The Effect of Different Drying Methods on Drying Kinetics and Texture of Pistachio

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Abstract

Background: Drying is one of the oldest methods that humans have employed to preserve and store foods. Today, this method is being widely utilized, as such there have been great advances in the production of dried fruits.

Materials and Methods: In this study, different drying methods including sun drying, oven at different temperatures (70, 80, 90 or 100 °C), and microwave were used to dry "Ohadi" pistachio cultivar. In this respect, the effect of these methods on drying kinetics and the duration of drying was investigated.

Results: The results showed a meaningful difference ($p<0.05$) between the drying methods. The results also demonstrated that the microwave method accelerates the drying process. The results of the drying methods on qualitative characteristics of the pistachio such as changes in color parameters showed that the application of the microwave method increases color changes. Based on the results of the modeling for pistachio drying, Newton model was the most suitable model for describing the drying process of pistachio layers at 70°C oven, binomial model was the most suitable model for describing drying process of pistachio layers by oven at of 80, 90 and 100 °C.

Conclusions: The Page model was the most suitable model for describing the drying process of pistachio layers by microwave, and the Wang and Singh model was selected as the most suitable model for describing the drying process of pistachio layers by sun drying method.

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1. Introduction

cients were determined using diffusion theory and second law of Fick, and the average activation energy for drying was calculated by Arrhenius equation [1]. Kashaninejad et al. (2003) stated that air temperature is the most important factor in controlling the quality of pistachio characteristics during the drying process. The drying process had a significant effect on the smilingness (shell splitting) of pistachios, as such by increasing the temperature the amount of splitting increased [2].

Midilli and Kucuk (2003) used thin layer drying and sun-drying methods to explain drying behavior of pistachio and develop mathematical modeling of shelled and unshelled pistachio [3]. Khakbaz Heshmati and Hamdami (2008) studied the experimental and semi-theoretical mathematical models based on kinetic data of thin layer drying of Ohadi pistachio cultivar in a cabinet dryer at four temperatures (45, 50, 55 and 60 °C) and three air velocities (0.5, 1 and 1.5 m/s). The comparison of the measured moisture loss data with the predicted values using the mentioned models showed that Page's model, due to higher correlation coefficient and lower root mean square error and chi-square score, can be used to describe and predict the kinetics of pistachio drying [4]. Zomorodian and Tavakoli (2004) determined the equilibrium moisture content for three important pistachio cultivars (Ohedi, Kalehghouchi and Abdollahi) using a weighting method. The findings showed that Oswin equations, Smith equation and Chang and Pfost models were respectively suitable for Ohedi, Kalehghouchi, and Abdollahi cultivars, to describe and predict the relationship between equilibrium moisture and relative humidity of the products. Furthermore, the results showed that in a constant relative humidity, the equilibrium moisture content of all cultivars reduces by increasing the temperature. The effect of cultivar and temperature on equilibrium moisture content was statistically significant [5]. Mohammad Pour and Mousavian (2007) designed a laboratory fluidized bed dryer to determine the kinetic of pistachio drying. Various experimental models were assessed for adaptability with laboratory data. Analysis of the results showed that the two-parameter logistic model in all the studied areas and Henderson-Pabis model at high temperatures and velocities had the best compatibility with the experimental data [6].

Yaghoubi et al. (2012) modeled the drying of thin potato slices using a hot air displacement laboratory dryer. Three standard kinetic mathematical models were fitted to empirical data and the evaluation of the models was performed using four criteria including correlation coefficient, root mean square error, chi-square score reduction and mean deviation error. The results showed that the Page model was more appropriate for the evaluation of the drying stages of potato slices compared to other models [7]. In a study carried out by Abbaspour Kalan et al. (2013) the drying process of thin slices of Urmia seedless white grapes was assessed in a hot air dryer, and the most suitable mathematical model was introduced to describe the drying curve. Empirical data were fitted to 10 semi-theoretical and experimental models based on coefficient of determination (R2), chi-square (x2) and root mean square error (RMSE).

