Effect of packaging method, temperature and storage period on physicochemical and sensory properties of wild almond kernel

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Abstract This research was performed to monitor the effect of different temperatures (4, 25 and 35 °C) and atmospheres (vacuum, CO₂ and normal air) on physicochemical and sensory properties of wild almond kernel during several weeks' storage. The color, moisture content and sensory analysis of the kernels, peroxide value (PV), 2-thiobarbitic acid (TBA), conjugated dienes and trienes (CD, CT) and acid value (AV) of the oils were determined in defined time intervals. The results showed that the influence of temperature, time and type of atmosphere on the following parameters were significantly different. At all temperatures studied, AV, PV, TBA and CD/CT of oils from all samples increased with time which was less in the modified atmosphere packaging (MAP) compared with vacuum packaging (VP) and air atmosphere packaging (AAP). At the end of storage, the samples stored under AAP at 35 °C had the highest amount of PV (15.5 meq/kg), TBA (0.056 mg/kg) and CT (0.193 μmol/g), while the samples packaged under MAP at 4 °C had the lowest. Irrespective of packaging type, L* and b* values decreased during storage with a parallel increase of values a* resulting in gradual product darkening, especially in AAP. Sensory analysis also showed the decrease of overall acceptability during the storage among the three packaging systems. In conclusion, the use of MAP was the most effective method for protecting wild almond kernel from deteriorative reactions such as oxidation and hydrolysis.

Keywords Wild almond kernel · Oil · Packaging · Oxidation · Sensory analysis

Introduction

Almonds (*Prunus amygdalus*) are among the most popular tree nuts in the world that can be beneficial for human health and nutrition. In addition to the domestic almond cultivars, there are more than thirty species of wild almond in the world, with about twenty species reported in Iran (Moayedi et al. 2010). *Amygdalus scoparia*, locally called “Badamak” or “Mountain Almond”, is one of the endemic species commonly found in southern regions of Iran. It could be used as edible nutritive oil and kernel after debittering. In addition to its value as a food source, it has wide application in medicine such as antidiabetic, anti-inflammation, antibacterial and laxative agent (Kermanshah et al. 2014). It also has potential for industrial applications such as in paint industries, soap making factories and as a bio-diesel. Wild almond kernel oil is generally rich in both oleic (as the main monounsaturated fatty acids or MUFA) and linoleic acids (as the only polyunsaturated fatty acids or PUFA) (Sorkheh et al. 2016). Moreover, the ratio of MUFA to PUFA in its oil (also domestic almond species) is at higher levels than those in the common vegetable oils like soybean, various nut oils, and those from the seeds of pomegranate, grape, date and sesame (Moayedi et al. 2010). Due to their high content of unsaturated fatty acids and the presence of riboflavin as a photosensitizer, auto-oxidation is the main cause of off-flavor development in almonds, as well as wild species of almonds (Mexis et al. 2009a, b).

The nature of unsaturated fatty acids and environmental factors such as oxygen concentration, storage temperature

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and light are likely to influence the lipid oxidation (Mexis et al. 2009a, b). The common approach for minimizing autoxidation of lipids in nuts is to control the gas composition inside the package by using proper packaging techniques including modified atmosphere packaging (MAP) or vacuum packaging (VP) and storage temperature. MAP has been applied for prolonging the shelf-life period of various types of products, where the mixture of gases in the package is dependent on the type of product, packaging materials and storage temperature (Sandhye 2010). Moreover, as external factors such as light, temperature and other radiations catalyze the initial reactions of autoxidation, they should be avoided in the package. Moisture is another important factor that prompts the deteriorative reactions and in turn affects the quality of nuts. For example, if moisture is too high, mold growth occurs, if too low, the kernel shrivels (Ghirardello et al. 2013). Several researches have already been carried out on suitable packaging materials and technologies to extend the shelf life of almond kernel (Carrasco-Del Amor et al. 2016; Mexis et al. 2011; Mexis and Kontominas 2010; Severini et al. 2003; Senesi et al. 1996).

