



ORIGINAL ARTICLE

Studying the Effect of Cultivars and Storage Time on Oxidative Parameters of Pistachio Oil through Response Curves

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ABSTRACT

Pistachio oil is golden yellow or greenish yellow in color, contains a variety of beneficial fatty acids and is obtained from pistachio kernel extract, which has numerous nutritional value and therapeutic properties. Therefore, pistachio oil is one of the best and healthiest vegetable oils as a strategic product. In order to investigate the effect of shelf life on the chemical properties of pistachio varieties through the response curve, a factorial experiment was conducted with two factors. The first factor was the shelf life of the oil after extraction at four levels (first day 40, 20 and 60 days) and the second factor was the pistachio varieties at three levels (Akbari, Shah Pasand and Badami) in a completely randomized design with three replications. In this experiment, after obtaining fresh pistachios from the garden and taking necessary steps such as separating the skin and drying under the same conditions and extracting the oil, the chemical properties of pistachio oil compounds such as iodine, peroxide, acidic, antioxidant, etc. were evaluated. After collecting the data, the data obtained from the experiment were analyzed by the statistical software SAS_{9.3} and the mean comparison was performed by Duncan's multiple range test at a probability level of 5%. Also, the trend of the response curve was used to examine the relationship between the shelf life and the characteristics under study, and the Pearson correlation coefficient was used to determine the relationships between the traits, and Excel software was used to draw the graph. The results of the analysis of variance showed that the effect of pistachio varieties, shelf life, and the dual interaction of pistachio varieties × shelf life on the acid, peroxide, and antioxidant indices was significant at a probability level of 1%. However, on the iodine index, only the dual interaction of pistachio varieties × shelf life was significant at a probability level of 1%. The trend of the response curves showed that with increasing shelf life, the antioxidant index decreases and the acid and peroxide indices increase, which leads to a decrease in oil quality if the necessary standards are not met.

Introduction

Pistachio, with the scientific name *Pistacia vera*, belongs to the Anacardiaceae family (Nazoori *et al.*, 2022). Pistachio is a perennial, dioecious and diploid

plant (2n=30), this family consists of 75 genera and 600 species (Rajabi *et al.*, 2025; Hosseini *et al.*, 2022). According to the Agricultural Statistics (2023),

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the special position of pistachios in Iran has caused their cultivated area to reach about 600 thousand hectares. This amount of cultivated area indicates the increasing level of this product in the agricultural economy of Iran. Overall, the statistics show a significant growth in the cultivated area and production of pistachios in Iran in recent years. This has doubled the importance of this strategic product in the agricultural economy of Iran and has attracted more attention to it. Given that in 2023, pistachio production in Iran was about 440 thousand tons, attention should be paid to the processing of quality products from pistachios (Agricultural Statistics., 2023). Pistachio oil is a valuable vegetable oil due to its nutritional properties and pleasant taste. It contains unsaturated fatty acids, vitamins, and antioxidants that are beneficial for human health (Nazoori *et al.*, 2024; Laei, 2021; Sharifkhah *et al.*, 2020).

Pistachios are one of the most popular edible nuts and a good source of oil in the world (Satil *et al.*, 2003). Pistachio oil is a golden yellow or greenish yellow oil extracted from pistachio kernels. Pistachio kernels contain approximately 40 to 60 percent oil, depending on the variety and environmental conditions, and contain a variety of beneficial fatty acids obtained from pistachio kernel extract, which has numerous nutritional and therapeutic properties (Ashaninejad *et al.*, 2006; Roozban *et al.*, 2006). This vegetable oil is also used as a flavoring in foods, juices, soups, and most salads. It can also be mixed with vinegar and honey, creating a very desirable flavor (Shaker Ardakani, 2017). However, pistachio oil, like other vegetable oils, is subject to spoilage and quality changes during storage. These changes can lead to a decrease in the nutritional value and an unpleasant taste of the oil.

One of the food additives is oils, which have a high consumption in the daily diet. The process of oxidation and oxidative degradation, which leads to off-flavor, reduction in quality and loss of nutritional value of oils and fats, is considered one of the most important problems in the oil industry (Habibi *et al.*,

2022). Antioxidants are compounds that delay the development of off-flavor and spoilage of oils and fats by extending their shelf life (Yanishlieva-Maslarova, 2001).

Hashemi *et al.* (2007) in a study titled "Extraction of pistachio oil and investigation of its qualitative properties under storage and packaging conditions" explained the storage conditions of pistachio oil. In this regard, roasted pistachios of the Ohadi variety were tested in terms of thiobarbituric index, free fatty acids, and induction time. In this experiment, four factors were tested: packaging material at three levels (metallized film, 5-layer composite film, OPP), packaging conditions at four levels (nitrogen and carbon dioxide gases, vacuum, and air), temperature at two levels (temperature, 20, and 40 degrees Celsius), and time at four levels (time periods of zero, 3, 6, and 9 months). Finally, they reported that metallized and 5-layer films had a greater effect on preserving the quality of pistachios than OPP films due to their light-blocking properties, preventing the intensification of autoxidation reactions. Also, in a study by Shakerdakani and Rahdari (2020), they stated that time affects the quality of fats in pistachios.

