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

The Effect of Different Drying Methods-Temperatures on Drying Time and Vitamin C in Pineapple, Kiwi, and Avocado Fruits

Ayşe BİÇER, **Filiz KAR***

Fırat University, Engineering Faculty, Department of Chemical Engineering, Elazığ, Turkey.

Abstract: In this study, kiwi, pineapple, and avocado fruits were dried at different temperatures and different types of dryers and Vitamin C detection was performed prior to and after drying. In order to determine the impact of the geometric shape of the fruit on drying, drying experiments were performed using fruits cut in cubic (1x1x1 cm), rectangular prism (1×1×2.5 cm) and spherical (1 cm diameter) shapes. The drying behaviors of 3 different fruits have been observed in tray dryer setting at 1.5 m/s air velocity, 45 °C and 55 °C temperature and infrared dryer. An examination of the data obtained at the end of the drying procedures yielded that, at 55°C drying temperature, drying occurred without any change in the color of samples. In the experiments made for pineapple, it has been observed that drying took an average of 420 minutes, that the velocity of moisture loss was highest with cubic shape, followed by rectangular and spherical shapes; as for the experiments made with kiwi, it has been observed that drying took 360 minutes on average and the velocity of moisture loss was highest with cubic shape, followed by rectangular and spherical shapes. About avocado fruit, the drying took 400 minutes on average and its geometric behavior is similar to the other fruits. The effective parameter for the drying of fruits in both flat flow and infrared is temperature. The drying periods of pineapple, kiwi, and avocado in infrared dryer are 400, 240, and 390 minutes, respectively. Among the examined fruits, pineapple and kiwi are rich in Vitamin C (before drying). At the end of the conducted experiments, ascorbic acid amount has been found as 485, 1002, and 75 mg/kg, respectively. After the drying procedure, vitamin C values were detected as 187, 25.9 and 385.4 mg/kg. These results show that 60-65% of vitamin C is lost during drying procedure. Page, Henderson & Pabis, and Logarithmic thin layer drying models, available in the literature were used to evaluate the experimental data. All the models were compared according to statistical parameters; i.e. model efficiency (R^2), chi-square (χ^2) and root mean square error (RMSE). It was observed that Modified Page model among the models used is best mathematical model represented the drying behavior of tropical fruits.

Keywords: Drying, ascorbic acid, pineapple, avocado, kiwi.

Submitted: December 06, 2018. **Accepted:** February 20, 2020.

Cite this: Biçer A, Kar F. The Effect of Different Drying Methods-Temperatures on Drying Time and Vitamin C in Pineapple, Kiwi, and Avocado Fruits. JOTCSB; 3(1): 9-18.

Corresponding author. E-mail: fkar@firat.edu.tr.

INTRODUCTION

Food materials can be spoiled by individual or combined effects of physical, biological, or chemical factors. Microorganisms (bacteria, mould, yeast), enzyme activities, lipid oxidation (oxidative rancidity), non-enzymatic browning (Maillard) events and physical impacts (striking, heat, etc.) can lead to such spoilage. In order to prevent the physical, biological or chemical factors that lead to spoilage, a variety of food preservation methods are being used. These include such methods as drying, thermal process (pasteurization/sterilization), fermentation, adding preservative materials (salting and sugaring), fuming (smoking), canning, freezing, cold-preserving and irradiation (1,2).

Drying is a process which occurs in nature spontaneously. People have observed nature and discovered that sun drying can protect foods. So they started to dry agricultural products. Today drying can be done industrially and more rapidly and healthily due to the increase in mechanization (3-6). Drying is reducing the water activity (aw) under a value preferred for food and making it durable against microbiological, chemical and enzymatic spoilage (7-9). The purpose of drying food materials is to prevent the spoilage of food, preserving its nutrient value and quality features, reducing its dimension for transportation and storage, and removing maximum amount of water in the food using minimum energy. Choosing the most suitable drying method in terms of energy consumption and economy is essential (10).

The drying process in the presence of surrounding hot air could be considered as one of the viable option to accomplish the satisfactory evaporation of moisture from fruits. The drying process could be defined as a progress of removal of moisture via simultaneous heat and mass transfer between the sample and the surrounding atmosphere by means of vaporization, generally caused by temperature and air convection forces (11).

The aim of this study is to dry kiwi, pineapple, and avocado fruits with two different methods in different geometric shapes and to determine the vitamin C values before and after drying. In addition, drying data were applied to various models and the most appropriate model was determined by statistical analysis.