To the best of our knowledge, there is no information in the literature on packaging of wild almond kernels. Hence, the objective of the present study was to investigate the effect of three packaging methods, three temperatures, and storage time on physicochemical properties and oxidative stability of wild almond kernel and oil. Discovering suitable conditions for storing wild almonds is an important factor in order to increase competitiveness by maintaining product quality during the selling period.

Materials and methods

Raw materials

The wild almonds used in this research were collected randomly from plants growing in Southern mountainous areas of Iran (Fars province, Kazerun city) in January 2016. Debittering process of almonds was done by soaking and replacing with fresh water at 6 h intervals for four consecutive days. Thereafter, they were manually cracked and obtained kernels were immersed in 2% (W/V) of NaCl solution for 4 h, then dried in dark environment for 12 h. The solvents and other chemicals used were of analytical grade and supplied by Merck Chemical Company.

Storage experiments

Three types of packaging were employed for storing wild almond kernels: modified atmosphere packaging (MAP) with 95% CO₂ and 5% O₂, vacuum packaging (VP), and air

atmosphere packaging (AAP). VP and MAP of kernels under CO₂ gas were performed by a packaging set with gas injector (KDZQ-300, Iran) in 10 × 15 cm polyamide/low density polyethylene (PA/LDPE) bags with 80 µm thickness. Partial pressure of gases was pO₂:0.04 kPa and pCO₂: 70.8 kPa during packaging process. Polyethylene bags were used for AAP samples. Each package consisted of 100 g wild almond kernels for each storage. Samples were stored in the dark incubators adjusted to 4, 25 and 35 °C. The samples at the temperatures of 4 and 25 °C were stored for 15 weeks, whereas the ones submitted to high temperatures were stored for only 30 days. At definite time intervals, marked samples by date were withdrawn for physical, chemical and sensory analysis. Moisture content, total oil contents, protein, ash, fiber and carbohydrate of fresh wild almond were determined using standard AOAC (2000) methods.

Oil extraction

Oil from wild almond kernels to determine the oil indices were extracted according to the method reported by Kornsteiner et al. (2006) (with minor modifications). The powdered almond (5 g) was stirred for 3 h with hexane (50 ml) at room temperature. After filtration of the mixture, the remaining solvent was evaporated by using a rotary evaporator (Heidolph, Germany) at 40 °C. The resulting oil was transferred into a small glass vial, flushed with nitrogen and maintained at – 18 °C until chemical analysis.

Chemical analysis

Standard chemical indices including acid value (AV), peroxide value (PV), 2-Thiobarbituric acid (TBA) and conjugated dienes and trienes were monitored for progress of lipid oxidation.

The *free fatty acid contents or acid value (AV)*, as extent of lipolysis, were examined by biochemical analysis according to AOAC (2000) and expressed as percent oleic acid. The *peroxide value (PV)*, as indicator of primary oxidation products, was determined eudiometrically according to IUPAC standard methods and the results were expressed in meq/kg oil (IUPAC 1992). The *conjugated dienes (CD)* and *conjugated trienes hydroperoxides (CT)*, as indicator of secondary oxidation products, were measured according to the method reported by Kim and Labella (1987). They were calculated based on measured absorbance at 232 and 268 nm of a solution containing 0.01–0.03 g of oil in 25 ml of isooctane, respectively. *Thiobarbituric acid value (TBA)*, as indicator of secondary oxidative aldehyde products, was acquired spectrophotometrically based on the pink complex formed after reaction of malondialdehyde (MDA), with

2-thiobarbituric acid (TBA) by reading absorbance at 532 nm (IUPAC 1992).

Color measurement

Color of samples was evaluated using a modified method of Yam and Papadakis (2004). A digital camera (Canon Power-Shot A720, 8.0 megapixels), previously calibrated with standard white and black tile, was used to take pictures after which pictures of the samples were transferred to a PC for further processing. Using Adobe Photoshop CS5 software, the color parameters of L^* (lightness), a^* (redness/greenness) and b^* (yellowness/blueness) were determined in the “Lab” mode of the software. The total color difference (TCD), the parameter considered for the overall color difference between a sample and the reference, was calculated by Eq. (1):

$$\text{TCD} = \left[(L - L_0)^2 + (a - a_0)^2 + (b - b_0)^2 \right]^{1/2} \quad (1)$$

Sensory analysis

Sensory evaluation of samples was carried out by 30 semi-trained panelists to score each treatment after equilibration at room temperature. A five point hedonic scale ranging from 1 to 5, where 1 = extremely dislike and 5 = extremely like was used to evaluate different parameters such as odor, flavor, color, juiciness and overall acceptance (Youn and Chung, 2012).

