The Effects of Solar Drying Systems and Packaging Types on the Quality Indicators of Dried Pistachio Nuts

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Abstract

Introduction: Pistachio nuts are among the most popular nuts in the world. Some postharvest operations, such as drying and packaging could affect the final quality of the product. Therefore, the main objective of this study is to determine the most suitable packaging materials and drying methods for the safe storage of pistachios.

Materials and Methods: The effects of solar drying systems (methods I & II) and various types of packaging (Cellophane & Nylon) on the oxidative stability of pistachio oil were investigated. For this purpose, the peroxide value was evaluated at a 45-day interval at 25°C.

Results: It was shown that solar drying systems and packaging types had meaningful and significant effects ($p<0.05$) on the hydro-peroxide forming of pistachio oil. According to the results obtained, the peroxide value was higher in pistachios dried using method I and packaged in cellophane films under atmospheric conditions (containing 21% O_2+79% N_2). In addition, the lowest peroxide value was observed in the samples dried using method I and packaged in nylon under vacuum conditions (containing 0% O_2 + N_2).

Conclusion: According to the results, the drying of pistachios using method II and packaging them in nylon under vacuum conditions maintained the quality of pistachios better and extended their shelf life.

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1. Introduction

Pistachios (*Pistacia vera L.*) are cultivated mainly in Iran, Turkey, and USA and dried after harvest to produce tasty nuts. According to FAO statistics, Iran produced about 500,000 MT of pistachio nuts (approximately 45% of the world's total production) in 2012, which is important for its national economy (1). Although pistachio nuts are mainly produced for snack consumption, their kernels are utilized as major or minor ingredients in making butter, cakes, pastries, ice creams, and Persian candies (Gaz, Baghlava, and Ghotab) (2, 3). Since valuable unsaturated fatty acids (linoleic, linolenic, and oleic acids) form 50-60% of pistachio kernels, they have many health benefits, including the regulation of cholesterol levels and the moderation of cardiovascular diseases, with antioxidant properties because of their polyphenols and tocopherols (4, 5).

Proper harvesting and postharvest handling are the two key activities in achieving a maximum yield of high-quality pistachio nuts, which improve marketability and profitability. Proper postharvest handling is a very important operation in producing pistachio nuts (6). Among the postharvest processing stages of this valuable crop, including handling, transportation, green-hull peeling, washing, dehydrating, grading, storing, and packaging, drying is the most important process for producing high-quality pistachios. Improper pistachio drying causes severe qualitative and quantitative damage to the produced nuts and reduces their market value considerably (7). The moisture content of harvested pistachios after green hull removal is about 40-50% (wet basis) based on the date and climatic location. However, their moisture should be reduced to less than 5% so as to protect their organoleptic and nutritional values during storage and distribution phases (8). Usually, industrial and traditional methods, i.e. shade and sunlight, are used to dry pistachio nuts in Iran. Traditional pistachio drying is a very slow process, which usually takes 2-3 days depending on weather conditions. In addition, it is not easy to control its final moisture content because of the contamination of the nuts with dust, dirt, rain, animals, birds, rodents, insects, and microorganisms. Therefore, a relatively low-quality product is obtained after drying. In contrast, industrial drying requires high processing costs and causes greenhouse gas emissions especially CO_2 because of burning fossil fuels and consuming significant amounts of energy to heat and move the air flow (9, 10). Additionally, it uses high temperatures (about 90^{o}C), which affect the sensory attributes of the good flavor of fresh pistachio nuts and generate a roasted taste. Solar drying could be used as a safer and more efficient preservation method than industrial and traditional drying methods. It improves the quality of the final product, reduces production costs, and generates no greenhouse gases, which damage the global environment (11). Few studies have been recorded in scientific literature on the solar drying of pistachio nuts. Mokhtarian *et al* (3) studied the effects of solar drying along with an air recycling system on the physicochemical and sensory properties of dehydrated pistachio nuts. The results showed that solar drying with an air recycling system (SDARS) had the lowest shrinkage rate and the highest drying, shell splitting (70% more than shade drying), bulk density, and kernel density rates among all other Methods. Pistachios dried using method SDARS were sweetest with the best roasting flavor among those dried by other methods, because of the higher drying rate. Kouchakzadeh (12) reported that the use of a combination of solar energy and acoustic energy in drying pistachios lowered processing costs (because of using renewable energy) and the dehydration time by four hours. Ghazanfari *et al* (13) used a thin layer forced air solar drier for drying pistachio nuts, which increased the ambient air temperature from 20 to 56^{o}C. Although they recorded a longer drying time than the conventional heated air drying time, their drying time and final quality were shorter and much better than the ones in sun drying, respectively. Midilli (14) dried pistachio nuts in 6 hours using a solar drying method with no air recycling system. However, he had to use an auxiliary heater and raise the air temperature to above 50^{o}C.