By comparing the evaluated models, the Midili model was found to be the most suitable model for explaining the thin layer drying curve of the grape slices [8]. Bagheri et al. (2012) conducted a study to select the best

mathematical model for drying tomato slices in a solar dryer. In order to find the most suitable drying mathematical model that is used for drying crops, the results of the experiment were fitted to 9 different models and the best coefficient was obtained for each model. Eventually, the Page model with R2=0.9974, $\chi 2$=0.01351 and RMSE=0.002 was selected as the most suitable model [9]. Considering the importance of the drying process reported by other researchers, the objective of this study was to investigate the effect of different drying methods (sun, oven and microwave drying) on drying kinetics of pistachio.

2. Materials and Methods

The amount of 12 kg pistachios of Ohadi variety was prepared from Rafsanjan Pistachio Research Institute and shortly after their skin was removed. After discarding leaves, small branches, and plant wastes, the unripe seeds or seeds with skin were separated. One part of the selected seeds was considered as a control group and the other samples were dried by different methods including sun drying, oven at 70°C, 80°C, 90°C, or 100°C, and microwave. Additionally, to determine the amount of moisture loss, the percentage of the moisture content of the samples (based on dry weight) was calculated. To study the color changes during drying process of samples at the specified times the L*, a*, and b* parameters were measured with Hunter Lab Colorflex (EZ model made by Hunterlab Company, USA). Moisture and color modeling was performed with Curvexpert Ver 1.4 software using the 8 formulas described in Table 1. Each test was repeated three times.

Table 1 . Drying Equations

Equation	Equation name
$MR = \exp(-Kt)$	Newton
$MR = \exp(-Kt^n)$	Page
$MR = a \exp(-Kt)$	Henderson–Pabis
$MR = a \exp(-Kt) + c$	Logarithmic
$MR = 1 + at + bt^2$	Wang and Singh
$MR = a \exp(-Kt^n) + bt$	Midilli–Kucuk

MR: Ratio of moisture; a, b, c, n: equation coefficients and K: drying constant

Pistachio drying

The prepared and cleaned pistachio was divided into 6 batches. The first batch was kept fresh and the desired experiments were carried out on it. The other 5 batches were dried by 5 different methods and the effect of these methods was tested on the pistachio seeds.

1. Drying at 70 °C oven

In this method, 200 gr pistachio was placed on aluminum foil with dimensions of 15 cm*15 cm and dried in the oven at 70 °C for 130 minutes. After drying, various tests were carried out on the seeds.

2. Drying at 80 °C oven

In this method, pistachio was placed on foil and dried at 80°C for 95 minutes. After drying various tests were performed on the pistachio kernels (same conditions applied like the previous temperature).

3. Drying at 90 °C oven

In this method, pistachio was placed on the foil and dried at 90°C oven for 75 minutes. After drying different tests were performed on the pistachio kernels (same conditions applied like the previous temperature).

4. Drying at 100 °C oven

In this method, pistachio was placed on the foil and dried at 100 °C oven for 45 minutes and after drying various tests were performed on the pistachio kernels (same conditions applied like the previous temperature).

5. Sun drying method

In this method, pistachio was placed on aluminum foil and exposed to direct sunlight for 48 hours and after drying, necessary tests were performed on the pistachio seeds.

6. Microwave drying

In this method, 200 g pistachio was transferred into a petri dish (15 cm in diameter) and placed in the microwave with power of 300 W for 9 minutes, then various experiments were performed on the pistachio seeds.

Texture evaluation

The texture hardness and fracture force were assessed using Brookfield texture analyzer (Middleboro, CT, USA). According to the definition, the texture hardness is the maximum force required during compression test and the fracture force is the necessary force for disintegration and the occurrence of initial fracture in the texture. Both of these parameters can be determined during a compression test. Three samples from each of the drying methods and without any defects were tested based on the following adjustments: the number of cycles: once per sample; minimum force for detecting target: 10 gr; the probe type: cylindrical (20 mm diameter); the speed of probe: 50 mm/min; and penetration rate of the probe: 4 mm.