Statistical analysis

Data were subjected to analysis of variance (ANOVA) using the SAS (version 9.1) software (Statistical Analysis System, Cary, NC) for Windows. Means and standard deviations were calculated, and when F-values were significant at the $P < 0.05$ level, mean differences were separated by the least significant difference procedure.

Results and Discussion

The wild almond kernels used in the current study initially (before debittering and packaging) contained 16.60% moisture, 37.51% oil, 18.03% protein, 20.96% carbohydrate, 3.20% fiber and 3.70% total ash.

Moisture

Table 1 shows the variations in moisture content of wild almonds packaged with different methods (AAP, VP and MAP) during the storage at 4, 25 and 35 °C. The moisture

content of all samples decreased with the extending storage time. During the first weeks of storage, no significant differences between the moisture content of the samples packaged under VP and MAP were observed ($P > 0.05$) while the variation of moisture content was significant for MAP and VP samples after 12 weeks at 4 and 25 °C, MAP samples after 18 weeks at 35 °C and VP samples after 12 weeks at 35 °C. In 3 different temperatures studied, the kernels in the MAP had higher amount of moisture than those packaged in the VP followed by AAP. This difference was more obvious and remarkable at the end of storage period (Table 1). This suggests that the polyethylene material used in VP and AAP allows more water vapor transmittance; hence, the wild almond kernels packaged in this material in both methods has lower moisture content. In all packaging methods, the moisture content of the samples stored at 4 °C was higher than those stored at 25 and 35 °C. During the storage period of 15 weeks, the moisture content of the samples in the MAP and VP at 4 °C decreased from 35.7 to 32.6% and 30.8%, respectively. Similarly, Torun (1999) and Gamli and Hayoglu (2007) reported that moisture content of walnut paste and pistachio nut paste decreased over the storage time at different temperatures with various packaging materials. In another study, the moisture content of fresh raw pistachios decreased over storage time; however, no notable differences was observed between the moisture content of the samples in AAP, VP and MAP during the storage (Ozturk et al. 2016). However, according to Meena et al. (2017), greater fluctuation was seen in the moisture content values of groundnut seeds stored in different packaging materials (gunny bags, high density polythene bags), but it was constant for vacuum packaging.

Acid value

Table 2 indicates the changes in acidity of the samples packaged (AAP, VP and MAP) under different temperature and storage conditions. The data obtained in this study demonstrate that the influence of temperature, storage time and type of packaging were all statistically significant ($P < 0.05$) on acidity. At the beginning of the experiment, the kernels exhibited very low acidity (0.07% oleic acid) and peroxide values (0.32 meq O_2 /kg oil), close to zero, indicating the absence of initial triglyceride hydrolysis and fatty acid oxidation. The acidity of all samples (MAP, VP and AAP) increased markedly over time, which was more obvious at higher temperatures. This could be attributed to faster chemical and enzymatic (lipolysis) reactions at the higher temperature than at the lower ones. Moreover, the kernels packaged in MAP showed the lowest acidity in comparison with VP and AAP samples. The acidity of wild almond kernels packaged in MAP increased to 0.37, 0.38

Table 1 Moisture content (%) of wild almond kernels as a function of types of packaging, temperatures and storage times