Fat oxidation is one of the main factors causing quality loss in pistachios, which changes the nutritional and organoleptic properties of this product during the storage period (2). Since pistachio kernels have high oil content (45-57%) and are a particularly good source of unsaturated fatty acids, such as oleic, linoleic, and linolenic acids, they are highly susceptible to oxidation. According to the findings of Tavakolipour *et al* (2), fat oxidation takes place in pistachio nuts by different mechanisms during the storage stage, namely photo-oxidation, auto-oxidation, and oxidation by lipoxygenase enzymes. In all fat oxidation mechanisms occurring in pistachio nuts, oxygen plays a key role. Therefore, removing atmospheric oxygen from a fatty or food product exerts a protective effect. Suitable packaging and adequate storage are crucial in preserving the organoleptic and nutritional properties of this product. Moreover, it is important to protect the kernels from molds and insects, such as *Plodia interpunctella* (Hubner) (15). In contrast to other food products, research on the storage stability of pistachio nuts is very limited. Tavakolipour (7) investigated the effects of different kinds of packaging materials, such as transparent cellulose and nylon, on the peroxide value of pistachio nuts. According to his results, nylon under vacuum conditions is the best packaging option for pistachio nuts among other packaging materials studied in this research. Shakerardekani and Karim (16) evaluated the effects of different types of flexible packaging films (LDPE, PVC, LDPE/PA, PA/PP, and PET) on the moisture and aflatoxin contents of pistachio nuts during the storage period at the ambient temperature (22-28°C) and relative humidity of 85-100%. Raei and Jafari (17) studied the effects of four packaging materials, including cellophane, two and three layers of plastic pouches, and metal cans on the quality attributes of pistachio nuts stored at two temperatures (ambient and 40°C) for one year. According to their results, the use of the two and three layers of plastic pouches resulted in higher quality attributes for the stored pistachios. Raei *et al* (18) investigated the effects of different packaging materials, including five layers of compound films, modified polypropylene, metalized plastic, and the packaging atmosphere on the quality of roasted pistachio nuts. The results showed that packaging pistachio nuts in metalized films and five-layer films with gases N2/CO2 gases under vacuum conditions maintained the quality of pistachios better and extended their shelf life.

For the above-mentioned reasons, it is necessary to find appropriate packaging materials and drying systems for protecting pistachio nuts against quality loss. Therefore, this study aims to find the most suitable packaging materials (among different types of flexible films available in the market) and drying conditions for extending the shelf-life of dried pistachio nuts.

2. Materials and Methods

2.1. Preparation of raw materials

The fresh famous pistachios of Kalle-Ghucchi variety (*Pistacia vera L.*) with the average moisture content of 37.17% (w.b.) were purchased daily from a local gardener. According to Mokhtarian *et al* (3), a Memmert hot air convective oven (model UNE 400 PA, Schwabach, Germany) was used for measuring the moisture content of pistachios at 105°C for 24 h. The harvested pistachios were de-hulled, cleaned, placed in sealed plastic containers, and stored in a refrigerator (Daewoo, FRS-2411S, Korea) at 3°C for about14 h. In addition, different chemicals were obtained from Germany Merck Co.

2.2. Drying process

To dry fresh peeled pistachios without green skin, different solar drying systems (conventional solar drying for method I and conventional solar drying with air recycling, for method II) were used. For this purpose, fresh peeled pistachios were conditioned to the room temperature and then dried by each of the drying methods. Table 1 shows the drying conditions of each method. Next, they were packed in sealed plastic containers and stored in a dark and dry place during night hours.