MATERIAL AND METHOD

Information on the fruits used in experiments

Pineapples (*A. comosus var. Perola*), kiwi (*Actinidia deliciosa)* and avocado (*Persea americana*) were purchased in a local market in Elazığ, Turkey. Fruits were washed and peeled. The fruits were cut in appropriate geometric shapes and used in experiments.

Kiwi is the common name given to the plants in cultivar group obtained from *Actinidia deliciosa,* which is a grapevine-like arboreal climbing plant, and the hybrids of *A. deliciosa* and other *Actinidia* species; it is also used for the edible fruits of these plants.

In recent years kiwi fruit has been begun to be farmed in and around Artvin, Yalova, Adapazarı, Rize, Ordu and Antalya/Turkey. Kiwi includes high levels of potassium, fiber, and vitamins A, E and C and potassium, kiwi is also rich in calcium, iron, and magnesium minerals. Kiwi has a high nutritive value and even one kiwi can meet the entire daily need for Vitamins A and C (12).

Pineapple (*Ananas comosus*) is a plant from Bromeliaceae family, which grows in warm countries; the word is also used to refer to the fruit of that plant. Its home is South America. Its fruit is big, fragrant and delicious, and it has a bunch of leaves on top (13, 14).

Avocado (Persea Americana) is a tree belonging to the Lauraceae family, which also includes cinnamon and camphor tree which is in the class Angiospermae (division Magnoliophyta), whose homeland is the central part of Mexico; this word is also used to denote the fruit of this tree. Its plant is cultivated in all warm climates; in Turkey, it is planted between Antalya and İskenderun in Mediterranean region and in eastern Black Sea region provinces such as Rize where frost is rare. On the back of rapidly growing global demand, world production of avocado reached an estimated 6.3 million tonnes in 2018, representing a 6.7 percent increase from 2017. Among all the major tropical fruits, avocado has seen the fastest production growth in the last decade, at an annual average rate of 6 percent, primarily due to increases in harvested area in the major producers (15). The consistent rise in the agriculture of avocado fruit is attributed to its increasing requirement as a consequence of numerous benefits of the same on human health (16,17). There have been many studies on avocado (18-20).

Straight air-flow experiments in tray dryer

Prior to beginning the experiments, dryers were operated idly for 30 minutes and the regime conditions were created as regards the internal temperatures of dryer rooms. The experiments were repeated in tray dryers for the straight flow condition of heating air at 1.5 m/s air velocity and 45 ^{o}C, 55 ^{o}C air temperatures (Figures 1-2). In the second experiment mechanism, the infrared dryer was operated at 55 ^{o}C temperature (Mettler LJ16).

The straight air flow tunnel-type dryer blower used in experiments includes electrical heater, thermometers, dryer trays, and precision scales. Drying air was heated through electrical resistance wires which were placed at the outlet of the blower and air temperature was adjusted using temperature control knob. Air velocity was controlled using a speedometer held at the air outlet through speedometer knob.

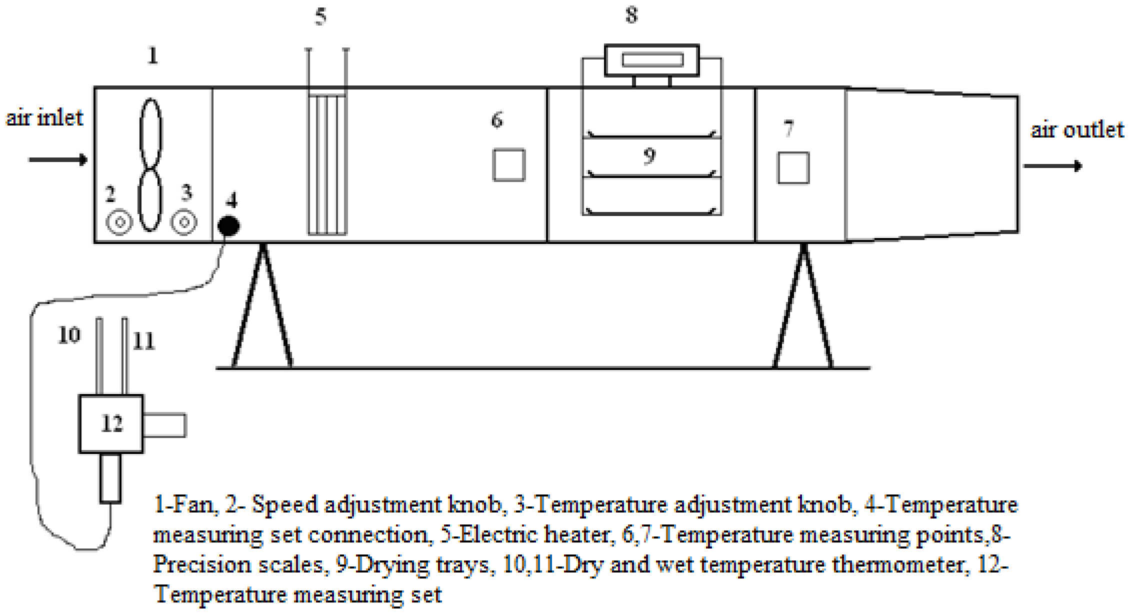

Figure 1. Tray type dryer (21)

Figure 2. Fruits in tray dryer.