Temperature (°C)	Type of packaging	Storage time (weeks)					
		0	3	6	9	12	15
4	MAP	35.7 ^{aA} ± 1.38	35.5 ^{aA} ± 0.48	34.6 ^{aAB} ± 0.40	33.6 ^{aBC} ± 0.32	33.0 ^{aC} ± 0.81	32.6 ^{aC} ± 0.57
	VP	35.7 ^{aA} ± 1.38	34.9 ^{aAB} ± 0.65	33.8 ^{aBC} ± 0.97	33.2 ^{aCD} ± 0.65	32.2 ^{aCD} ± 0.73	30.8 ^{bD} ± 0.81
	AAP	35.7 ^{aA} ± 1.38	30.4 ^{bb} ± 0.44	27.51 ^{bC} ± 0.35	25.88 ^{bD} ± 0.54	–	–
25	MAP	35.7 ^{aA} ± 1.38	35.0 ^{aAB} ± 0.51	34.8 ^{aAB} ± 0.57	34 ^{aB} ± 0.40	32.6 ^{aC} ± 0.44	31.0 ^{aD} ± 0.48
	VP	35.7 ^{aA} ± 1.38	33.2 ^{bb} ± 0.73	32.6 ^{bb} ± 0.48	31 ^{bC} ± 0.57	28.3 ^{aD} ± 0.14	26 ^{bE} ± 0.65
	AAP	35.7 ^{aA} ± 1.38	27.4 ^{cB} ± 0.19	21.3 ^{cC} ± 0.40	–	–	–
Temperature (°C)	Type of packaging	Storage time (days)					
		0	3	6	12	18	30
35	MAP	35.7 ^{aA} ± 1.38	35.4 ^{aAB} ± 1.14	35 ^{aAB} ± 0.48	33.89 ^{aBC} ± 0.66	32.9 ^{aC} ± 0.59	30.7 ^{aD} ± 0.40
	VP	35.7 ^{aA} ± 1.38	35.2 ^{aA} ± 0.73	34.5 ^{aA} ± 0.40	32.6 ^{abB} ± 0.57	31.54 ^{bb} ± 0.45	29.3 ^{bC} ± 0.23
	AAP	35.7 ^{aA} ± 1.38	33 ^{bb} ± 1.22	32.1 ^{bBC} ± 0.36	31 ^{bC} ± 1.46	26.4 ^{cD} ± 0.48	24.8 ^{cD} ± 0.48

Each value is the average of three replicates. In the same row different capital letters indicate significant difference ($P < 0.05$). In the same column different lowercase letters indicate significant difference ($P < 0.05$)

Table 2 Acid value (% oleic acid) of wild almond kernels as a function of types of packaging, temperatures and storage times

Temperature (°C)	Type of packaging	Storage time (weeks)					
		0	3	6	9	12	15
4	MAP	0.07 ^{aD} ± 0.02	0.12 ^{cC} ± 0.03	0.24 ^{bB} ± 0.04	0.25 ^{bb} ± 0.06	0.26 ^{bB} ± 0.02	0.28 ^{bA} ± 0.04
	VP	0.07 ^{aC} ± 0.02	0.20 ^{bb} ± 0.04	0.26 ^{bAB} ± 0.03	0.28 ^{bAB} ± 0.05	0.31 ^{aA} ± 0.04	0.33 ^{aA} ± 0.06
	AAP	0.07 ^{aC} ± 0.02	0.27 ^{aB} ± 0.03	0.49 ^{aA} ± 0.04	0.52 ^{aA} ± 0.06	–	–
25	MAP	0.07 ^{aC} ± 0.02	0.25 ^{cB} ± 0.08	0.26 ^{cB} ± 0.05	0.29 ^{bAB} ± 0.06	0.33 ^{bAB} ± 0.06	0.38 ^{bA} ± 0.02
	VP	0.07 ^{aC} ± 0.02	0.56 ^{bb} ± 0.03	0.66 ^{bA} ± 0.05	0.69 ^{aA} ± 0.06	0.70 ^{aA} ± 0.08	0.72 ^{aA} ± 0.02
	AAP	0.07 ^{aC} ± 0.02	0.70 ^{aB} ± 0.08	0.83 ^{aC} ± 0.02	–	–	–
Temperature (°C)	Type of packaging	Storage time (days)					
		0	3	6	12	18	30
35	MAP	0.07 ^{aD} ± 0.02	0.09 ^{cD} ± 0.02	0.15 ^{cC} ± 0.02	0.20 ^{cB} ± 0.04	0.24 ^{cB} ± 0.03	0.37 ^{cA} ± 0.04
	VP	0.07 ^a ± 0.02	0.13 ^{bD} ± 0.02	0.27 ^{bC} ± 0.04	0.36 ^{bB} ± 0.03	0.48 ^{bA} ± 0.03	0.51 ^{bA} ± 0.03
	AAP	0.07 ^{aD} ± 0.02	0.43 ^{aC} ± 0.02	0.49 ^{aB} ± 0.02	0.53 ^{aB} ± 0.02	0.96 ^{aA} ± 0.03	0.99 ^{aA} ± 0.05