Table 1. Specification of different drying methods of pistachio nut

Parameter	Drying Method	
	MI*	MII**
Initial weight of fresh pistachio (kg)	4	4
Initial moisture content (%w.b.)	34.75	36
Final moisture content (%w.b.)	4.38	4.38
Bed thickness (cm)	~1.5	~1.5
Mass density (kg/m^2)	~2.71	~2.71
Average of solar radiation (W/m^2)	790	752
Average of drying air temperature (°C)	~40	~43
Average of drying air RH (%)	~16	~11.5***

(*) Conventional solar drying, and (**) Conventional solar drying along with heated air circulation.
(***) In this method, when the RH of the output air from the drying chamber (sensed by electronic controlling unit) dropped to≤ 15% (after about 2 h of drying), the air recycling was started.

It should be noted that the drying process continued until the final moisture content of the dried pistachios reached about 4 %W.B. Pistachios in methods I and II were dried every day from 8:00 AM to 6:00 PM continuously. All experiments were carried from September 20 to 30, 2014. The latitude and longitude of the experimental location were 36° 13´N and 57° 37´E, respectively.

2.3. Solar dryer specifications

The solar system (according to Fig. 1) had two porous flat plate collectors (primary and secondary ones), a drying chamber with two trays, a centrifugal fan, an output damper for adjusting the amount of air dried for circulation or exhausting, fittings and connection pipes, as well as an electrical controlling system. The body of the primary solar collector was made of a white galvanized sheet 0.5 mm thick, with its external dimensions having been 1.98 m (long)×1 m (wide)×0.22 m (high). The bottom and sides of both collectors were insulated with 3 cm thick glass wool to minimize heat loss. The collector had a transparent glass cover 4 mm thick.

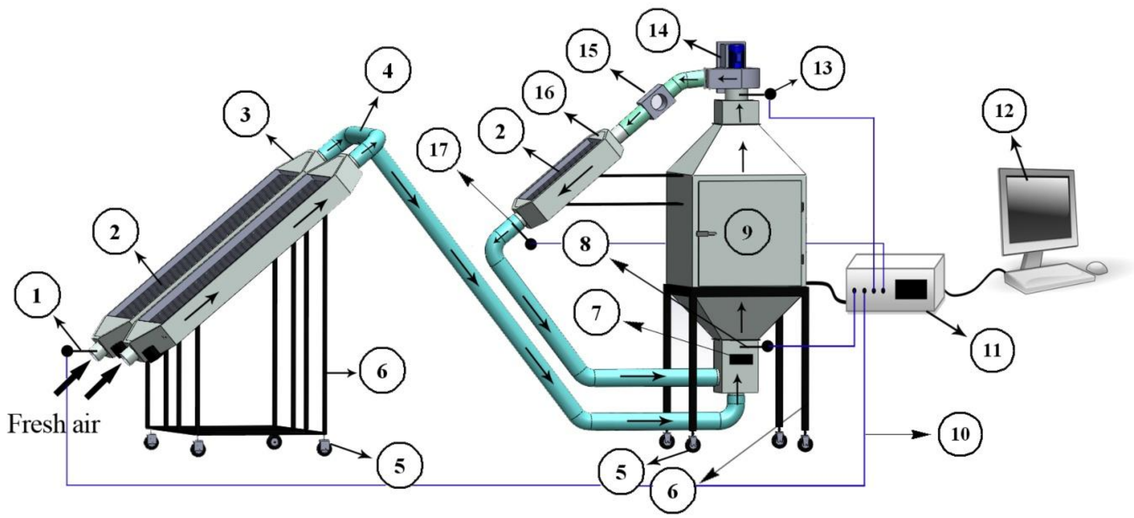


Fig. 1. The actual view of drying system: (1) T & RH sensors for controlling inlet air in primary solar collector, (2) heat absorber plate, (3) primary solar collector, (4) connecting pipes and fittings, (5) moving wheels, (6) stands for holding primary solar collector & drying chamber, (7) auxiliary electrical heater for night time and cloudy days, (8) T & RH sensors for controlling inlet air in drying chamber, (9) drying chamber with two perforated plates inside, (10) wire connection between the sensors and data logger, (11) data logger for continuous recording of T & RH at different points, (12) computer for connecting different sensors to the LabVIEW program, (13) T & RH sensors for controlling outlet air, (14) centrifugal fan, (15) outlet air damper, (16) secondary solar collector, and (17) T & RH sensors for controlling outlet air of secondary solar collector.