Ascorbic acid (vitamin C) content of dried fruits

Using HPLC device, the ascorbic acid standard curve required for ascorbic acid designation was determined and data were evaluated using this curve (22).

Calculations made to determine drying characteristics and Drying Model Equations

During the drying of fruits samples in cabin-type dryer moisture content is calculated as follows:

$$M_t = \frac{(m - KM)}{KM} \quad (1)$$

Drying speed is found by taking the derivative of the drying time curves as per moisture content.

$$\text{Drying speed} = \frac{(M_{t+dt} - M_t)}{dt}$$

(g water/g dry material. min.) (2)

Moisture ratio is calculated as follows:

$$MR = \frac{(M_t - M_e)}{(M_o - M_e)} \quad (3)$$

While drying food materials with hot air, M_e value is negligible compared to M_t and M_o. For this reason, it is reported that Me value could be taken as zero in the calculations (23).

While using MR values M_t/M_o equation was used directly.

Previous studies include equations which are used to design drying processes, ensuring large-scale drying and improving drying processes. Among these equations, experimental drying data can be used to determine the model which best represents drying (24-29).

The constants in models were determined by the non-linear regression analysis to examine the goodness-of-fit of the models. Statistical software package (Statistica for Windows 5.0, 1995) was used to perform the nonlinear regression analysis of experimental drying data. The quality of the fit of the model was estimated using the various statistical parameters such as root mean square error (RMSE), chi-square (χ^2) , mean bias error (MBE), mean percentage error (MPE) and the coefficient of determination r^2 (30).

Determination of diffusion coefficient

Diffusion, which occurs during the drying of food materials, is a complicated process. In decreased speed period, the drying parameters of biological products can be defined using Fick's diffusion equation (31,32). Diffusion coefficient is an important parameter in drying, and was calculated using different velocities and temperatures for fruits. For sliced fruits for which diffusion coefficient is fixed and the first moisture content is homogeneous, this equation was obtained by Crank as follows (33).

$$MR= \frac{M-M_e}{M_i-M_e} = \frac{8}{\pi}\sum_{n=0}^{\infty}\frac{1}{(2n+1)^2}\exp\left(\frac{-(2n+1)^2\pi^2 D_{eff} t}{4L^2}\right) \quad (4)$$

where D_{eff} is diffusion coefficient (m^2/s), L is the semi-thickness of dried products, and t is drying period. This equation can be simplified as based on the first term of series for long drying processes (34).

$$MR= \frac{M-M_e}{M_i-M_e} = \frac{8}{\pi}\sum_{n=0}^{\infty}\left(\frac{-\pi^2 D_{eff} t}{4L^2}\right) \quad (5)$$

Diffusion coefficient can be found by solving Equation (5) using regression analysis.

EXPERIMENTAL RESULTS

Geometric shapes of the samples were chosen as cubic (1×1×1 cm), rectangular prismatic (1×1×2.5 cm) and spherical (1 cm diameter) which were placed separately into the dryers (Figure 3).

Figure 3. Dried fruits.

Experiments performed at tray dryer

As a result of the experiments conducted in tray dryer at 45 an 55 °C, it was found out that drying was faster at 55 °C. For this reason, effort was paid to determine how geometric shape of the material would affect drying at fixed temperature and air velocity.

The results of fresh food drying processes conducted for tray dryer are given in Figure 4. As a result of the examination of Figure 4, it was observed that at 1.5 m/s drying velocity and 55°C drying temperature the color of the samples did not change, which meant that drying was realized in 420 minutes without carbonization at material level. An examination of Figure 4 shows that cube is the geometric shape which witnessed fastest moisture removal followed by rectangular prism and sphere.