Statistical analysis

In order to investigate the effect of different treatments on the measured characteristics, a completely randomized design was used. Analysis of variance (ANOVA) was performed using SAS software version 9.2 and the statistical significance was considered 0.05 ($p \leq 0.05$). The least significant difference (LSD) test was used when the effect of each experimental factor was significant. In this part of the study, the results were presented as mean± standard deviation (SD) and Excel software was used to draw the charts.

3. Results

3.1. Drying kinetics of pistachio layers

Figures 1 to 3 represent the changes in moisture content during the pistachio drying process by sun, microwave, and oven (at 70, 80, 90 and 100 °C), respectively. In all drying methods, moisture content decreased over time. The results of the statistical analysis of different drying methods are shown in Table 2.

Table 2. Statistical analysis of drying methods modeling

Mathematical model		Oven 70°C	Oven 80°C	Oven 90°C	Oven 100°C	Microwave	Solar
Wang and Sing	a	-.051	-0.063	-0.069	-0.073	-0.093	-0.009
	b	0.0003	0.003	0.0041	0.0049	0.003	0.0005
	R^2	0.9233	0.9134	0.9244	0.9113	0.981	0.9978
	RMSE	0.035	0.068	0.061	0.065	0.074	0.022
Logarithmic	a	0.98	1.05	1.09	1.14	1.08	-
	c	-0.110	0.052	0.064	0.069	-0.034	-
	k	0.0004	0.009	0.012	0.25	0.098	-
	R^2	0. 911	0.9345	0.9244	0.9314	0.9822	-
	RMSE	0.064	0.104	0.112	0.121	0.108	-
Henderson-Pabis	a	0.879	0.998	1.003	1.002	1.087	-
	k	0.069	0.121	0.130	0.132	0.98	-
	R^2	0.891	0.9334	0.9211	0.9311	0.9711	-
	RMSE	0.099	0.098	0.111	0.144	0.034	-
Page	k	0.023	0.028	0.031	0.038	0.064	0.153
	n	1.46	1.68	1.83	1.98	1.42	1.091
	R^2	0.986	0.978	0.988	0.986	0.968	0.9455
	RMSE	0.031	0.026	0.030	0.022	0.025	0.037
Newton	k	0.078	0.083	0.089	0.091	0.076	
	R^2	0. 878	0.881	0.891	0.902	0.9422	
	RMSE	0.103	0.098	0.0882	0.112	0.042	
Midilli–Kucuk	a	0.932	0.936	0.941	0.952	0.99	
	b	-0.057	-0.043	-0.032	0.211	0.004	
	k	0.0052	0.0044	0.0039	0.0031	0.043	
	n	0.822	0.788	0.742	0.722	1.42	
	R^2	0.922	0.912	0.908	0.931	0.9995	
	RMSE	0.089	0.088	0.762	0.113	0.008	

