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EFFECTIVENESS OF PRE-STORAGE OXYGEN, CARBON DIOXIDE AND NITROGEN-ENRICHED ATMOSPHERES ON SHELF-LIFE, QUALITY AND BIOACTIVE COMPOUNDS OF FRESH APRICOT FRUIT

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ABSTRACT. *Fresh apricot fruit is nutritious and delicious, but due to its short shelf-life and high perishability, it is available in the market for a short time. Therefore, this experiment aimed to investigate the effect of the modified atmosphere on qualitative properties, microbial load, and shelf-life of fresh apricot fruit 'Shahroudi' cultivar. Treatments included: control (air), high-N_2 (90%), high-CO_2 (90%), and high-O_2 (90%) atmospheres for 12 days at 2˚C before eight weeks cold storage. Results indicated that high-N_2 treatment significantly reduced weight loss and fruit total soluble solids, and retained fruit color and firmness compared with other treatments. Also, fruit exposed to high-N_2 maintained better the sensory evaluation, total phenolic compound, and total carotenoid than other treatments. Interestingly, the shelf-life of fruit in high-N_2 treatment (58.2 days) markedly extended and increased more than 3-folds compared to control (17.5 days). At the end of the storage period, total bacteria, yeast, and mould were lowest in high-N_2. However, high-O_2 reduced chemical properties, including vitamin C. In general, the results indicated that the use of high concentrations of nitrogen gas as a modified atmosphere packaging is an effective and safe way to prolong postharvest life and preserved quality properties of fresh apricot.*

KEY WORDS: *Prunus armeniaca**,** high carbon dioxide**,** high nitrogen, high oxygen, microbial load, postharvest.*

INTRODUCTION

Apricot (*Prunus armeniaca* L.), is widespread, popular and appreciated by consumers as it is an early seasonal fruit and has excellent quality and sweetness. This fruit is rich in minerals such as potassium and carotenoid like beta-carotene. Apricot is a climacteric fruit, and it has a short shelf life and rapid post-harvest ripening process (Wei et al., 2014). During storage, apricots undergo softening and rotting, which mainly results in loss of quality, microbial decay, and mechanical injury (Wang et al., 2015). Several post-harvest technologies, such as modified or controlled atmospheres, with high CO_2, O_2, and N_2 concentrations, have been shown to control physiological disorders in fruit and vegetables, thereby prolonging their storage life (Brody et al., 2010). High CO_2 regarded as an effective preservation strategy for fruit and vegetables with high tolerance to a high concentration of CO_2 (Thompson et al., 2018; Hosseini & Moradinezhad, 2018). Besides antibacterial properties, CO_2 treatment can also maintain the overall quality during post-harvest storage, including delayed color change, inhibited fruit softening, and retained flavor quality (Li et al., 2020). Moradinezhad and et al. (2018) reported that the use of short-term high CO_2 (85%) treatment effectively reduced postharvest losses of pomegranates fruits and improved the qualitative and sensory characteristics of the fruit at 5°C for 12 weeks. Besides, they showed that high CO_2 treatment could be used as an alternative to fungicide and chemical treatments. High O_2 concentration in the storage atmosphere also maintains the quality of fresh produce (Guo et al., 2019). High O_2 levels inhibit enzymatic discoloration, prevent anaerobic fermentation reactions, and suppress aerobic and anaerobic microbial growth (Jacxsens et al., 2001). However, exposure to super atmospheric O_2 may have very different effects, depending on the commodity (Art´es and Allende, 2005). Zheng et al. (2008) reported that high O_2 (60-100%) atmospheres significantly exhibited less decay rate on bayberry, strawberry, and blueberry fruit during cold storage at 5°C for 35 days. Another study on fresh-cut apples showed that pretreatment with 100% O_2 inhibited the surface browning and increased tissue firmness for 90 days (Jia et al., 2019). Nitrogen in its N_2 form, it does not participate in any physiological reactions within plant tissues, nor does it affect the growth of microorganisms except to the degree that it significantly displaces O_2 (Brody et al., 2010). Tomás-Callejas et al. (2011) reported N_2 (100%) increased vitamin C and phenol content on fresh-cut red chard at 2°C for six days compared to high O_2 (100%) and passive MAP. CA and MA storage applications are limited in developing countries due to its high expenses, so an alternative and cheap method may be the treatment of fresh fruit with an atmosphere enriched of respiratory gases during the pre-storage stage. Various studies have also been conducted on the modified atmosphere storage of apricot (Ezzat, 2018; Moradinezhad & Jahani, 2019; Muftuoğlu et al., 2012; Wang et al., 2011). However, there is no report focused on the effects of pre-storage treatment by applying enriched O_2, CO_2, or N_2 atmospheres on microbial growth and post-harvest storage quality of apricot fruit cultivar 'Shahroudi'. The objective of this study, therefore, was to investigate the effect of pre-storage atmospheres enriched with oxygen, carbon dioxide, or nitrogen on the physicochemical, sensorial, and microbial properties of apricot fruit as well as the fruit shelf-life.