Nikzadeh and Sedaghat (2008) reported that "the effects of roasting temperature, formulation, and storage time are effective on the quality characteristics of pistachio oil and its organoleptic properties." Chemical tests including measuring peroxide index, thiobarbituric acid index, and free fatty acid, as well as sensory tests including pungency and overall acceptance, were performed on the samples during 3 months of storage. The percentage of free fatty acid, peroxide index, thiobarbituric acid index, and pungency in all the samples studied increased over time. During the storage period, pistachios with salt alone and no additives had higher peroxide index, thiobarbituric acid index, and free fatty acid than other formulations, and their overall acceptance was lower than the others.

Mazinani *et al.* (2011) in a study titled "Evaluation of thermal stability, antioxidant properties

of phenolic compounds and fatty acid profile in oil obtained from edible nuts (pistachio, walnut and almond)" investigated some properties of oil obtained from three edible nuts, walnut, almond and pistachio, with Damavand and Ahmad Aghaei cultivars, respectively, with 4% excellence. In the evaluation of oxidative stability by oven method, pistachio oil had the highest stability, followed by almond and walnut oils, respectively. Dini *et al.* (2016) in a study evaluating the resistance to oxidation and predicting the storage life of five pistachio varieties including Baneh, Ahmad Aghaei, Kaleh Ghouchi, Akbari and Fandoghi pistachio, using a rancimet, studied oxidation and the effect of chemical properties on thermal stability and concluded that the fatty acid composition and high antioxidant content are the most important factors for the high resistance of wild pistachio peel and kernel oil and the reason for its longer shelf life compared to commercial varieties. Among commercial pistachio varieties, the Ahmad Aghaei variety is suitable for oil extraction and high-heat processes such as roasting.

Daneshmandi *et al.* (2011) conducted a study on the identification and investigation of fatty acids, antioxidants, and oil peroxide in Daneshmandi pistachio and its comparison with some dominant cultivars in Khorasan Province. They investigated some important biochemical characteristics of pistachio oil, Daneshmandi cultivar, with three dominant cultivars in Khorasan Province (Badami Sefid, Kalle Ghochi, and Akbari). The desired traits included oil percentage, amount and type of saturated and unsaturated fatty acids, total polyphenols, total tocopherol, peroxide value, and acid value. The results showed that Daneshmandi cultivar had the highest oil percentage, the highest ratio of unsaturated to saturated fatty acids, and the lowest peroxide value. However, it was ranked second in terms of antioxidant content (tocopherol and total polyphenols) compared to other cultivars. According to the results obtained, Daneshmandi pistachio had the lowest acid value, and Kalle Ghochi had the highest value.

Ghiyathvand and Nateghi (2014) in their study of the physicochemical properties and fatty acid composition of Qazvin pistachio kernel oil in three varieties: Khandan, Badami, and Shamshiri, stated that the fat content in Khandan, Badami, and Shamshiri varieties was 53.32, 56.42 and 57.99 percent, respectively, and their iodine number was 88.95, 84.12, and 92.84, respectively, and their soap number was 192.03, 192.4, and 190.56, respectively.

Abdolshahi *et al.* (2015) evaluated the fatty acid composition and heat resistance of oil of Damghan pistachio cultivars. Their studies showed that the most important commercial Damghan pistachio cultivars include: Akbari, Kaleh Ghochi, Khanjari, Abbasali and Shah Pasand. Their results showed that the fat content of pistachio cultivars is in the range of 52.48-60.64%.

Esmaili *et al.* (2013) studied the effect of different packaging on the oxidative stability of pistachio oil. The results indicated that: One of the effective strategies in reducing adverse reactions in food, especially oils, is the selection of appropriate packaging, which can prevent internal, external and oxidative spoilage factors and increase shelf life.

Maghsoudi (2010) also studied the chemical structure of pistachios and the compounds related to pistachio oil, and Shaker Ardakani (2017) explained the characteristics of pistachio oil and its properties, and introduced pistachio oil as a desirable oil. Fazli Aghdaei (2013) also positively evaluated the effect of the type of roasting process on the oxidative stability, antioxidant properties, and physicochemical properties of the oil obtained from two varieties of domestic and wild pistachios. Jalili (2008) stated that the rancidity of fats is due to oxidation and the creation of acidic and aldehyde factors in fats.

The aim of this study was to investigate the effect of storage time on the chemical properties of pistachio oil through designed and implemented response curves.

Materials and Methods

In order to investigate the effect of storage time on the chemical properties of pistachio oil varieties, a factorial experiment was conducted with two factors, the first factor being the storage time after oil extraction at four levels (beginning of oil extraction, 20, 40, and 60 days) and the second factor being the pistachio varieties including Akbari, Shah Pasand, and Badami, in a completely randomized design with three replications in the Food Industry Laboratory of Islamic Azad University, Damghan Branch. After preparing fresh pistachios from the varieties under study and separating the green skin and drying them under the same conditions, the kernel was then separated from the bone skin. Finally, the oil was extracted from the pistachio kernels using a cold-press oil extraction machine and also by laboratory method using the Soxhlet (Sweden) method (Soxtec 2050). Finally, after applying the desired treatments in this experiment, the chemical properties of pistachio oil compounds such as iodine index, peroxide index, antioxidant index, acid index were evaluated based on the AOAC (Association of Official Analytical Chemists) standard, etc.