Abbreviations: R2, coefficient of determination; RMSE, root mean square error

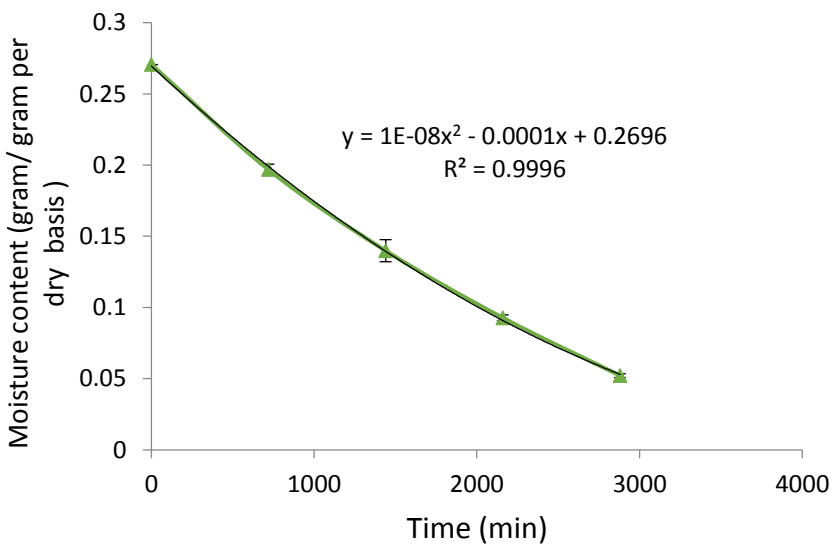

Fig. 1. Changes in pistachio moisture content over drying process time using sun drying method

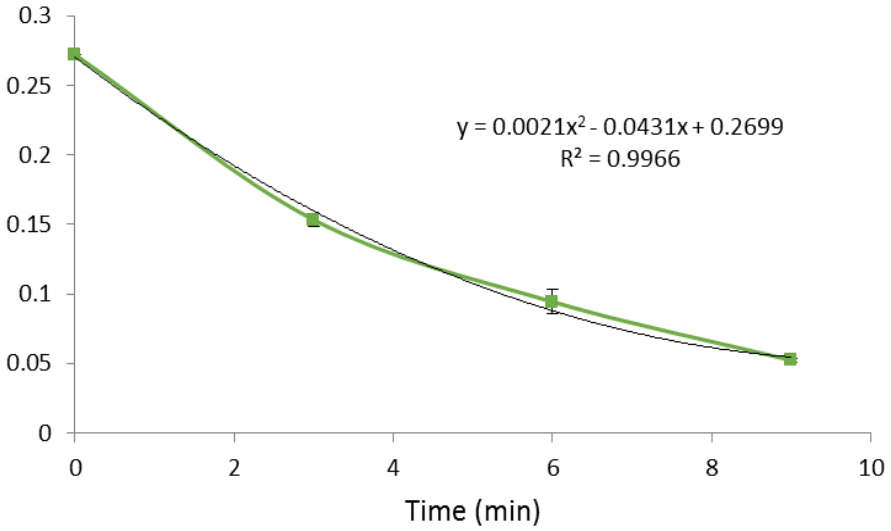

Fig. 2. Changes in pistachio moisture content over microwave drying process time

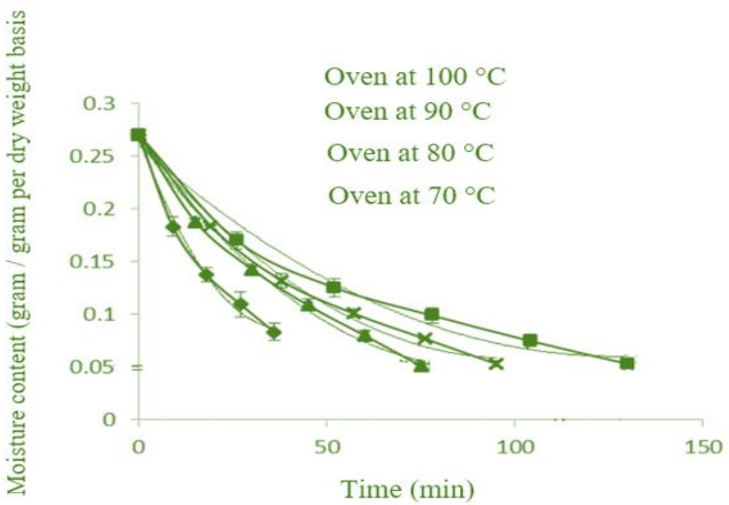

Fig. 3. Changes in pistachio moisture content over drying process time in the oven at different temperature levels

The drying rate of pistachio layers over time is shown in figures 4 to 6. In all experimental treatments, the drying rate decreased over time. In the oven method, the drying rate increased with increasing temperature.