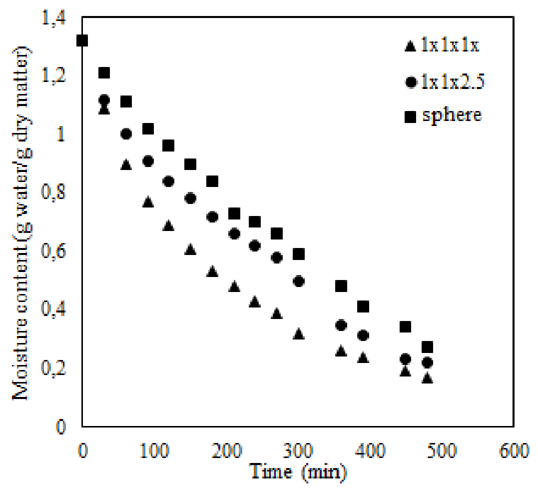

Figure 4. Variation in moisture content as a function of drying time (pineapple fruit).

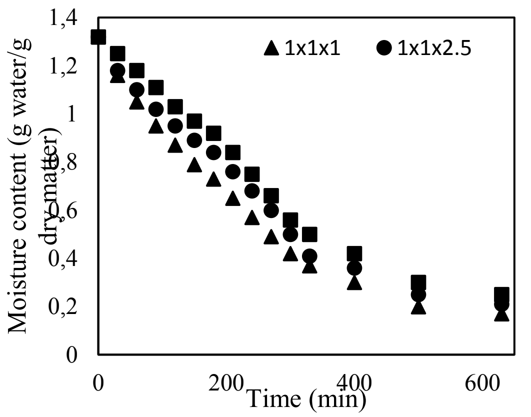

Figure 5. Variation in moisture content as a function of drying time (avocado fruit)

As for avocado fruit, it is seen that average drying took 500 minutes and, similar to the other fruits given above, drying was fastest in cubic shape followed by rectangular prismatic and spherical (Figure 5).

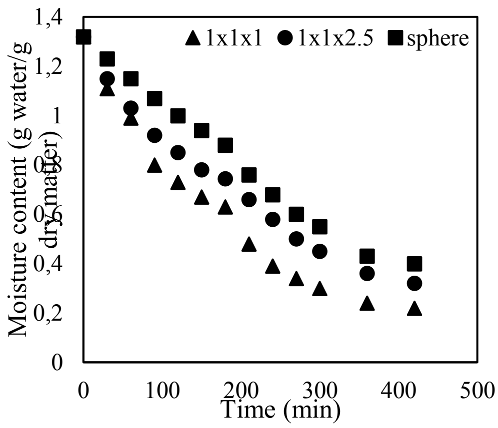

Figure 6. Variation in moisture content as a function of drying time (kiwi fruit)

The experiments conducted for kiwi showed that average drying period was 360 minutes and, similar to the pineapple fruit, moisture removal was fastest in cubic followed by rectangular prismatic and spherical (Figure 6).

Moisture content values were obtained by drying tropical fruits in three different geometrical shape in the tray dryer. The relevant experimental data is modeled using five different drying models and the results are presented in the Table.

Equation 5 is solved in order to determine diffusion speed. Table 1 provides the change of diffusion coefficient according to the geometric shape of fruits. An examination of the table shows that diffusion coefficient is higher in fruits sliced in 1x1x1 dimension. Results are in harmony with the data obtained in the literature (35, 36).

Table 1. Regressions for the Lewis' Model (M_R = exp(-kt).

Fruits		k	a	n	c	R^2	RMSE	χ2	MBE	MPE
pineapple	1x1x1	0.0065	-	-	-	0.989	0.00047	-0.0005	0.00962	-18.8869
	1x1x2.5	0.0046	-	-	-	0.968	0.00257	-0.0027	0.02177	-102.990
	sphere	0.0049	-	-	-	0.975	0.00620	-0.0066	-0.0601	-12.7089
avocado	1x1x1	0.0054	-	-	-	0.971	0.00313	-0.0033	-0.0279	1.5188
	1x1x2.5	0.0052	-	-	-	0.928	0.00872	-0.0094	-0.0579	7.5148
	sphere	0.0035	-	-	-	0.964	0.00679	-0.0073	0.00765	-12.7089
kiwi	1x1x1	0.0091	-	-	-	0.957	0.00827	-0.0089	-0.0639	10.859
	1x1x2.5	0.0067	-	-	-	0.956	0.00433	-0.0047	-0.0335	-0.3501
	sphere	0.0057	-	-	-	0.947	0.01066	-0.0115	-0.0507	-13.3486

Table 2. Regressions for the Page model M_R = exp(-kt).