Statistical analysis

After collecting information, the data from the experiment were analyzed using SAS9.3 statistical software. Analysis of variance and comparison of means were performed using Duncan's multiple range

test at a probability level of 5%. Also, the response curve trend was used to investigate the relationship between the shelf life after oil extraction and the characteristics under study. Pearson's correlation coefficient was used to determine the relationships between the characteristics, and Excel software was used to draw the graph.

Results

Acidity index

Analysis of variance (Table 1) showed that the effect of pistachio cultivars, shelf life, and the two-way interaction of pistachio cultivars $\times$ shelf life on the acid index was significant at the 1% probability level.

The comparison of the average effect of pistachio cultivars showed that the highest acid index in Shah Pasand pistachio cultivar was 0.64 mg KOH/gr and the lowest acid index in Badami pistachio cultivar was 0.30 mg KOH/gr and the acid index in Akbari pistachio cultivar was 0.52 was mg KOH/gr (Fig.1).

The acid index in the Badami pistachio variety was 34% lower than that in the Shah Pasand variety. Similarly, the acid index in the Akbari variety was 12% lower than in Shah Pasand. This indicates that the oil quality of the Badami variety is better than that of the Akbari and Shah Pasand varieties, primarily due to its lower acid index.

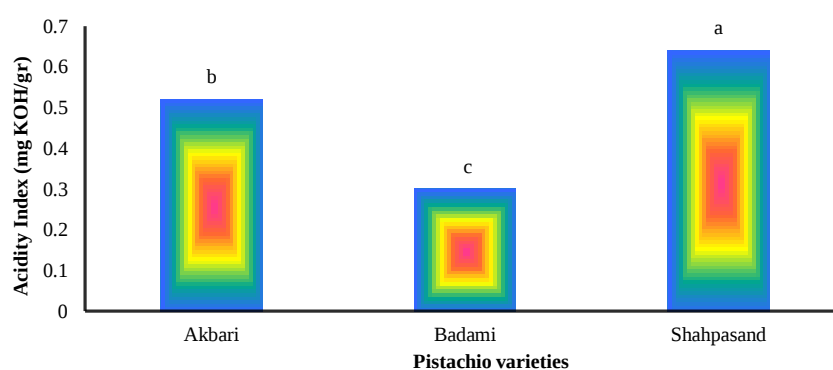


Fig. 1. Effect of cultivars on the acid index of pistachio oil

Therefore, based on this study, it can be seen that the Shah Pasand variety oil has a higher acidity than the Badami and Akbari varieties. Comparison of the average effect of oil storage time showed that the highest acid index was 0.55 mg KOH/gr at 60 days after oil extraction, although there was no statistically significant difference between 20 and 40 days after oil extraction, and the lowest acid index was 0.33 mg KOH/gr on the same day of oil extraction. Therefore, it can be seen that the acid index increases with increasing storage time, which leads to a decrease in the quality of pistachio oil (Table 2).

As storage time increased, the acid index also increased. This highlights the need for measures to be implemented early to maintain oil quality and prevent a rise in the acid index. Analysis of variance of the response curves showed that the linear and quadratic models were significant at the one percent probability

level, but the cubic model was not significant. Out of 100 percent of the changes, 77% of the model was linear, 19% of the model was quadratic, and 4% was cubic (Table 1).

The general model of the equation is $y = -9E-05x^2 + 0.0083x + 0.357$. Given the high percentage of the linear model and the regression coefficient ($y = 0.0031x + 0.392$), it can be concluded that the acid index increases by 0.0031 mg KOH/gr with each additional day of shelf life. Furthermore, the coefficient of determination ($R^2 = 0.77$) indicates that 77% of the changes in the acid index are influenced by shelf life, while the remaining 33% are due to unknown factors (Fig. 2). Therefore, with the increase in the length of storage time, if the necessary standards are not observed in pistachio oil, the quality of pistachio oil decreases and may lead to unpleasant odor and taste and food poisoning.

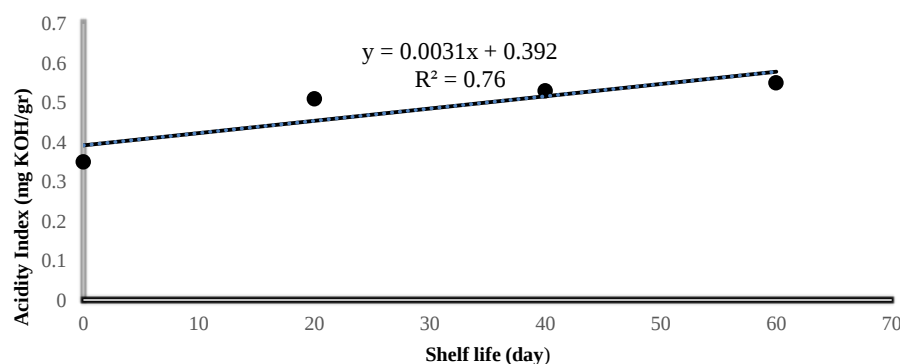


Fig. 2 . Relationship between shelf life and acid index of pistachio oil

Comparison of the mean interaction of pistachio cultivars $\times$ oil storage time showed that the highest acid index in the Shah Pasand cultivar was 0.75 mg KOH/gr during the storage period of 20 days after oil extraction, and the lowest acid index in the Badami cultivar was 0.12 mg KOH/gr on the same day of oil extraction (Table 2). Acid number indicates the amount of free fatty acids in the oil. An increase in acid number during storage time indicates an increase in the amount of free fatty acids and, consequently, an increase in the rate of oil spoilage. This increase could

be due to hydrolysis reactions and triglyceride decomposition.