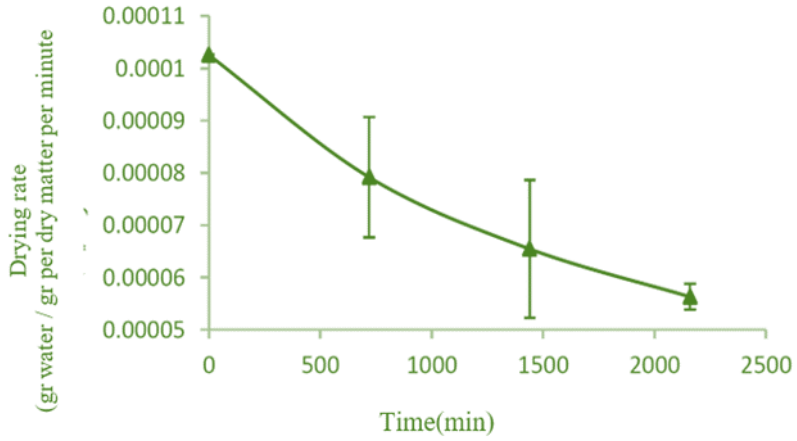

Fig. 4. Changes in the drying rate of pistachio during the sun drying process.

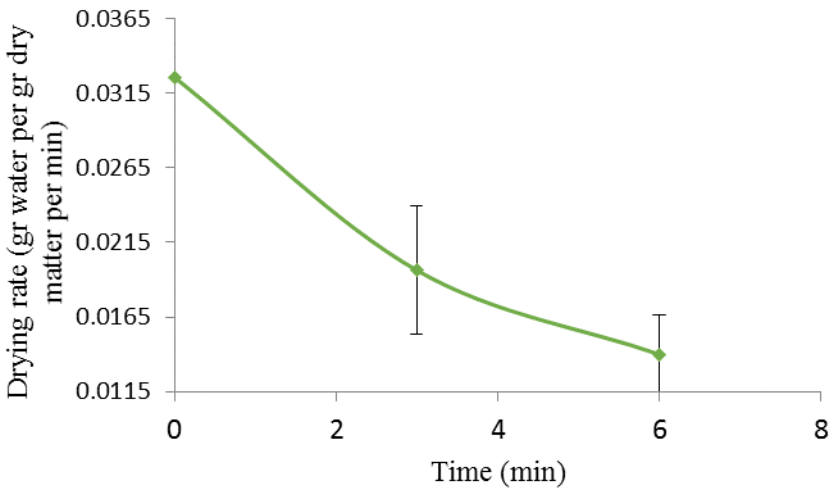

Fig. 5. Drying rate of pistachio over time during microwave drying process.

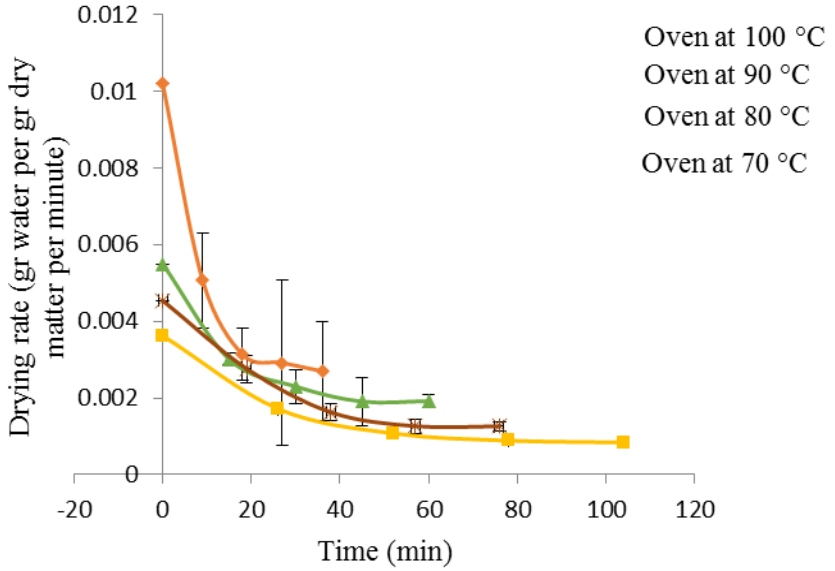

Fig. 6. Changes in the drying rate of pistachio during drying process in the oven with different temperature levels.