MATERIALS AND METHODS

Preparation of the fruit

Apricot fruit cv. 'Shahroudi' were picked at the ripening stage with total soluble solids (TSS) of approximately 10% (minimum commercial ripening stage) from a commercial orchard at Birjand, South Khorasan, Iran, late of May 2018. The fruits were then transferred to the Postharvest Laboratory of the Department of Horticultural Science, University of Birjand. For pre-cooling, the fruits were then stored in the refrigerator for 24 h at 2°C with 85±5% relative humidity. About 200 uniform and free of defects fruits with an average weight of 55±5 g were selected.

Packaging

Fruits were allocated to 30×40 cm polyethylene bags. The bags vacuumed and were then flushed with different gas compounds (high-CO_2, high-O_2, and high-N_2) and then sealed (except for control). As shown in Table 1, treatments included control: air (O_2:21%|CO_2: 0.03%|N_2:78.97%), high-CO_2: (O_2:5%|CO_2:90%|N_2:5%), high-O_2: (O_2:90% |CO_2:5%|N_2:5%), and high-N_2: (O_2:9%|CO_2:1%|N_2:90%). The fruits were then placed in a cold room for 12 days at 2°C and 85±5% relative humidity. After that, the apricots were unpacked and placed in polyethylene containers (9×9×12 cm) with 500 ml volume (packed with its lid), and then stored in a cold room at 2°C with 85±5% relative humidity for six weeks. Temperature and relative humidity were recorded during the storage period by a digital data logger (Extech Instrument, Model RHT 20, humidity and temperature data logger, USA). At the end of the storage period (six weeks), physicochemical and sensory evaluation parameters of fruit were measured. Shelf-life was evaluated after eight weeks of storage.

Gas analysis inside packages

Gas composition (O_2, CO_2 and N_2) inside the packages was determined using a gas

Table 1. Active MAP treatments applied on apricot fruit for 12 days at 2 °C.

Treatment	O_2 (%)	CO_2 (%)	N_2 (%)
Control (air)	21†	0.03	78.97
High-CO_2	5	90	5
High-O_2	90	5	5
High-N_2	9	1	90

*Initial concentrations

analyzer (OXBABY 6+ $CO_2/O_2/N_2$ Gas Analyser, Germany). The gas analysis was performed by inserting a needle attached to the gas analyzer through an adhesive seal fixed on the lidding material. In three intervals, changes in the composition of respiratory gases in sealed polyethylene bags were measured using the gas analyzer.

Measurement of weight loss and firmness

The weight loss of each package was monitored by recording the initial weight of the fruit at harvest day before packing, and at the end of the experiment. Weight loss values are expressed as gram of weight loss per initial fruit weight. The firmness of apricot fruit was measured using a digital penetrometer (Fruit Hardness Tester, Model FHT 200, Extech Co., USA) with a 2 mm probe. Data were presented in Newton.

Measurement of total soluble solids (TSS), total phenol contents (TPC), total carotenoid (TC) and fruit color

Total soluble solids in apricot juice were measured using a hand-held refractometer (RF 10, Brix, 0-32%, Extech Co., USA), and data were expressed as °Brix. Total phenolic content was determined using the Folin-Ciocalteau method (Emmons et al. 1999), and by mixing, 8.25ml of deionized water, 0.5ml of extract (fresh weight), 0.75ml of 20% Na_2CO_3 and 0.5ml of reagent Folin-Ciocalteu was obtained. After 40 minutes reaction in a water bath at 40°C, the absorbance at 755nm was measured using a spectrophotometer (Bio Quest, CE 2502). The final results were expressed as mg of Gallic acid per gram of fresh apricot (Chuah et al., 2008). The carotenoid values were determined using the Arnon method (Arnon, 1967). First, 0.5 g of the fruit was mixed in 10 ml of acetone 80%, and then the extract was centrifuged, and the supernatant was separated. All supernatant was collected, and the absorbance was measured at 470 nm (for carotenoid), 645 nm (for chlorophyll b), and 663 nm (for chlorophyll a) using a spectrophotometer. The carotenoid amount was calculated as mg/100 g of fresh weight. Total carotenoid content was calculated by the following equation:

$$Total\ cartenoid = \frac{1000\ \text{A470} - 2.270\ \text{chla} - 81.4\ \text{chlb}}{227}$$

Vitamin C content was determined using 2, 6-dichlorophenol indophenols (Nielsen, 2010). The results were expressed as mg /100 g of fresh weight. Color components include L* (brightness), a* (redness and greens), and b* (yellowness and blue color) of apricot fruit were measured using a colorimeter (TES, 135-TAIWAN).

