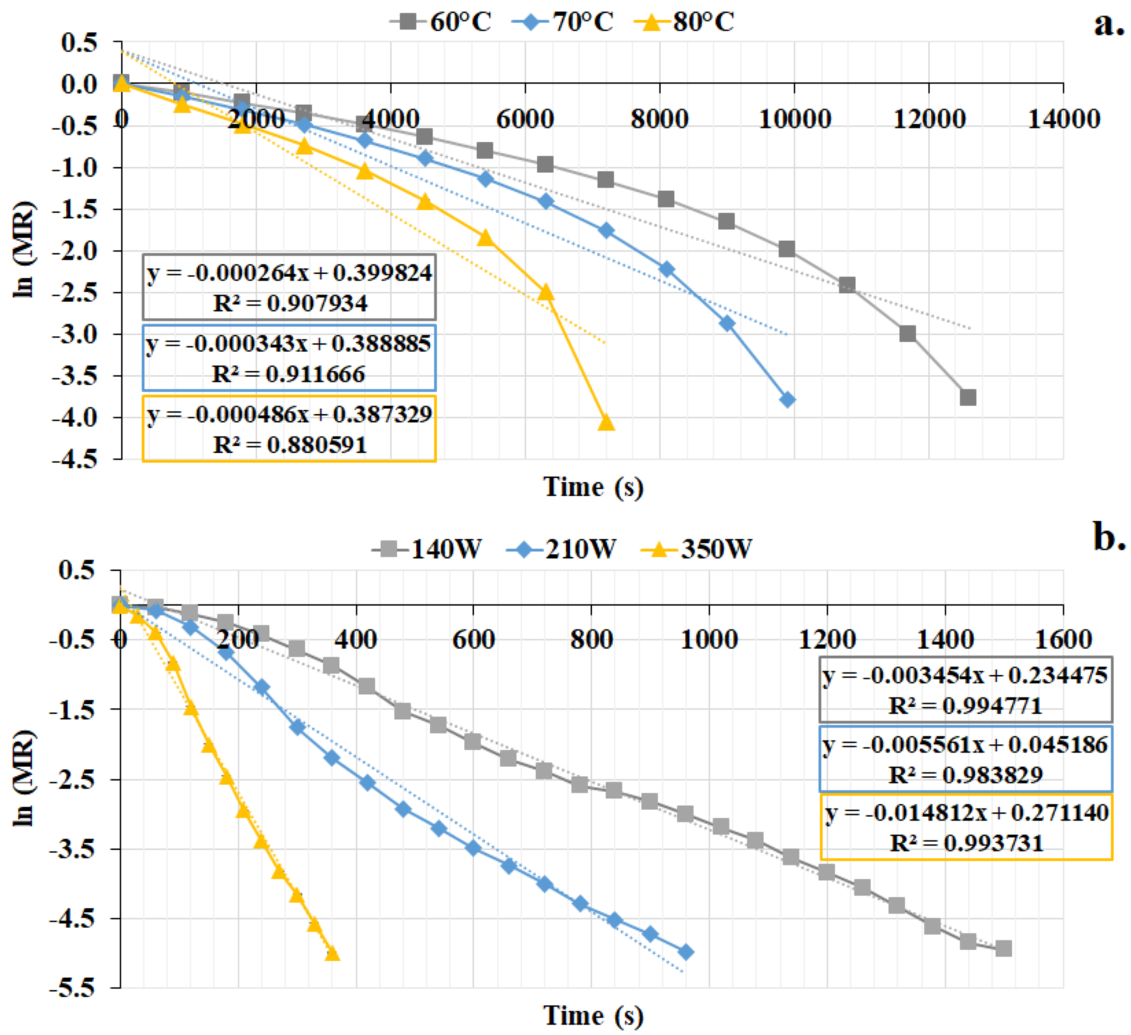


Figure 4: ln(MR) vs time graph for a. IR and b. MW.

All drying results are summarized in Table 1. As can be seen from Figures 1 and 2, and the color values in the table, local burns have occurred in the MW due to instantaneous high power levels and the quality of the final product has deteriorated considerably. In addition, it was determined that the lowest change was achieved in 80 ºC products, which have the fastest drying time in IR.

Table 1: Data for thin-layer drying of pepino.

Drying method	Drying time (min)	Final moisture content (kg water/kg dry matter)	Effective moisture diffusivity (m^2/s)	Color change (ΔE)
IR - 60 ºC	210	0.4306	6.69×10^{-10}	9.89
IR - 70 ºC	165	0.4218	8.69×10^{-10}	10.67
IR - 80 ºC	120	0.3250	1.23×10^{-9}	12.43
MW - 140 W	25	0.1322	8.75×10^{-9}	11.14
MW - 210 W	16	0.1286	1.41×10^{-8}	12.36
MW - 350 W	6	0.1263	3.75×10^{-8}	19.91

CONCLUSION

In this study, infrared and microwave drying properties of thin-layer sliced pepino fruit were investigated. Effective moisture diffusivity values, activation energies, and drying rates were calculated and color changes of dried fruits as a quality parameter were investigated. As a result of the experimental studies, it has been determined that the sample final moisture contents and drying times in MW drying are much less than IR. In addition, local burns occurred due to rapid drying in

MW, but no burnt areas were found in the samples dried with IR. The color analysis supported visual examinations and the least color change was observed with IR. Accordingly, it can be said that IR drying is more effective when the quality of the final product is ahead of the drying time.