Fruits		k	a	n	c	R^2	RMSE	χ2	MBE	MPE
pineapple	1x1x1	0.0062	-	1.32	-	0.987	0.00039	-0.0004	-0.0010	-14.537
	1x1x2.5	0.0059	-	1.13	-	0.985	0.00767	-0.0089	-0.0604	-36.166
	sphere	0.0055	-	1.15	-	0.990	0.00164	-0.0192	-0.0020	-11.718
avocado	1x1x1	0.0029	-	1.27	-	0.995	0.05280	-0.1616	-0.1945	56.7868
	1x1x2.5	0.0035	-	1.19	-	0.993	0.05533	-0.0645	-0.1976	50.2778
	sphere	0.0036	-	1.43	-	0.985	0.20722	-0.2417	-0.3882	77.1123
kiwi	1x1x1	0.0017	-	1.38	-	0.954	0.01727	-0.0204	-0.0985	45.1689
	1x1x2.5	0.0026	-	1.26	-	0.960	0.02200	-0.0259	-0.1169	40.5022
	sphere	0.0028	-	1.11	-	0.943	0.00559	-0. 006	-0.0119	-25.768

Table 3. Regressions for the Modified Page Model (M_R = exp(-kt)).

Fruits		k	a	n	c	R^2	RMSE	χ2	MBE	MPE
pineapple	1x1x1	0.2204	-	0.2813	-	0.997	0.00038	-0.0004	-0.0006	-15.8836
	1x1x2.5	0.205	-	0.274	-	0.991	0.01269	-0.0148	-0.0866	23.9696
	sphere	0.190	-	0.274	-	0.981	0.00758	-0.0088	-0.0665	8.0315
avocado	1x1x1	0.2113	-	0.3011	-	0.996	0.00658	-0.0077	-0.0557	9.6452
	1x1x2.5	0.227	-	0.2990	-	0.990	0.01795	-0.0209	-0.0995	17.8466
	sphere	0.315	-	0.3150	-	0.976	0.01694	-0.0197	-0.0927	14.2536
kiwi	1x1x1	0.2345	-	0.2703	-	0.998	0.00771	-0.0091	-0.0594	5.9008
	1x1x2.5	0.230	-	0.2540	-	0.988	0.01047	-0.0123	-0.0725	12.4995
	sphere	0.209	-	0.2980	-	0.988	0.02335	-0.0275	-0.1083	8.8510

Table 4. Regressions for the Henderson and Pabis model (M_R = (a) exp (-kt).

Fruits		k	a	n	c	R^2	RMSE	χ2	MBE	MPE
pineapple	1x1x1	0.0069	1.0037	-	-	0.985	0.00052	-0.0006	-0.0045	-8.6598
	1x1x2.5	0.0076	1.117	-	-	0.980	0.00265	-0.0031	0.0086	-3.5396
	sphere	0.0027	1.115	-	-	0.944	0.03280	-0.0382	0.1757	-73.827
avocado	1x1x1	0.0070	1.4179	-	-	0.947	0.02283	-0.0266	0.0506	-3.4628
	1x1x2.5	0.0059	1.463	-	-	0.953	0.03151	-0.0367	0.0918	-16.4503
	sphere	0.0055	1.316	-	-	0.908	0.01443	-0.0168	0.01337	-0.6117
kiwi	1x1x1	0.0089	1.2596	-	-	0.955	0.00923	-0.0109	0.0234	-14.1932
	1x1x2.5	0.0081	1.296	-	-	0.946	0.01337	-0.0158	0.01767	-1.2819
	sphere	0.0067	1.282	-	-	0.963	0.01285	-0.01518	0.01455	-17.9026

Table 5. Regressions for the logarithmic model.

Fruits		k	a	n	c	R^2	RMSE	χ2	MBE	MPE
pineapple	1x1x1	0.015	0.944	-	-0.43	0.973	0.00038	-0.0004	-0.00075	-14.6425
	1x1x2.5	0.013	0.901	-	-0.027	0.981	0.00623	-0.0079	0.07277	-73.5226
	sphere	0.009	0.911	-	-0.043	0.961	0.00183	-0.0023	-0.00416	-8.4672
avocado	1x1x1	0.013	1.113	-	-0.013	0.966	0.06895	-0.0878	-0.2185	62.4314
	1x1x2.5	0.015	1.105	-	-0.017	0.976	0.01213	-0.01544	-0.0676	15.3346
	sphere	0.021	1.085	-	-0.018	0.959	0.20440	-0.2602	-0.3879	78.9746
kiwi	1x1x1	0.011	1.125	-	-0.017	0.947	0.01647	-0.0214	-0.0896	39.5625
	1x1x2.5	0.010	1.133	-	-0.019	0.952	0.02385	-0.0310	-0.1130	39.7571
	sphere	0.017	1.097	-	-0.034	0.935	0.13415	-0.1744	-0.3065	81.3499

The higher the values of the EF and R, the better the goodness of the fit. The lower the values of the RMSE, χ^2 and MBE, the better the goodness of the fit. The results have shown that highest values of EF and r and the lowest RMSE, χ^2 and MBE values could be obtained with the statistically fitted model of Modified Page Model.