Iodine index

In chemistry, it is the amount of grams of iodine consumed by one hundred grams of a chemical substance. Iodine number is usually a measure of the number of unsaturated bonds in fatty acids. Unsaturated bonds are actually double bonds that react with iodine. A higher iodine number indicates a greater number of C=C bonds in a substance such as a fatty acid. Iodine index, along with factors such as

peroxide index, soap index, percentage of trans fatty acids and others, is of particular importance in controlling edible oils and fats. It is a measure of the degree of unsaturation of fatty acids, and therefore, in many cases, by measuring this index, the quality of the type of oil can be determined to some extent.

Analysis of variance (Table 1) showed that the double interaction effect of pistachio cultivar $\times$ storage time on the iodine index was significant at the 1% probability level. However, the main effect of pistachio cultivar and storage time on the iodine index was not significant. Comparison of the mean interaction effect of pistachio cultivar $\times$ storage time on the iodine index showed that the highest iodine index in the Akbari cultivar at a storage time of 20 days after oil extraction was 105.73 (gI/100g) and the lowest iodine index in the Badami cultivar at a storage time of 20 days after oil extraction was 94.13 (gI/100g) (Table 2).

Antioxidant index

Antioxidants are compounds that prevent the oxidation of oils and fats by donating hydrogen to free radicals formed during the initiation and propagation stages of oxidation. There are generally two types of antioxidants: natural and synthetic. Synthetic antioxidants are often added to edible oils and fats to inhibit oxidation during storage and frying. However, consumers do not have a favorable opinion of

synthetic antioxidants and consider them undesirable. Antioxidants, as workers against free radicals, can help in the prevention, repair, and cell damage caused by these radicals. In pistachio oil, due to the presence of chlorophyll and carotenoid pigments, which are lipid-soluble antioxidants, they prevent peroxidation, and the value of pistachio oil has been increased due to the soluble antioxidants in pistachio oil.

Analysis of variance (Table 1) showed that the effect of pistachio cultivars, shelf life and the interaction of pistachio cultivars $\times$ shelf life on the antioxidant index was significant at the 1% probability level.

Comparison of the mean effect of pistachio cultivars on the antioxidant index showed that the highest antioxidant index was in the Akbari cultivar at (mmole) 24.36 and the lowest antioxidant index was in the Shah Pasand cultivar at (mmole) 6.41, and in the Badami pistachio cultivar the peroxide index was (mmole) 7.82 (Fig. 3). Therefore, it can be seen that the antioxidant index in the Shah Pasand pistachio cultivar was 74% lower than the Akbari pistachio cultivar, and also the antioxidant index in the Badami pistachio cultivar was 68% lower than the Akbari pistachio cultivar, which indicates a better quality of oil in the Akbari pistachio cultivar than the oils of the Badami and Shah Pasand pistachio cultivars, and the reason for this is the high antioxidant index.

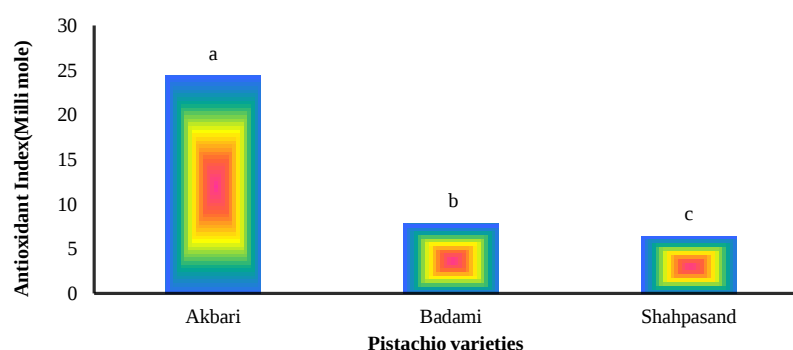


Fig. 3. Effect of cultivars on the Antioxidant Index of pistachio oil

the high antioxidant index prevents oxidation and results in relatively good stability of the oil. Comparison of the average effect of storage time on

Therefore, based on this study, it can be seen that Akbari variety oil has a higher antioxidant index than the two varieties of almond and Shahpasand. Because

the antioxidant index of the oil were in the linear model, 0.09% in the second-order model and 0.01% in the third-order model (Table 1). Therefore, the general model of the equation is $y = 1E-05x^3 - 0.0008x^2 - 0.1138x + 16.3$, which, considering the high percentage of the linear model, can be concluded, and considering the regression coefficient of the linear model ($y = -0.1082x + 16.113$), that with each day of increase in the shelf life, the antioxidant index of the oil decreases by -0.1082 M mole, and considering the coefficient of determination ($R^2 = 0.99$), it can be concluded that 99% of the changes in the antioxidant index of pistachio oil in this experiment were affected by the shelf life and 1% were affected by unknown factors (Fig. 4).