By comparing the average drying time of pistachio, it can be concluded that there was a significant difference between drying times at different temperature levels in the oven (Table 3). The drying time of the pistachio layers decreased with increasing temperature in the oven. This result is consistent with the results of the study reported by Oztekin et al. (2022) [10]. As it is observed, considering sun drying method there was no significant difference between drying by oven methods at different temperature levels and the microwave. However, there was a significant difference between the sun drying method and other methods. Without considering the sun drying treatment, LSD test was performed to compare the effect of temperature and the type of drying method on drying time.

Table 3. The effect of different treatments on the average drying time of pistachio layers

Drying method	°C (Temperature)	min (Drying time)
Oven	70	1/0$^{\bullet b}$±130/0
Oven	80	1/0^{bc}±95/0
Oven	90	2/0^{bc}±75/0
Oven	100	3/0^{cd}±45/0
Microwave	---	0/57^{d}±9/33
Sun drying	---	80/0±0 ^{a}2880/0

Mean Deviation of the values with similar Latin letters is not significantly different at 5% probability level based on the LSD test.

Lower case letters indicate the difference in the mean value of the six treatments.

2-3 Texture evaluation

One of the most important structural changes that occur during the drying process of foods is volume reduction. Water loss and heating can cause tension in the cellular structure of the food, which results in cellular deformation and reduction of its dimensions.

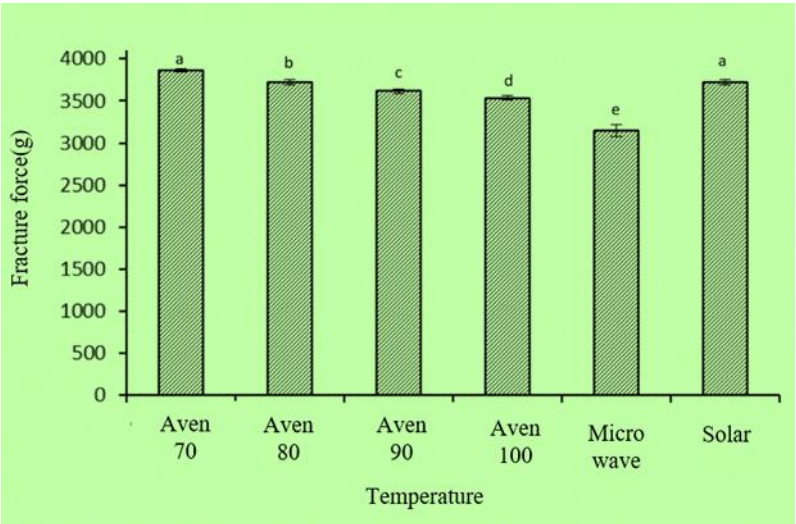

Fig. 7. The effect of drying methods on the mean fracture force of pistachio kernels
Lower case letters indicate the difference in the mean of the six treatments

The effect of drying methods on the texture hardness of the dried pistachios are shown in Figure 8. As indicated, pistachio hardness decreased with increasing temperature of the oven. The highest hardness belonged to the dried seeds prepared at 70 °C. Also, the softest texture was observed in microwave- dried seeds [11].