A black-painted aluminum porous plate 1.1 mm thick was inserted below the glass cover of each collector to improve the heat absorption of solar radiation. The heat absorber plates had circular holes (d= 2 mm) spaced 1 cm away from each other. The external dimensions of the secondary collector were 0.805 m (long)×0.55 m (wide)×0.22 m (high). To receive the maximum heat energy of sun radiation, the solar collector was faced inclined to the south at an angle of 40^o, which was selected according to the pistachio harvest season.

The external body of the drying chamber was made of a black iron sheet 3 mm thick. The external dimensions were 1 m (long)×1 m (wide)×1 m (high). In addition, the inner sides of the drying chamber were coated with a white galvanized sheet 0.6 mm thick to prevent rusting. The outsides of the drying chamber were insulated with glass wool 3 cm thick to decrease the heat transfer rate and minimize heat loss. Two constructed trays of 0.88 m (long)×0.84 m (wide)×0.04 m (high) were inserted in the drying chamber and covered with a monolayer of fresh and peeled pistachios. A backward curved and closed-type centrifugal fan was installed to provide enough air flow inside the drying chamber.

2.4. Packaging and storage conditions

After drying fresh pistachio nuts with two solar drying systems, two packaging materials, including cellophane and nylon were used for product packaging under atmospheric (at the presence of 21% O_2 & 79% N_2) and vacuum (at the presence of 0% O_2 & N_2) conditions at the ambient temperature of (about 25°C). Next, each dry pistachio nut (about 200 g) was placed in one package. The samples were placed in cellophane films and packaged under atmospheric conditions (T=25^{o}C and P_{sur}= 90.118 kPa). In addition, about 400 g of dried pistachio nuts were divided in two groups, with half of them placed in nylon under atmospheric conditions and another half packaged under vacuum conditions. In the end, the adequate number of each type of packages was stored at about 25°C for an 8-month storage period. To evaluate the quality index of the packed product, one package of each type of packages was selected (at a 45-day interval), and then the samples were de-hulled and ground for future examinations. It is noteworthy that a coffee grinder (Black and Decker Co., London, UK) was used for about 30 s to grind the dried pistachio kernels until their average particle sizes, as measured by a Vernier Caliper, reached about 250 μm (2, 7).

2.5. Assessing peroxide values of pistachio oil during storage

A mixed chloroform/methanol solvent (2:1 v/v) was used to extract ground pistachio oil at <20^{o}C in a relatively dark environment. A rotary evaporator (Laboratorium-Technic AG, Swiss) was used for separating the solvent portion of pistachio oil at 40^{o}C under vacuum conditions (under the negative pressure of about 0.1 MPa). Iodometric titration was used to measure the peroxide values of pistachio oil during storage (4).