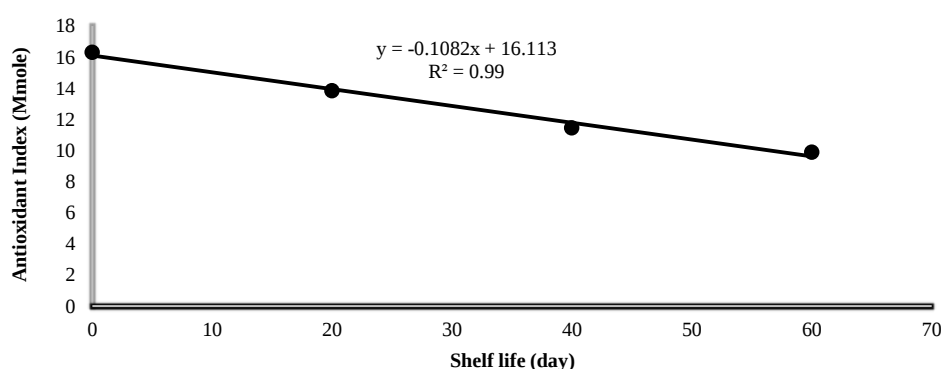


Fig. 4. Relationship between shelf life and antioxidant index of pistachio oil

Comparison of the mean of the two-way interaction of pistachio cultivars $\times$ storage time on the antioxidant index of pistachio oil showed that the highest antioxidant index was in the Akbari cultivar and on the first day after oil extraction at 28.5 mmol, and the lowest antioxidant index was in the Shah Pasand cultivar and on 60 days after oil extraction at 3.37 mmol (Table 2).

Peroxide index

Analysis of variance (Table 1) showed that the effect of pistachio varieties, shelf life, and the dual interaction of pistachio varieties $\times$ shelf life on the peroxide value was significant at the 1% probability level.

the antioxidant index showed that the highest antioxidant index was 16.3 mmol on the first day after oil extraction and the lowest antioxidant index was 9.88 mmol 60 days after oil extraction. Therefore, it can be seen that with increasing storage time, the antioxidant index decreases, which leads to a decrease in the quality of pistachio oil (Table 2).

Therefore, as the storage time of the oil in this experiment increased, the antioxidant index of the oil in this experiment decreased, which requires that necessary measures be taken from the very beginning to maintain quality and prevent the reduction of the antioxidant index. Analysis of variance of the response curves showed that the linear, second-order and third-order models were significant at the one percent probability level. That 99% of the changes in

Comparison of the average effect of pistachio cultivars on the peroxide index showed that the highest peroxide index in the Shah Pasand pistachio cultivar was 4.25 (meq O₂/Kg Oil) and the lowest peroxide index in the Badami pistachio cultivar was 1.09 (meq O₂/Kg Oil). In the Akbari pistachio cultivar, the peroxide index was 2.94 (meq O₂/Kg Oil). Therefore, it can be seen that the peroxide index in the Akbari pistachio cultivar was 31% lower than the Shah Pasand pistachio cultivar, and the peroxide index in the Badami pistachio cultivar was 74% lower than the Shah Pasand pistachio cultivar, which indicates a better quality of oil in the Badami pistachio cultivar than the oil of the Akbari and Shah Pasand pistachio cultivars. The reason for this is the

low peroxide index, which results in it aging later and

allows its quality to be maintained better (Fig. 5).

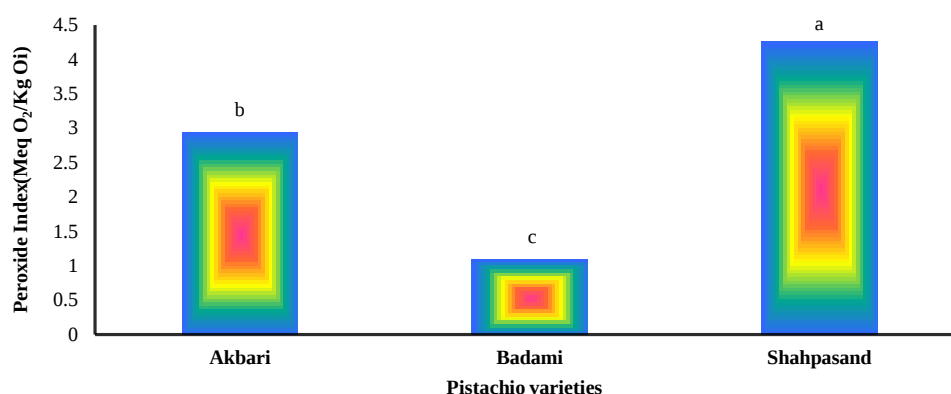


Fig. 5. Effect of cultivars on the Peroxide Index of pistachio oil

Comparison of the average effect of shelf life on the peroxide index showed that the highest peroxide index was 4.62 (meq O₂/Kg Oil) in 60 days after oiling and the lowest peroxide index was 1.30 (meq O₂/Kg Oil) in the first day after oiling (Table 2). Therefore, it can be seen that the peroxide index increases with increasing shelf life, that is, the rate of oxidation increases with increasing shelf life. Therefore, with increasing shelf life, the rate of oxidation in the oil increases and it is more exposed to oxidation and spoilage, which requires necessary measures to be taken in this regard to maintain quality and prevent oxidation. Analysis of variance of the response curves showed that the linear, second-order and third-order models were significant at the one

percent probability level, with 93% of the changes in the linear model, 2% in the second-order model and 5% in the third-order model (Table 1).