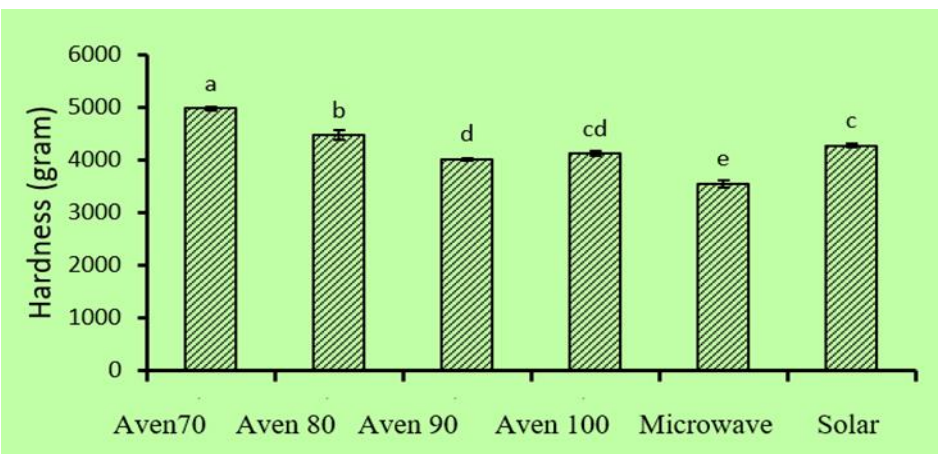

Fig 8. The effect of drying methods on mean hardness of pistachio kernels

3-3 Sensory Test

Sensory test was performed using a five-point ranking desirability method (Table 4). The sensory assessment forms were used for two independent tests. The pistachio samples were placed on separate plates 30 minutes before consumption by the assessors, and encoded with three-digit numbers. The assessors were asked to rinse their mouths with water before each test and then taste different pistachio samples.

Table 4. The Effect of Different Treatments on Mean Sensory Evaluation

Overall desirability	Flavor and taste	Appearance	Texture	Color	Method
4.5±0.2a	3.75±0.11a	3.5±0.16b	4.5±0.23a	4.25±0.21a	Oven at 70 °C
4.25±0.11a	3.75±0.10a	3.25±0.15b	4±0.20b	3.25±0.17c	Oven at 80°C
3.75±0.23b	3.25±0.21b	4.25±0.22a	3.75±0.17b	3.75±0.13b	Oven at 90 °C
4.25±0.28a	3.5±0.17a	4±0.20a	4±0.19b	4.25±0.19a	Oven at 100 °C
1.75±0.14d	1.75±0.12c	1.75c	1.5c	1.75±0.12e	Microwave
3c	3±0.21b	2c	3.75b	2.25±0.13d	Sun drying

The mean values with the same Latin letters do not differ significantly at 5% probability level based on the LSD test.

4. Discussion

Drying kinetics of pistachio layers

As shown in figures 1-3, there is a substantial difference in the reduction rate of moisture content between different types of the assessed drying methods. As such, in the sun drying method, the moisture content decreases at a very low rate (Figure 1). However, the moisture content in the microwave method (Figure 2) decreases at a higher intensity [12]. In the oven, the speed of changes is more than the sun drying method. The results showed that increasing the temperature of the oven decreases the required time to reduce the amount of moisture content of the pistachio kernels (Figure 3). Yarahmadi et al. (2019) investigated the effects of microwave drying and sun drying methods and found that the fastest reduction in moisture content was related to the microwave method, which is consistent with the results of the current study [13].

As shown in Figures 4 and 6, in the early phase of the experiment the drying rate decreases very quickly due to the presence of moisture content mainly on the surface and the adjacent layers. Therefore, changes in drying rate per unit time (curve slope) are high, but over time and due to the loss of surface moisture content and its adjacent layers, the drying rate per unit time changes [13]. The average drying rate in sun and microwave methods was 7.588×10-5 and 0.022 gr water per gr dry matter per minute, respectively.

The average drying rates in the oven at 70, 80, 90 and 100 °C were 0.001, 0.0022, 0.0029, and 0.0048-gram water per gram dry matter per minute, respectively. Comparison of the drying rate between different methods showed that the highest rate belonged to the microwave method and the slowest rate belonged to the sun–based method. Moreover, the average drying speed in the microwave method was 4.6 times higher than drying in the oven at 100°C.