Equation 5 is solved in order to determine the speed of diffusion. Table 1 provides the change of diffusion coefficient according to the geometric shape of fruits. An examination of the table shows that diffusion coefficient is higher in fruits sliced in 1 x 1 x 1 dimension. Results are in harmony with the data obtained in the literature (36, 37).

Table 6. Variation of the diffusion coefficient with the geometric shape of the fruits.

Fruits	**geometric shapes**	**Diffusion Coefficients (m²/s)**
Pineapple	1x1x1	1.654×10^{-8}
	1x1x2.5	1.140×10^{-8}
	sphere	9.100×10^{-9}
Avocado	1x1x1	9.380×10^{-9}
	1x1x2.5	8.110×10^{-9}
	sphere	1.540×10^{-8}
Kiwi	1x1x1	$1.190\text{x}10^{-8}$
	1x1x2.5	$9.128\text{x}10^{-9}$
	sphere	$1.650\text{x}10^{-8}$

Experiments conducted in infrared dryer

In an infrared dryer, the time-moisture content of pineapple, kiwi, and avocado at different sizes was examined and presented in figures.

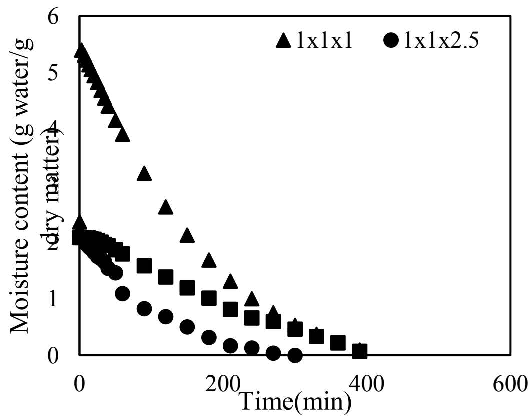

Figure 7. Variation in moisture content as a function of drying time (pineapple fruit)

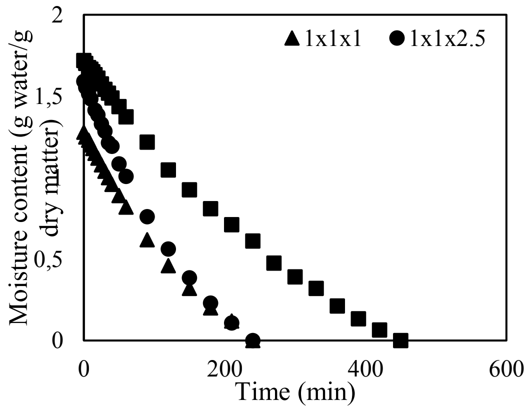

Figure 8. Variation in mois ture content as a function of drying time (kiwi fruit)

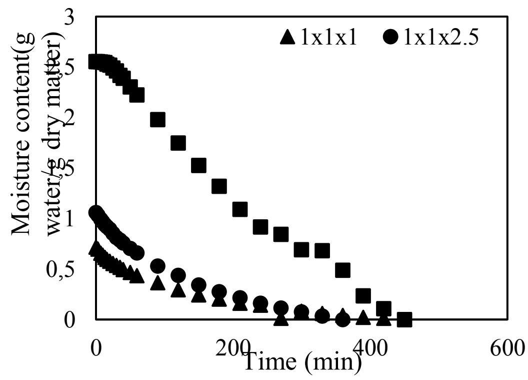

Figure 9. Variation in moisture content as a function of drying time (avocado fruit)

The experiments conducted in infrared dryer showed that fruits sliced in 1x1x1 dimensions dried faster. Only the experiment conducted for pineapple showed deviations in the fruits sliced in 1x1x1 dimensions. It is believed that this situation was caused by experimental errors.

Ascorbic acid (vitamin C) content of dried fruits

Prior to drying process, the Vitamin C values found in pineapple, avocado and kiwi were 485, 75 and 1002 mg/kg, respectively. After the drying process, Vitamin C values were found as 187.0, 25.9 and 385.4 mg/kg, respectively. These results show that during drying process 60-65% of vitamin C is lost.