ACKNOWLEDGMENTS

The authors received no financial support for the research, authorship, and/or publication of this article.

REFERENCES

1. Gurung S, Chakravarty S, Chhetri B, Khawas T. An introduction to Pepino (*Solanum muricatum Aiton*): Review. International Journal of Environment, Agriculture and Biotechnology. 2016;1(2):143-8. Available from: <URL>.

2. Lenaerts S, Van Der Borght M, Callens A, Van Campenhout L. Suitability of microwave drying for mealworms (*Tenebrio molitor*) as alternative to freeze drying: Impact on nutritional quality and colour. Food Chemistry. 15 July 2018;254:129-36. Available from: <URL>.

3. Radoiu M. Microwave drying process scale-up. Chemical Engineering and Processing - Process Intensification. Sep;2020;155:108088. Available from: <URL>.

4. Ozyalcin ZO, Kipcak AS. The Effect of Ultrasonic Pre-Treatment on the Temperature Controlled Infrared Drying of *Loligo Vulgaris* and Comparison with the Microwave Drying. Turkish Journal of Fisheries and Aquatic Sciences. 29 Dec;2020;21(03):135-45. Available from: <URL>.

5. Delfiya DSA, Prashob K, Murali S, Alfiya PV, Samuel MP, Pandiselvam R. Drying kinetics of food materials in infrared radiation drying: A review. Journal of Food Process Engineering. 2022;45(6):e13810. Available from: <URL>.

6. Raaf A, Putra TW, Mulana F, Syamsuddin Y, Supardan MD. Investigation of kinetics of amla (*Emblica officinalis*) fruit drying process. South African Journal of Chemical Engineering, 2022;41, 10-16. Available from: <URL>.

7. Ozgen F, Celik N. Evaluation of Design Parameters on Drying of Kiwi Fruit. Applied Sciences. 2019; 9(1):10. Available from: <URL>.

8. Raj Bhagya, Dash Kshirod. Microwave vacuum drying of dragon fruit slice: Artificial neural network modelling, genetic algorithm optimization, and kinetics study. Computers and Electronics in Agriculture. 2020; 178, 105814. Available from: <URL>.

9. Izli N, Izli G, Taşkın O. Influence of different drying techniques on drying parameters of mango. Ciência e Tecnologia de Alimentos. 2017; 37. Available from: <URL>.

10. Luelue H, Qiao F, Fan D. Microstructure changing and moisture removing of lychee during microwave vacuum drying. International Journal of Agricultural and Biological Engineering 9.3 2016; 162-169. Available from: <URL>.

11. Uribe E, Vega-Galvez A, Di Scala K, Oyanadel R, Saavedra Torrico J, Miranda M. Characteristics of Convective Drying of Pepino Fruit (*Solanum muricatum Ait.*): Application of Weibull Distribution. Food and Bioprocess Technology. 01 Nov;2009;4:1349-56. Available from: <URL>.

12. Di Scala K, Vega-Galvez A, Uribe E, Oyanadel R, Miranda M, Vergara J, vd. Changes of quality characteristics of pepino fruit (*Solanum muricatum Ait*) during convective drying. International Journal of Food Science & Technology. 14 Feb;2011;46:746-53. Available from: <URL>.

13. Izli G, Taskin O, Izli N. Convective, Microwave and Combined Microwave-Convective Drying of Pepino. Erwerbs-Obstbau. 01 June;2021;63(2):175-84. Available from: <URL>.

14. Ozcan MM, Al Juhaimi F, Ahmed IAM. et al. Effect of microwave and oven drying processes on antioxidant activity, total phenol and phenolic compounds of kiwi and pepino fruits. J Food Sci Technol; 2020;57, 233–242. Available from: <URL>.

15. AOAC. Official method of Analysis. 18th Edition. Washington DC. USA: 2005. Association of Officiating Analytical Chemists.

16. Ozyalcin ZO, Kipcak AS. The Ultrasound Effect on the Drying Characteristics of *Loligo vulgaris* by the Methods of Oven and Vacuum-oven. Journal of Aquatic Food Product Technology. 07 Feb;2022;31(2):187-99. Available from: <URL>.

17. Doymaz I, Kipcak AS, Piskin S. Microwave drying of green bean slices: drying kinetics and physical quality. Czech Journal of Food Sciences. 21 July;2015;33 (2015) (No. 4):367-76. Available from: <URL>.