As indicated in table 3, The results showed substantial differences between all treatments. Microwave method significantly reduced the drying time of pistachio. This was in agreement with the results of a study by Mokhtarian et al. that investigated the effect of different drying methods on physical properties of pistachio kernels [14].

Texture evaluation

Deformation and volume reduction in most materials is a negative characteristic from consumers' point of view [3]. Textural features that can be mainly evaluated in the seeds include hardness and fragility, brittle and crispy texture of the roasted seeds that makes them tastier and more desirable for eating. Based on the statistical analysis of the results, there was a significant difference between the effect of different temperatures of the oven, microwave and sun drying method ($p<0.05$) on the pistachio, which was in line with the results of Jahanbakhshi et al. (2020). The effect of the drying method on the fracture force of the dried pistachios is shown in Figure 7. As it is observed, by increasing the temperature of the oven, the rate of fracture force of pistachio decreases [5]. The highest and lowest fracture force was obtained from samples dried in the oven at 70 °C and microwave, respectively. The effect of drying methods on the texture hardness of the dried pistachios are shown in Figure 8. As indicated, pistachio hardness decreased with increasing temperature of the oven. The highest hardness belonged to the dried seeds prepared at 70 °C. Also, the softest texture was observed in microwave-dried seeds [11].

3–3 Sensory Test

As illustrated in table 4, The scores for the colors of the dried pistachio ranged from 1.75 to 4.25. The effect of different treatments on the mean sensory evaluation is shown in Table 4. Data analysis showed that the temperature and the drying method had a substantial impact on the quality of pistachio. From the assessors' point of view, the highest color quality belonged to the dried seeds at 70 and 100 °C oven and the lowest quality belonged to the microwave–dried seeds.

As mentioned above, the highest color changes were observed in microwave and sun–dried seeds and the least amount of these changes was observed in oven–dried seeds. These color changes were negative from the assessors' point of view; hence sun and microwave treatments obtained lower scores. The scores for the quality of texture ranged from 1.5 to 4.5 . The highest and lowest textural scores for dried pistachio seed kernels belonged to the 70°C oven and microwave method, respectively [16].

In the microwave method, the given score by the assessors was 3.75, which in terms of satisfaction was somewhere between good and neutral. The analysis of the results showed that the appearance of pistachio texture was significantly different among the treatment methods [17]. The highest score belonged to the oven method and the lowest score belonged to the microwave method [18].

The range of the scores for the flavor intensity and taste of pistachio samples showed that the microwave method had the lowest desirability rate among other treatment methods, which can be attributed to high fat oxidation rate [19]. The analysis of the results showed that the highest and the lowest desirability belonged to the oven–dried seeds at 70°C and the microwave–dried seeds, respectively.

Conclusion

The obtained results indicated that different drying methods have several advantages and disadvantages. For instance, the use of microwaves compared to other methods increased the drying speed of the seeds, which was one of the best advantages of the microwave method. In contrast, a longer drying time in the sun–based method was one of the disadvantages of this traditional method. In the oven method, higher temperature reduced the drying speed of the seeds. However, one of the disadvantages of the microwave method is the high oxidation rate of fat in pistachio kernels. This downside was also observed in seeds dried in the oven at high temperatures. In terms of the color changes, sun–dried and microwave–dried pistachio had the lowest color quality while the seeds dried in the oven at higher temperatures and in a shorter time had the highest color quality. The overall results showed that the microwave method despite the good advantage of high drying speed has various disadvantages that makes its application for drying the seeds at an industry level impractical . In contrast, from the perspective of assessors, the oven method is more suitable in maintaining the quality of the dried seeds. According to the study carried out on modeling of the pistachio drying behavior, the Page model was the most suitable model for describing drying process of pistachio layers in the oven at 70, 80, 90 and 100 °C as well as microwave while the Wang and Singh model was selected as the most suitable model for describing the drying process of pistachio layers by sun drying method.

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