The general model is represented by the equation $y = -8E-05x^3 + 0.0078x^2 - 0.1377x + 1.5533$. Given the high percentage of the linear model and the regression coefficient, it is concluded that the rate of oil oxidation decreases by 0.059 meq O₂/Kg Oil with each additional day of shelf life. Considering the coefficient of determination ($R^2 = 0.93$), it is concluded that 93% of the changes in the rate of pistachio oil oxidation in this experiment are affected by the shelf life and 7% are affected by unknown factors (Fig. 6).

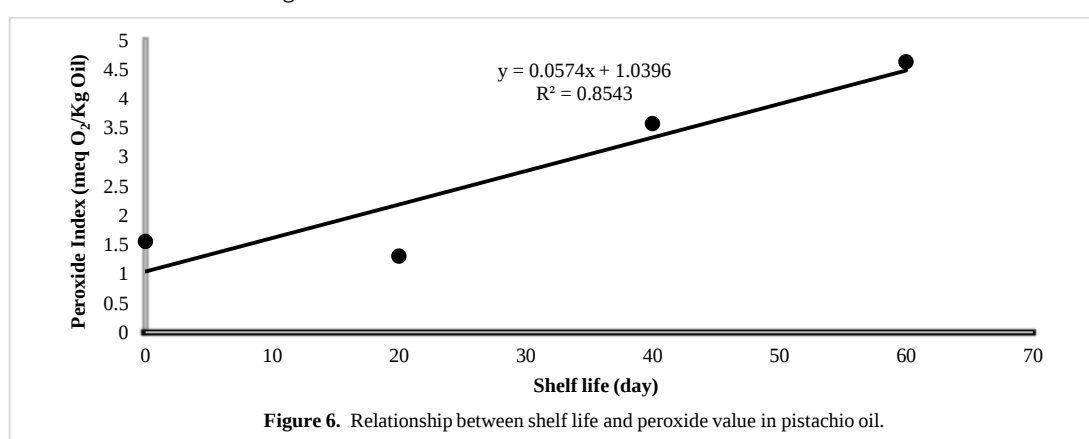


Figure 6. Relationship between shelf life and peroxide value in pistachio oil.

Comparison of the mean interaction effect of pistachio cultivars $\times$ storage time on the peroxide index showed that the highest peroxide index was in the Shah Pasand pistachio cultivar and at 60 days of

storage after oil extraction at 7.83 (meq O₂/Kg Oil), and the lowest peroxide index was in the Badami pistachio cultivar and on the first day after oil extraction at 0.83 (meq O₂/Kg Oil) (Table 2).

Table 1. Analysis of variance of the effect of time on the chemical properties of pistachio oil cultivars.

S.O.V	df	Sum of Squares			
		Acid index	Iodine index	Peroxide index	Antioxidant index
Variety	2	0.704**	24.831 ^{ns}	60.588**	2390.359**
Time	3	0.226**	34.501 ^{ns}	69.376**	212.674**
Linear	1	0.173**	11.145 ^{ns}	64.599**	210.665**
Quadratic	1	0.044**	7.317 ^{ns}	1.454**	1.782**
Cubic	1	0.009 ^{ns}	16.038 ^{ns}	3.323**	0.227**
Varity* Time	6	0.189**	312.857**	33.026**	24.731**
Error	24	0.060	200.000	0.022	0.060
Total	35	1.180	572.189	163.012	2627.825
Coeff Var		10.239	2.914	1.087	0.389

ns, * and ** insignificant and significant at the probability levels of 5% and 1%, respectively

Table 2. Comparison of the average effect of storage time on the chemical properties of pistachio oil of different varieties

Effect	Acidity Index (MgKOH/gr)		Iodine Index (Gi/ 100g)		Peroxide Index (Meq O ₂ /Kg Oil)		Antioxidant Index (Millimole)	
	Mean	Grouping	Mean	Grouping	Mean	Grouping	Mean	Grouping
Shelf Life								
First Day	0.35	b	97.573	a	1.55	c	16.3	a
20 Day	0.51	a	100.17	a	1.30	c	13.833	b
40day	0.53	a	98.873	a	3.56	b	11.457	c
60day	0.55	a	99.663	a	4.62	a	9.88	d
Interaction Of Shelf Life* Variety								
Akbari- First Day	0.33	ef	96.013	dc	1.34	g	28.5	a
Akbari-20day	0.54	bc	105.73	a	1.052	h	25.7	b
Akbari-40day	0.59	b	97.813	dbc	4.57	c	23.18	c
Akbari-60day	0.63	b	94.853	d	4.8	b	20.07	d
Badami- First Day	0.12	g	99.183	dbc	0.83	j	10	f
Badami-20day	0.25	f	94.133	d	0.96	i	8	g
Badami-40day	0.38	de	98.073	dbc	1.1	h	7.1	i
Badami-60day	0.46	dc	102.08	ab	1.47	f	6.2	j
Shahpasand- First Day	0.61	b	97.523	dbc	2.36	d	10.4	e
Shahpasand-20day	0.75	a	100.63	abc	2.02	e	7.8	h
Shahpasand-40day	0.63	b	100.73	abc	4.8	b	4.09	k
Shahpasand-60day	0.57	b	102.05	ab	7.83	a	3.37	l