Each value is the average of three replicates. In the same row different capital letters indicate significant difference ($P < 0.05$). In the same column different lowercase letters indicate significant difference ($P < 0.05$)

and 0.28% after 4 week-storage at 35 °C and 15 day-storage at 25 and 4 °C, respectively.

Considering the acceptable limit of acidity (0.4% oleic acid), as reported by Ghirardello et al. (2013), the quality of wild almonds packaged by MAP has remained relatively good during 4 week-storage at 35 °C, and 15 week-storage at 4 and 25 °C. However, AAP samples were unacceptable after 6 weeks (0.49%), 3 weeks (0.7%) and 12 days (0.36%) of storage at 4, 25 and 35 °C, respectively. In VP samples, the acidity was acceptable until the end of storage

(0.33%) at 4 °C, while at 25 °C after 3 weeks (0.56%) and at 35 °C after 12 days (0.36%) was unacceptable.

Peroxide values

Changes in PV of the wild almonds stored under different conditions are given in Fig. 1. Analyzed data showed that the effect of temperature, type of packaging and time on PV was significant ($P < 0.05$). The initial PV of fresh wild almond kernels was low (0.32 meq O₂/kg oil), which is indicative of good quality of product in terms of lipid

oxidation. After 15 weeks storage at 4 °C, the primary oxidation products (PV) of samples packaged in MAP and VP increased significantly to 2.14 meq O₂/kg oil and 3.5 meq O₂/kg oil, respectively, and for AAP samples to 3.5 meq O₂/kg oil after 9 weeks. At 25 °C, respective PV for samples packaged in MAP and VP both after 15 weeks storage were 7 and 12.2 meq O₂/kg oil, and for those packaged with AAP 7.8 meq O₂/kg oil after 6 weeks storage. Similarly, the PV values of MAP, VP and AAP samples during the 30 days storage at 35 °C increased significantly to 5.4 meq O₂/kg oil, 6.8 meq O₂/kg oil and 15.5 meq O₂/kg oil, respectively. Moreover, the higher the storage temperature, the higher the PV. Similar results were observed by Bakkalbaşı et al., (2012) and Tavakoli-pour et al. (2017) regarding walnut kernels and pistachio powder, respectively.

Regarding the type of packaging, the PV of wild almond kernels packaged in MAP and VP did not show significant

difference ($P < 0.05$) until the 6th (at 4 °C) and 3rd weeks of storage (at 25 °C), whereas noticeable difference was detected between the PV of AAP samples with VP and MAP methods from the beginning of storage at 4 and 25 °C. In addition, at high temperature (35 °C) condition, the PV of all samples packaged with different methods demonstrates significant difference during 30 days of storage. It is also observed that, at a definite temperature, samples packaged under MAP resulted in the lowest PV compared to those packaged under VP or AAP. The results of acidity and peroxide values are in agreement with those of Ghirardello et al. (2013) who reported storage of hazelnut at low temperature maintains a low level of acidity and lipid oxidation compared to ambient storage for 1 year, with the best performance in modified atmosphere (0.13% of oleic acid and O₂ of 0.057 mmol kg⁻¹). Ozturk et al. (2016) also monitored that all the packaging materials used except AAP delayed the microbial growth, peroxide and the free fatty acid formation of fresh raw pistachios during storage at 4 °C for 30 days. Buransompob et al. (2003) reported that the peroxide values less than 2.0 meq O₂/kg in almond oils can be taken as the acceptability threshold for evaluation of fresh almonds. Based on present results, wild almond kernels packaged under MAP and VP may be categorized as fresh until about 14 and 7 weeks of storage at 4 °C; however, at 25 °C those samples packaged in MAP and VP until about 4 weeks of storage and at 35 °C until about 9 days (for MAP) and 3 days (for VP) of storage were within satisfactory limit.