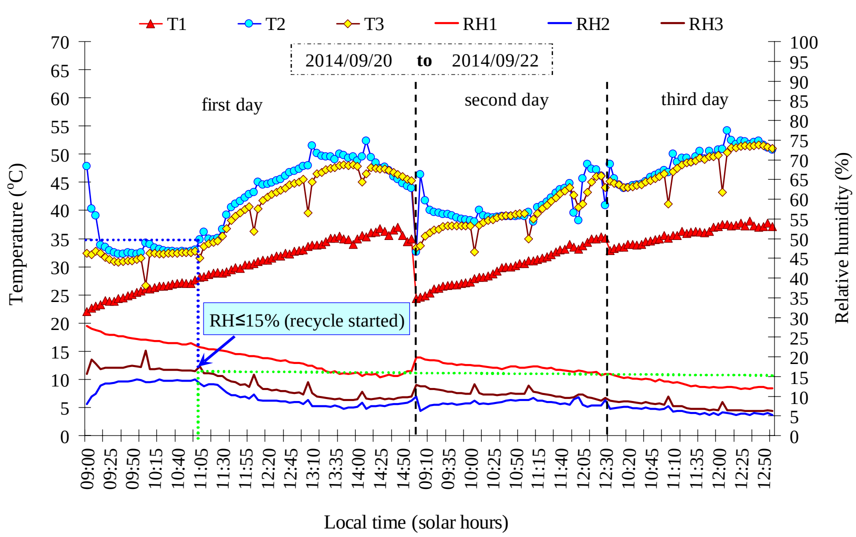
2.6. Statistical analysis

Statistix (statistical software version 8) was used to perform analysis of variance (ANOVA) for the recorded data obtained from the three replicates. In addition, the means of different treatments were compared using the least significant difference (LSD) test at the confidence level of 95%.

3. Results

3.1. Climate conditions and drying kinetics behavior

Changes in the drying air temperature and relative humidity during the drying process of pistachio nuts were monitored by the sensors of the installation air temperature and relative humidity in three parts of the solar drying system, including solar collector input air (the surrounding air temperature), solar collector output air (drying chamber input air), and drying chamber output air. Fig. 2 shows variations in the drying air temperature and relative humidity in different drying modes (methods I and II). According to the results, the drying air temperature changed in different drying modes and increased gradually from morning to afternoon. It reached the maximum value at about 1:00 pm due to the direct sun drying heat. The results show that the maximum, minimum, and mean values of the ambient air temperature for methods I and II were (38.1, 22, and 31.52°C) and (37, 27.5, and 32.1°C), respectively. In addition, the maximum, minimum, and mean values of the air temperature for the primary solar collector and the drying chamber output for methods I and II were (47.10, 30.70, and 40.03°C) and (45.40, 31.50, and 39.48°C) as well as (54.2, 32.3, and 42.99°C) and (51.6, 26.7, and 41.28°C), respectively. The comparison of the collector input and output air temperature showed that the solar collector was able to increase the ambient air temperature to 11.47°C and 7.94°C for methods I and II, respectively.



(b)

Fig. 2. Variation of the climate conditions at different pistachio drying modes: (a) Method I and (b) Method II (T_1: collector input air temperature, T_2; drying chamber input air temperature, T_3; drying chamber output air temperature, RH_1; collector input relative humidity, RH_2; drying chamber input relative humidity and RH_3: drying chamber output relative humidity).

Variations in the moisture content of pistachio nuts in various drying modes have been presented in Fig. 3. As it can be seen, the descending trend of the moisture content against the drying time is observed in both drying modes. The drying time for reaching the safe moisture content of less than 5% (w.b) in methods I and II was 16 and 13 h, respectively (Fig. 3). According to the results, the dehydration time in method II was about 23% less than that in method I. In another study, the lowest and highest pistachio drying rates were observed in method I and method II, respectively.

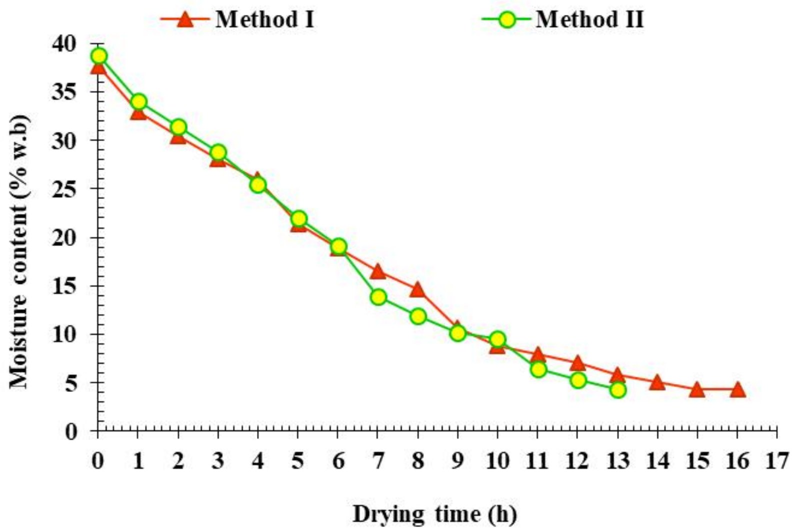


Fig. 3. The moisture reduction of pistachio nut versus dehydration time in different drying methods; conventional solar drying (Method I) and conventional solar drying along with heated air circulation (Method II).