According to duncan's multi-range test, the numbers with the same letters in each column do not have a significant difference

The correlation coefficient (Table 3) showed that the acid index was positive with the iodine index ($r=0.83^{**}$) and significant at the 1% probability level, and with the peroxide index ($r=0.65^*$) and significant at the 5% probability level, meaning that with an increase in the acid index, the iodine and peroxide indices increase, and vice versa, but with the

antioxidant index ($r=-0.90^{**}$) it was negative and significant at the 1% probability level, meaning that with an increase in the acid index, the antioxidant index decreases, and with a decrease in the antioxidant index, the peroxide rate increases, leading to rancidity and unpleasant odor, and ultimately a decrease in the quality of the oil.

Table 3. Correlation coefficient between the variables studied in pistachio oil under the influence of shelf life and cultivars

Variable	Acid Index	Iodine Index	Peroxide Index	Antioxidant Index	Weight of green skin	Bone skin	Brain	Water	Oil percentage	Meal
Acid Index	1.00									
Iodine Index	0.83 ^{**}	1.00								
Peroxide Index	0.65 [*]	0.21 ^{ns}	1.00							
Antioxidant Index	-0.90 ^{**}	-0.58 [*]	-0.91 ^{**}	1.00						
Weight of green skin	-.792 ^{**}	-0.21 ^{ns}	-.60 [*]	.94 ^{**}	1.00					
Bone skin	0.35 ^{ns}	-0.03 ^{ns}	0.23 ^{ns}	.94 ^{**}	-0.48	1.00				
Brain	.702 [*]	0.13 ^{ns}	0.52 ^{ns}	.94 ^{**}	-.90 ^{**}	.81 ^{**}	1.00			
Water	-0.30 ^{ns}	0.05 ^{ns}	-0.19 ^{ns}	-.91 ^{**}	0.42 ^{ns}	-.99 ^{**}	-.76 ^{**}	1.00		
Oil percentage	0.42 ^{ns}	0.23 ^{ns}	0.36 ^{ns}	-.84 ^{**}	-0.48 ^{ns}	-0.54 ^{ns}	0.07 ^{ns}	.59 [*]	1.00	
Meal	0.26 ^{ns}	-0.06 ^{ns}	0.16 ^{ns}	.94 ^{**}	-0.37 ^{ns}	.99 ^{**}	.72 ^{**}	-.99 ^{**}	-.63 [*]	1.00

ns, * and ** insignificant and significant at the probability levels of 5% and 1%, respectively

Discussion

The results of this study showed that the acid index of oil obtained from pistachio kernels is affected by the shelf life and pistachio varieties. Therefore, it can be said that the shelf life on the chemical properties of oil obtained from pistachio kernels in different varieties is different. In the study of Sedaghat *et al.* (2004), it was also reported that the acid index of pistachios increases with increasing temperature and storage time. Therefore, the results of this study are consistent with the results of Sedaghat *et al.* (2004). Robertson (2012) stated that the interaction of time and temperature is one of the important factors that affects the acid index oil and also stated that the most important factor that increases the acid index in foods is the presence of the lipase enzyme in the food environment, and this enzyme can be naturally Iodine index is a measure of

the unsaturation of edible oils and is determined based on the analysis of fatty acids. Therefore, according to the results this research, pistachio oil can be considered a stable oil. In addition, the presence of abundant unsaturated fatty acids in an oil can have an incredible effect on reducing blood lipids and reducing cardiovascular diseases (Nagendran 2000, Ozdemir 2001).

Beigi and Urzegar (2013) conducted an experiment to examine the iodine value of oils in some plants and reported the lowest value (84.12) and the highest value (104.16) respectively, which is consistent with their results.

The antioxidant index of the oil decreases with the increase of the storage period, if the necessary standards are not met in the pistachio oil, and ultimately it leads to the reduction of the quality of the

pistachio oil. Therefore, it can be concluded that over time, the antioxidant index of pistachio oil decreases, and as the antioxidant index decreases, its shelf life decreases, and the rate of oil spoilage may increase.

Tavakoli *et al.* (2009) stated that the reason for the high stability of base oil is due to its antioxidant compounds and it plays a role in oxidative stability. Gordon (2001) stated that oxidation in oils starts with the decomposition of fatty acids and leads to a decrease in natural antioxidants, nutritional value and sensory properties of the oil. Oxidation resistance is one of the important parameters in the qualitative evaluation of oils and fats, which is influenced by the composition of fatty acids of the oil and minor components, the most important of which are natural antioxidants such as polyphenols and vitamins of group E (Thiyam, 2006; Pakrah *et al.*, 2021). Free radicals play the main role in antioxidant. They form hydroxides and, as a result of further decomposition, secondary antioxidant products such as ketones and aldehydes are formed. The cause of an unpleasant or pungent nut flavor is due to improper storage of the nuts or their long-term storage (Kaijser, 2000). The results of the present study showed that the interaction effect of storage time and cultivars is effective on the antioxidant properties of pistachio oil and is consistent with the results of other researchers.