CONCLUSIONS

The impact of parameters in the drying process of fruits is discussed and explained with the findings. At the end of this study, the following conclusions can be reached:

1. The effective parameter in both straight flow and infrared drying of fruits is temperature. If the temperature is increased, drying period can be shortened. Temperatures under 50 °C are not suitable for drying. In the study, drying period can be extended. Again, drying at temperatures above 70 °C causes change of color and the fruit tends to be baked and then carbonated; thus, it is not recommended.
2. The impact of air velocity on the drying of fruits is not as much as temperature as, during drying, the external shell of the fruit can show excessive resistance against drying, which, in turn, makes the diffusion of moisture more difficult. Air velocity is effective at drying processes where moisture is accumulated especially at external section, meaning at fixed velocity zone. Diffusion is more effective than convection while drying fruits; thus, keeping air velocity low is essential in terms of cost.
3. Among the examined fruits, pineapple and kiwi are very rich in terms of Vitamin C. At the end of the experiments, ascorbic acid amount of pineapple, kiwi and avocado was found as 485, 1002 and 75 mg/kg, respectively. After the drying process, Vitamin C values were determined as 187.0, 25.9 and 385.4 mg/kg. These results show that during drying process 60-65% of Vitamin C is lost.
4. Five different drying models (Modified Page model, Page model, Henderson and Pabis model, Lewis model, and Logarithmic model) were used in order to define the theoretical model which gives the best approach to experimental values. For fruits in different geometric shapes dried at 55 °C and 1.5 m/s air velocity, it can be said that Modified Page equation provides relatively good results in determining drying behavior. In addition, in all drying models it has been observed that drying coefficient (k), which is an essential parameter, reduced as the shape grew larger. This is an indicator that drying will be faster when the size of the fruit becomes smaller.
5. It has been observed that diffusion coefficient was larger for fruits sliced in 1x1x1 dimension. The results are in harmony with the values given in the literature.

ACKNOWLEDGMENTS

This research was presented at the 13th National Chemical Engineering Congress (UKMK-2018). We thank the 13th National Chemical Engineering Congress.

REFERENCES

1.Kowalski SJ, Mierzwa D, Stasiak M. Ultrasound-assisted convective drying of apples at different process conditions. Drying Technology. 2016 Nov 11;35(8): 939-47.

2. Maskan M, Drying, shrinkage and rehydration characteristics of kiwifruits during hot air and microwave drying. Journal of Food Engineering. 2001;48(2): 177-82.

3. Gürlek G, Akdemir Ö, Güngör A, Gıda Kurutulmasında Isı Pompalı Kurutucuların Kullanımı ve Elma Kurutmada Uygulanması. Pamukkale Üniversitesi Müh. Bilim Dergisi. 2015; 21(9): 398-403.

4. Demiray E, Tülek Y. Kurutma İşleminin Kırmızı Biberdeki Renk Maddelerine Etkisi. Gıda Teknolojileri Elektronik Dergisi. 2012; 7(3): 1-10.

5. Cemeroğlu B. Kurutma teknolojisi. Meyve ve sebze işleme teknolojisi. Gıda Teknolojisi Derneği, 1986; Yayın no:6, Böl: 9, Ankara.

6. Geankoplis CJ. Transport process and unit operations. Allyn and Bacon, Inc., Boston, 1983; 508-657.

7. Alibaş İ. İnce Tabaka Mango Dilimlerinin Mikrodalga Tekniği ile Kurutulması, Uludağ Üniversitesi Ziraat Fakültesi Anadolu Tarım Bilimleri Dergisi. 2015; 30: 99-109.

8. Can A. Kurutma koşullarında biyolojik ürünler içinden nem transportunun kinetiği. Mühendis ve Makine Dergisi. 2000; 33: 392, 9–12.

9. Demir F, Ozcan M. Chemical and technological properties of rose (Rosa canina L.) fruits grown wild in Turkey. Journal of Food Engineering. 2001; 47: 333-6.

10. Avhad MR, Marchetti JM. Mathematical modelling of the drying kinetics of Hass

avocado seeds. Industrial Crops and Products. 2016; 91: 76–87.

11. Perea-Flores MJ, Garibay-Febles V, Chanona-Pérez JJ, Calderón-Domínguez G, Méndez-Méndez JV, Palacios-González E, Gutiérrez-López GF. Mathematical modelling of castor oil seeds (Ricinus communis) drying kinetics in fluidized bed at high temperatures. Ind. Crops Prod. 2012; 38: 64–71.

12. Kaya A, Aydın O, Kolaylı S. Effect of different drying conditions on the vitamin C (ascorbic acid) content of Hayward kiwifruits (Actinidia deliciosa Planch). Food and Bioproducts Processing. 2010; 88(2): 165-73.

13. Arabhosseini A, Huisman W, Van Boxtel A, Müller J. Food and Agriculture Organization of the United Nations Statistics Division. http://faostat3.fao.org/browse/Q/QC/E.