CD and CT values

After formation of hydroperoxides through oxidation, the rearrangement of non-conjugated double bonds present in natural unsaturated lipids generated conjugated dienes (CD), which absorb at 232 nm. Conjugated trienes (CT) formed through conjugation that occurred with extension of oxidation of polyunsaturated fatty acids contain three or more double bonds (e.g., linolenic acid), which absorb at 268 nm. The presence of CD and CT is a better measurement of oxidation (Kim and Labella 1987). The initial value of CD and CT of fresh wild almonds were 0.192 and 0.0109 µmol/g, respectively. The highest and the lowest amount of CD at the end of the storage period were recorded for VP samples at 25 °C (1.043 µmol/g) and the MAP samples at 4 °C (0.506 µmol/g) both after 15 weeks with considering the note that AAP samples undergo microbial deteriorations from the middle period of storage at 4 and 25 °C. At the end of storage, the highest and the lowest concentration of CT were reported for AAP samples at 35 °C after 30 days (0.1933 µmol/g) and the MAP samples at 4 °C after 15 weeks (0.0309 µmol/g) (data not shown). These results are comparable to those reported by

Fig. 1 Peroxide value of wild almond kernels as a function of types of packaging and storage times at 4 °C (a), 25 °C (b) and 35 °C (c)

Raisi et al. (2015) who stated that at the end of storage the ground almond sample exposed to air at ambient temperature (with PV of 3.41 meq O₂/kg and K₂₆₈ value of 3.42 µmol/g) was the least stable, and the whole kernels under vacuum kept at 4 °C (with PV of 0.69 meq O₂/kg and K₂₆₈ of 0.63 µmol/g) were the most stable form against oxidation. Moreover, as storage time increased, the CD and CT of all samples enhanced significantly at all temperature conditions. Similar results for the increase of the secondary oxidation products over storage time in almonds (malondialdehyde, hexanal content) have been obtained by Raisi et al. (2015), Mexis and Kontominas (2010), Mexis et al. (2009a, b), and Senesi et al. (1996). In addition, quantitative differences were also found in the CD and CT of all samples with different packaging (MAP, VP and AAP) at a definite storage time and temperature.

High temperatures cause re-arrangement of double bonds in polyunsaturated fatty acids of wild almond oil and convert nonconjugated fatty acids to conjugated diene and triene during the advanced stages of rancidity (Chun et al. 2005). Hence, the amount of CD and CT increased as a function of temperature. It should be noted that the CD or CT for all stored wild almonds at different conditions was strongly correlated with PVs. As shown in Fig. 2, there was a strong linear correlation between PVs and CDVs of wild almond kernels packaged with different methods at 4 °C ($R^2 > 0.96$). This relation has also been observed in peanut butter (St. Angelo et al. 1975), fish oil (Kulas and Ackman 2001) and air or vacuum packaged raw/dry roasted peanuts (Chun et al. 2005) with $R^2 > 0.98$. The results also indicated that CD and CT of all wild almond kernels packaged with MAP were lower than that for VP and AAP under all storage temperatures. Based on the studies of Raisi et al. (2015) K₂₆₈ values of whole kernels and ground almonds stored in vacuum packaging were lower than that for CO₂-

filled and air atmosphere at storage temperatures of 4 and 23 °C.