Hydroperoxides are the primary products of lipid oxidation, and in general, the higher the degree of unsaturation of oils, the more readily the oil or fatty substance is susceptible to oxidation. When the peroxide level reaches a certain level, various changes occur and volatile aldehyde and ketone substances are produced, which are effective in creating unpleasant odors and tastes of fatty substances (Athari *et al.*, 2021).

The purpose of determining the peroxide value of oil is to determine the quality of fat, examine oxidative spoilage, measure the amount of peroxide in the oil, and examine the aging of unsaturated oil, and the number of unsaturated fatty acids. It can also be said that in very old oil, hydroperoxides and other

substances such as acetone, aldehyde, and alcohol decompose, which results in an undesirable and inappropriate odor from the produced oil. In the early stages of the oxidation process, the amount of these compounds is low, but in the diffusion stage, the amount of hydroperoxides increases rapidly. At this stage, determining the peroxide index is a good indicator of the oxidation state of oils (Mohammadi *et al.* 2016). The results of this study are consistent with those of Mohammadi *et al.* (2016). Oxidation of fats negatively affects the aroma, flavor, color, and nutritional value of the product during storage (Alasalvar 2003).

Therefore, an increase in the peroxide index during storage time indicates an increase in the amount of peroxides and, consequently, an increase in the amount of oil spoilage. Therefore if storage standards are not maintained, prolonged storage can reduce the quality of pistachio oil, potentially resulting in unpleasant odors, tastes, and even food poisoning.

The results of the present study showed that the interaction of storage time and cultivars is effective on the peroxide index of pistachio oil. Sharma *et al.*, (2000) also found that when using TBHQ antioxidant while roasting Ballard nuts, the peroxide index of samples containing antioxidant was significantly lower than the control sample during 5 months (Alasalvar 2003). Ebrahiman *et al.*, (2024) stated in a study that in the absence of encapsulation, the peroxidation index of pistachio oil increases over time, which is consistent with the results of this study. According to the results of Pennat *et al.*, (2004), adding natural antioxidants to roasted peanuts will protect the product against oxidation during storage. Fat oxidation is one of the most important factors of spoilage and destruction of nutrients in it. Oxidative spoilage of oil causes unpleasant taste and aroma and partial or complete destruction of vitamins and other nutrients through chemical mediators in different stages of oxidation. Oxidized fat reacts with proteins and carbohydrates and causes significant changes in

the food (Mellemal, 2003). Nikzadeh and Sadaghat (2008) stated that the peroxide index increases with increasing storage time.

Fatemi *et al.*, (2024) stated that with increasing storage time of pistachios, the peroxidation index increases, and the results of this study are consistent with their results. Other researchers also stated that increasing time and temperature increases the oil peroxide index of pistachios (Tavakolipour, 2000). In a study, Mortazavi *et al.*, (2015) stated that time has a significant effect on increasing the amount of peroxidation, and the highest peroxide amount was related to pistachio oil on day 90 and the lowest peroxide amount was on the first day. Farhoosh (2008) reported the trend of changes in the level of peroxidation in a study of cold-pressed pistachio oil during three months of storage at room temperature and in the dark. Also, according to Labuza *et al* (1985), time and temperature are effective factors that aggravate spoilage in oil. Therefore, the results of this study are consistent with the aforementioned studies.

Conclusions

In the present study, the variables of acid index, iodine index, peroxide index, and oxidant index were investigated at four different times of the first day, 20, 40, and 60 days of storage on pistachio oil of Akbari, Badami, and Shah Pasand cultivars. The effect of storage time on acid index, peroxide index, and oxidant index was significant. Therefore, it can be stated that the length of storage time is effective on the quality of pistachio oil and if the necessary standards are not observed, it will reduce the quality of the oil. Also, the interaction effect of storage time and pistachio variety on acid index, peroxide index, oxidant index, and iodine index was significant. The correlation coefficient between the antioxidant index and peroxide index ($r=-0.91^{**}$) was negative and significant at the 1% probability level, meaning that the higher the antioxidant index, the lower the sensitivity to oxidation. Because the peroxidation index causes an undesirable odor and taste in fatty

substances, and as this index decreases, the quality of the oil increases and the value of the oil increase. In this study, the rate of peroxidation was very slow in the early stages, but with the passage of time, the texture increases, so the rate of peroxidation may vary from a few weeks to a few months depending on the type of oil, its storage conditions, temperature, etc. Therefore, the peroxide index is considered as one of the health indicators of the oil. It can also be said that the packaging, storage and consumption conditions of the oil are among the most important factors affecting the health of the consumed oil. Looking at the results obtained, it can be seen that the Akbari variety pistachio oil can be considered a suitable variety for oil extraction with acceptable characteristics, and it can be considered a suitable variety for the production of processed export products such as oil, although the need for additional research in this field is inevitable.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability Statement

All data are available upon request.

Conflict of interests

The authors declare no competing interests.

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