3.2. Evaluation of the peroxide value

Fig. 4 shows variations in the peroxide value in pistachio lipid versus the storage time in different drying methods (methods I & II) and various packages (nylon & cellophane) at the ambient temperature during the storage period. The ANOVA results showed that different drying modes and packages had meaningful and significant effects ($p<0.05$) on the peroxide value in pistachio nuts (Fig. 4). As it can be seen, the increasing trend of the peroxide value has been observed in all treatments. In addition, pistachio nuts dried using method I had higher peroxide values than the samples in method II. According to the findings, pistachio nut samples packaged in cellophane films under atmospheric conditions (21% O_2 & 79% N_2 gases) showed the highest increase in the peroxide value; in contrast, samples packaged in nylon under vacuum conditions (0% O_2 & N_2 gases) showed the lowest increase in the peroxide value.

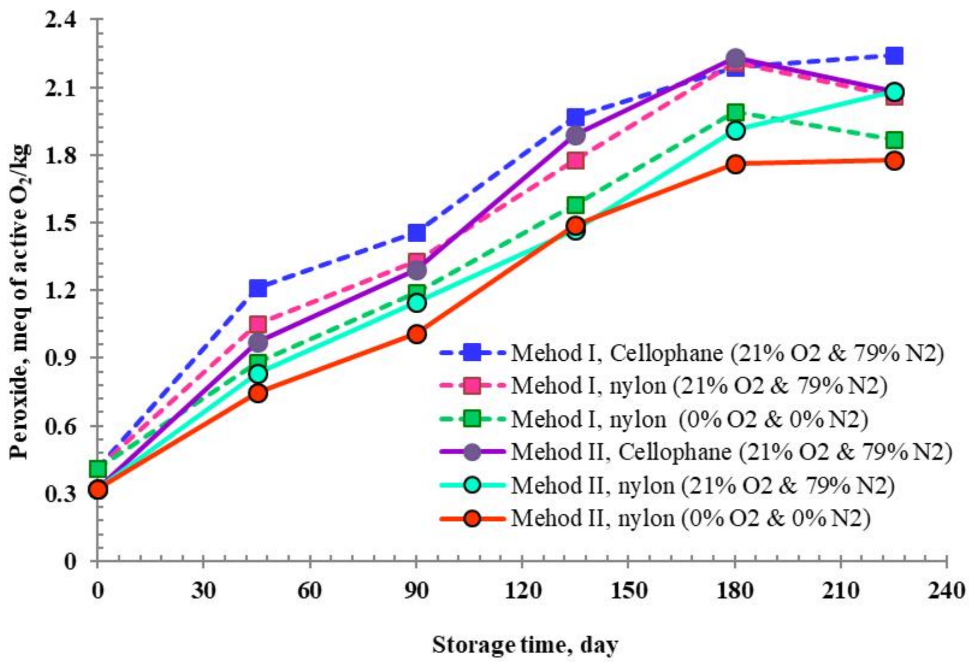


Fig. 4. The effect of solar drying systems (Method I & II) and packaging materials (cellophane & nylon under different atmospheric conditions) on peroxide value of pistachio nut during storage