14. Rodríguez O, Gomes W, Rodrigues S, Fernandes FAN. Effect of acoustically assisted treatments on vitamins, antioxidant activity, organic acids and drying kinetics of pineapple, Ultrasonics Sonochemistry. 2017;35: 92–102.

15. Altendorf, S. 2019. Major tropical fruits market review 2018. Rome, FAO

16. Dreher ML, Davenport AJ. Hass avocado composition and potential health effects. Crit Rev Food Science Nutrition. 2013 May;53 (7): 738–50.

17. Pieterse Z, Jerling J, Oosthuizen W. Avocados (monosaturated fatty acids),weight loss and serum lipids. South Afr. Avocado Growers Assoc. Yearbook, 2003; 26: 65–71.

18. Fernandes FAN, Oliveira VS, Gomes WF, Rodrigues S. Degradation kinetics of vitamin E during ultrasound application and the adjustment in avocado purée by tocopherol acetate addition. LWT Food Sci. Technol. 2016; 69: 342– 7.

19. Dantas D, Pasquali, MA, Cavalcanti-Mata M, Duarte ME, Lisboa HM. Influence of spray drying conditions on the properties of avocado powder drink, Food Chemistry. 2018; 266: 284-91.

20. Avhad MR, Marchetti JM. Mathematical modelling of the drying kinetics of Hass avocado seeds. Industrial Crops and Products. 2016; 91: 76-87.

21. Özen E. Farklı Kurutma Teknikleri İle Domatesin Kurutulması. Yüksek Lisans Tezi, Fırat Üniversitesi Fen Bilimleri Enstitüsü, 2017.

22. Erentürk S, Gulapoglu MS, Gultekin S. The effects of cutting and drying medium on the vitamin C content of rosehip during drying. Journal of Food Engineering. 2005; 68: 513-8.

23. Wang Z, Sun J, Chen F, Liao X, Hu X. Mathematical modelling on thin layer microwave drying of apple pomace with and without hot air predrying. Journal of Food Engineering. 2007; 80: 536-44.

24. Doymaz I, Pala M. The effects of dipping pretreatments on air-drying rates of the seedless grapes. Journal of Food Engineering. 2002; 52: 413-7.

25. Yaldiz O, Ertekin C, Uzun HI. Mathematical modeling of thin layer solar drying of sultana grapes. Energy. 2001; 26: 457-65.

26. Midilli A, Kucuk H, Yapar Z. A new model for single-layer drying. Drying technology. 2002; 20: 1503-13.

27. Yağcioglu A, Değirmencioglu A, Çağatay F. Drying characteristic of laurel leaves under different conditions, in: Proceedings of the 7th international congress on agricultural mechanization and energy. Faculty of Agriculture, Cukurova University, Adana, Turkey, 1999;565-9.

28. Kalender M. Makine Sıva Alçısının İnce Tabaka Infrared Kuruma Kinetiği. Karakteristiği ve Modellenmesi Fırat Üniv. Mühendislik Bilimleri Dergisi. 2017; 29(1): 285-91.

29. Yoğurtçu H. Determination of Drying Kinetics of Tunceli Garlic with Microwave Drying Technique, Tarım Bilimleri Dergisi, 2016; 22: 237-48.

30. Karataş M, Arslan N. Flow behaviours of cellulose and carboxymethyl cellulose from grapefruit peel. Food Hydrocolloids. 2016; 58: 235-45.

31. Sacilik K, Keskin R, Elicin AK. Mathematical modeling of solar tunnel drying of thin layer organic tomato. Journal of Food Eng. 2006; 73: 231-8.

32. Liu Q, Bakker-Arkema FW. Stochastic modelling of grain drying: Part 2. Model development. Journal of Agricultural Engineering Research. 1997; 66: 275–80.

33. Crank J, The mathematics of diffusion. Oxford University Press. OX,UK, 1975.

34. Doymaz İ, Evaluation of some thin-layer drying models of persimmon slices (Diospyoskaki L.) Energy Conversion Management. 2012 April; 56: 199-205.

35. Aboltins A, Upitis A, Experimental and Theoretical Investigation of Agricultural Material Drying Process Engineering for Rural Development. 2012; 24.
36. Dissa A, Desmorieux H, Degraeve P, Bathiebo J, Koulidiati J. Impact of Fruit Ripeness on Physicochemical Properties and Convective Drying Characteristics of Kent Mango (Mangifera indica L. cv. 'Kent'). International Journal of Food Engineering, 2011; 7(3). doi:10.2202/1556-3758.2126. ISSN: 1556-3758.
37. Türk Toğrul İ, Pehlivan D, Modelling of drying kinetics of single apricot Journal of Food Engineering, 2003; 58(1): 23-32.