TBA value

A more accurate parameter for monitoring oil seed deterioration during storage is TBA, as in food products with low peroxide value, little amount of iodine is released and absorbed by unsaturated bonds of fatty acids (Raei and Jafari 2013). The TBA values of MAP and VP packaged wild almond samples did not show significant differences ($P < 0.05$) until 6th week of storage at 4 °C, afterwards it increased considerably to 0.021 and 0.032 mg MDA/kg, respectively, whereas significant difference was identified between the TBA values of all samples (MAP, VP and AAP) stored at 25 and 35 °C from the first week of storage till the end. A similar pattern was recorded by Gamli and Hayoglu (2007), that until the 5th month of storage the TBA values of packaged pistachio nut paste (vacuum/non-vacuum polypropylene and sealed glass jar) were constant and insignificant (0.03 mg MDA/kg), then increased to 0.04 mg MDA/kg. They have ascribed these changes to higher amount of oleic and less amount of linoleic acid in pistachio nut paste. Like other oxidation parameters, for a given temperature, the TBA values of AAP packaged wild almonds were markedly higher than MAP or VP samples. In reality, application of CO₂ or vacuum restricted the amount of oxygen and therefore the lipid oxidation. These findings are in good agreement with Sedaghat et al. (2015), Raie and Jafari (2013) and Gamli and Hoyaglu (2007) who reported that by applying N₂, vacuum or CO₂ inside packages, the highest quality in terms of TBA has been achieved in comparison with the air in pistachio nut, pistachio oil and paste, respectively. Furthermore, by increasing temperature from 4 to 35 °C, TBA index also increased notably in all types of packaging. Raei and Jafari (2013) and Gamli and Hayoglu (2007) observed similar results for TBA index of pistachio nut and pistachio nut paste packaged with different methods at 4 °C compared with 20 °C.

Colour

Table 3 shows the effect of different packaging (AAP, MAP and VP) on colour parameter L* of wild almond kernels as a function of storage time at different temperatures. The initial values of L*, a* and b* for fresh wild almonds with seed coat was 35.75, 12.35 and 28.57, respectively. For all types of packaged samples, L* and b* values decreased with storage time with a parallel increase in a* values leading to a gradual darkening of kernels during storage especially in AAP samples. A similar trend, but to a lesser extent, was observed for wild almond kernels

Fig. 2 The relationship between the peroxide values and conjugated diene values for wild almond kernels packaged with different methods during storage at 4 °C

Table 3 The changes in L* of wild almond kernels as a function of types of packaging, temperatures and storage times

Temperature (°C)	Type of packaging	Storage time (weeks)					
		0	3	6	9	12	15
4	MAP	35.75 ^{aA} ± 0.8	34.77 ^{cC} ± 0.1	34.54 ^{aB} ± 0.0	32.16 ^{aC} ± 0.1	31.68 ^{aCD} ± 0.1	31.24 ^{bA} ± 0.0
	VP	35.75 ^{aA} ± 0.8	35.46 ^{abA} ± 0.0	33.06 ^{bB} ± 0.1	32.79 ^{aBC} ± 0.2	31.58 ^{aC} ± 0.1	31.08 ^{aA} ± 0.5
	AAP	35.75 ^{aA} ± 0.8	34.27 ^{aB} ± 0.7	32.75 ^{bC} ± 0.7	30.82 ^{bD} ± 0.7	–	–
25	MAP	35.75 ^{aA} ± 0.8	35.46 ^{aA} ± 0.5	33.78 ^{aB} ± 0.2	33.00 ^{aB} ± 0.3	32.38 ^{aBC} ± 0.1	29.24 ^{aC} ± 0.2
	VP	35.75 ^{aA} ± 0.8	34.57 ^{abA} ± 0.1	33.61 ^{aB} ± 0.4	31.87 ^{bBC} ± 0.6	30.56 ^{bC} ± 0.21	29.16 ^{bD} ± 0.31
	AAP	35.75 ^{aA} ± 0.8	33.33 ^{cB} ± 0.1	28.27 ^{bC} ± 1.0	–	–	–
Temperature (°C)	Type of packaging	Storage time (days)					
		0	3	6	12	18	30
35	MAP	35.75 ^{aA} ± 0.8	35.37 ^{aA} ± 0.3	34.87 ^{aAB} ± 0.2	33.05 ^{aA} ± 0.2	32.16 ^{aB} ± 0.3	30.57 ^{aC} ± 0.2
	VP	35.75 ^{aA} ± 0.8	34.45 ^{aA} ± 0.4	33.66 ^{bA} ± 0.5	31.26 ^{bB} ± 0.2	30.02 ^{bBC} ± 0.8	30.36 ^{bC} ± 0.0
	AAP	35.75 ^{aA} ± 0.8	32.25 ^{bB} ± 0.1	31.86 ^{cB} ± 0.4	30.96 ^{cC} ± 0.1	29.34 ^{cD} ± 0.2	25.67 ^{bE} ± 1.0