4. Discussion

4.1. Climate conditions and drying kinetics behavior

In this study, the effects of solar drying systems (methods I and II) on the drying process of pistachio nuts were investigated. According to the results, the collector air temperature and the absorber temperature increased at the beginning of the drying process with an increase in solar radiation, yet they reached a peak in the noon (about1:00 pm) and then decreased at a slower rate in the afternoon. During the drying period, the average collector output air temperature in methods I and II was 40.03°C and 42.99°C, respectively, which were about 9°C and 11°C above the average ambient temperature, respectively. Elkhadraoui *et al* (19) studied a new mixed-mode solar greenhouse dryer for drying red peppers and grapes in September in 2013. The ambient air temperature was recorded within the range of 21.25-35.71°C. The outlet drying air temperature of the solar collector and the temperature inside the greenhouse were (27.87 to 54.68°C) and (29.21 to 49.88°C), respectively. Fudholi *et al* (20) carried out energy and exergy analyses for the solar drying of red chili. The daily mean values of the drying chamber air temperature, drying chamber relative humidity, and solar radiation ranged from (28°C to 55°C), (18 to 74%), and (104 to 820 W/m^2), respectively, with the corresponding average values of 45°C, 30%, and 420 W/m^2. Amer *et al* (21) studied a new hybrid solar dryer for banana drying. They observed that under Mid-European summer conditions, the drying air temperature raised from 30 to 40°C above the ambient temperature. Hossain *et al* (22) evaluated a hybrid-type solar dryer for tomato drying. The results demonstrated that the mean value of the collector outlet air temperature in all drying modes was about 30°C above the ambient temperature. Midilli (14) studied the drying behavior of pistachios in a forced convection solar dryer. The drying air temperature and the ambient temperature were recorded within the range of 40-60°C and 21-32°C, respectively. In general, the results of these studies showed that variations in the drying air temperature only depended on solar radiation and the ambient air temperature.

As stated previously, the drying time of method II (13 h) was 23% less than that of method I (16 h). Kashaninejad *et al* (23) spent 11 h at 55°C to reduce the initial moisture content of pistachios from about 37% (w.b) to about 5% (w.b) using an electrical heater. In contrast, our results showed that the solar drying of pistachios using air recycling dried pistachios at temperatures lower than 45°C and reduced their moisture content from 40% to less than 5% within 13 h, with higher quality and most probably less energy. Gazor and Minaei (24) dried pistachios within the temperature range of 80-90°C to reduce their moisture content from about 40 to 50% of the wet basis within 6 h. They reported that the peroxide value increased during storage, indicating their rancidity. The air recycling system exerts some effects on the drying time in the solar drying of nuts. Tavakolipour (7) reported that the time required for the drying of various Kerman pistachio nuts in monolayer thickness culture at 50oC and the velocity of 1 m/s was about 5 h.

4.2. Evaluation of the peroxide value

Fig. 4 shows peroxide value changes in various drying methods and packages at the ambient temperature during the storage period. Peroxide is the first chemical compound produced after the oxidation of fats and oils. When peroxides reach a certain value, different reactions occur. According to the results, the oxidation of fatty acid molecules and the forming of hydro-peroxides were higher in pistachio nuts dried using method I than in the samples dried using method II, mainly due to the longer drying time in method I (Fig. 3). Furthermore, the highest peroxide value was obtained in pistachio nut samples packaged in cellophane films under atmospheric conditions (21% O_2 & 79% N_2) and dried using method I. The highest increase in the peroxide value in pistachio nut samples packaged in cellophane films among other packages refers to the higher permeability coefficient of cellophane films than that of O_2 and their higher access to oxygen than vacuum packaging (7). Some researchers have used other packages; for example, they packaged pistachio nuts in metalized five-layer films with gases N2/CO2 gases under vacuum conditions, which maintained the quality of pistachios better and extended their shelf life. In a research, authors reported that two- and three-layer plastic pouches resulted in higher quality attributes for stored pistachios (17, 18).

5. Conclusions

The following conclusions are drawn from this research:

- Regarding the effects of different drying modes (methods I & II) on the quality index of pistachio nuts, it was observed that the peroxide value was higher in method I with significant effects.

- The results indicated that the storage period had meaningful and significant effects on the formation of hydro-peroxides so that the highest value of peroxides was observed almost at the end of the storage time, i.e. after about 6 months.

- The effects of various types of packaging on the quality of pistachio nuts indicated that different packages had significant effects on the quality index of pistachio nuts. It was also found out that nylon under vacuum conditions (0% O_2 & N_2) was the best packaging material for pistachio nuts.

Conflict of interest

The authors declare that there is no conflict of interests regarding the publication of this article.

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