Each value is the average of three replicates. In the same row different capital letters indicate significant difference ($P < 0.05$). In the same column different lowercase letters indicate significant difference ($P < 0.05$)

stored at 4 °C compared with 35 °C. Indeed, higher temperatures and non-existence of oxygen in package (by applying CO₂ or vacuum) delayed the mentioned trend of colour parameters. Darkening of almond kernels during storage have been reported by Ledbetter and Palmquist (2006), Sanchez-Bel et al. (2005) and Mexis et al. (2009a, b, 2011). They attributed this event to browning reactions due to the oxidation of phenols that are abundant in almond skins.

The lowest and the highest L* values at the end of storage was detected for AAP samples at 35 °C and MAP samples at 4 °C with the values of 25.67 and 31.24, respectively. A similar trend for the highest and lowest amount of a* and b* was observed for the mentioned samples. For better evaluation of the change of colour, TCD was calculated (data not shown). The results indicated that storage of wild almond kernels in MAP at 4 °C is the best method to keep this product due to the lowest level of TCD in relation to the reference colour at the end of storage (TCD equals 5.41). Moreover, the higher the temperature, the more the TCD was. Guiné et al. (2015) also found that the storage of hazelnut at 50 °C (either with 13 or 90% RH) is the worst method for keeping, as seen by the high values of TCD. They reported that the high temperatures favour the browning reactions, thus originating the formation of coloured compounds that contribute to darkening of the surface of the product.

Sensory evaluation

The overall acceptability scores of wild almond samples stored in different packaging types at 4, 25 and 35 °C are depicted in Fig. 3. In our study, this parameter is the sum of the scores of taste, flavor, texture and colour acceptability. No significant differences were observed between overall acceptance of AAP, VP and MAP samples after three week of storage. However, significant difference were found between MAP and VP samples at 9th week of storage at 25 °C, also 15th week at 25 and 4 °C. After 30 days of storage at 35 °C, changes in acceptability were the least in samples packaged in MAP (score 3.5), while the lowest score was recorded for wild almond packaged conventionally in AAP (score 1.5). The highest score of overall acceptability at the end of storage was recorded for wild almond packaged under MAP conditions at 4 °C after 15 weeks (score 4). Respective scores at 25 and 35 °C were 3.5 (at 15 weeks) and 3.2 (at 30 days) both for MAP samples. Similarly, Sanchez-Bel et al. (2005) reported that almonds reached the limit of overall acceptability score of 3 on a scale of 5 (very pleasant) to 1 (very unpleasant) after 6 months of storage. Results of sensory evaluation in all three temperatures have shown that the overall acceptability of all packaged samples (AAP, MAP and VP) decreased significantly during storage period. Moreover, with the increase of storage temperature, the sensory scores for overall acceptability of all samples decreased.

Fig. 3 Sensory evaluation of wild almond kernels as a function of types of packaging and storage times at 4, 25 °C (a) and 35 °C (b)

Conclusion

Wild almond is a strategic product that in recent years has secured a particular position as a non-oil export product especially in Middle East. Unsuitable packaging and storage condition influences the quality and acts as an obstacle for its export. This research was undertaken to select the proper packaging by controlling the gas composition inside the package. Three types of packaging namely AAP, VP and MAP were tested. According to obtained results, the storage temperature (4, 25 and 35 °C), atmosphere (CO₂,

vacuum and air) and time significantly affected oxidative stability and hydrolysis changes of wild almond oil as well as its physical characteristics. Regarding PV, TBA, CD/CT and AV storage in CO₂ atmosphere resulted in higher oxidative and hydrolysis stability products since these indices were low. The higher temperature and longer storage times would result in a product with minimum quality attributes. Thus, a combination of MAP (followed by VP) and low temperature is essential to maintain the quality of the product during storage.

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