Measurement of microbial load, shelf-life, and sensory evaluation

Microbiological quality of the samples were analyzed for aerobic mesophilic bacteria, yeasts, and moulds by surface inoculation method, using plate count (PCA) and potato dextrose agar (PDA), respectively. To enumerate microbial load ten grams of sample (a mix of skin/surface and pericarp, to have a homogeneous and representative sample of apricot fruits) was mixed with 90 ml peptone saline solution and homogenized for 1 min. Dilutions were made in peptone water, as needed for plating. Plate Count Agar (PCA, Scharlau Chemie, S.A., Barcelona, Spain) was used as the media for total mesophilic counts pour plate, incubated at 30 °C for three days. Also, to determine the amount of mold and yeast, Potato Dextrose Agar (PDA, Scharlau Chemie, SA., Barcelona, Spain) used; surface inoculation, and then incubated at 25°C for two days. Each test was performed in duplicate and results were expressed as colony-forming units (CFU) per mL. Shelf-life was based on the physical appearance of the fruit as judged by the retention of freshness, color, and glossy appearance of fruit without any desiccation, and was expressed as a day (Moradinezhad, & Jahanani, 2016). To evaluate the taste, aroma, texture, appearance, and overall acceptance of apricot fruits, a five-point hedonic test was performed by ten trained panelists at the end of the storage period. The taste and appearance characteristics of the fruits were evaluated by the panelists. A score of 5 was rated as very good (high quality fruit and without defects), and a score of 1 was calculated as very bad (unpleasant, and off-flavor). Score 3 was determined as an acceptable quality level.

Experimental design and statistical analysis

The design used in this experiment was a completely random design with four treatments and four replications. All results (except sensory evaluation data) were expressed as mean ± standard error (SE). Data were analyzed by analysis of variance (ANOVA). Analyzes were performed with the GenStat program (Discovery Edition, version 9.2, 2009, VSN, International, UK). The LSD test at the level of 1% ($P \leq 0.01$) was also used to identify the significant differences between the means.

RESULTS AND DISCUSSION

Changes in O_2 and CO_2 concentrations

Changes in the concentration of oxygen and carbon dioxide gases in packaged apricots under the modified atmosphere are shown in Figure 1. The fruit of the control group was kept in the air until the end of the storage. Therefore, there were no changes in gas concentrations. In high carbon dioxide and high oxygen treatments, on day three oxygen and carbon dioxide concentrations decreased from 90% to about half, and on the twelfth day it was balanced from 10-20%. Also, in high nitrogen treatment, the concentration of both oxygen and carbon dioxide gases at the end of the storage period was about 10%. It has been reported that suppression of respiration for some fruit occurs at CO_2 levels above 10-20% (Wu et al., 2019).

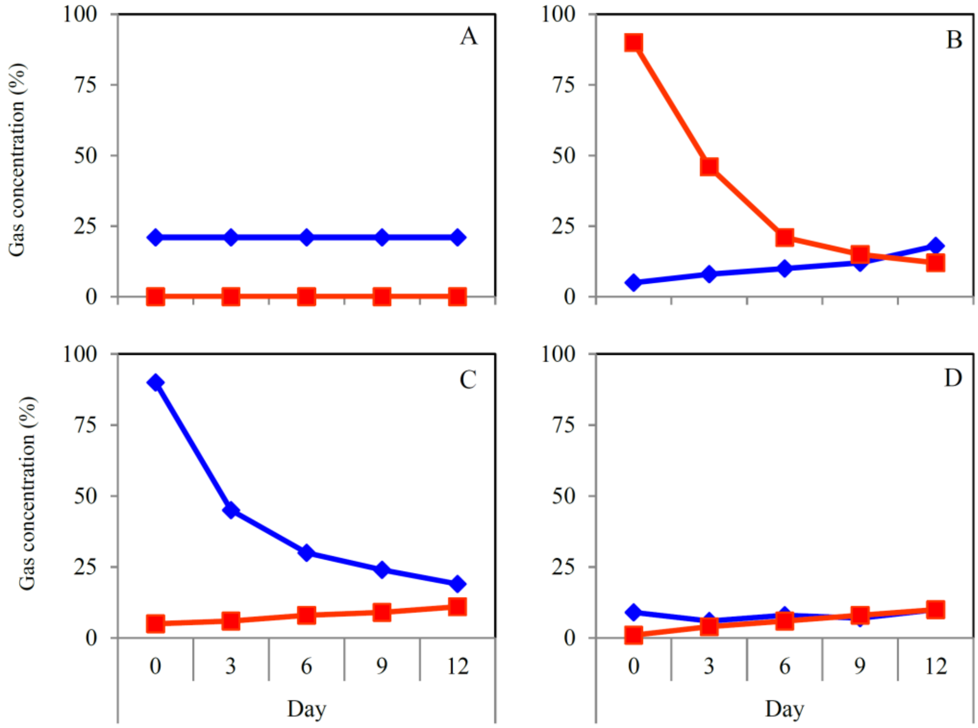

Figure 1. Changes in O_2 (♦-♦) and CO_2 (■-■) composition in polyethylene bags with different gas treatments included apricot fruit during 12 days at 2 °C. A: Control (air); B: High CO_2; C: High O_2; D: High N_2.

Weight loss

In this study, all MAP treatments significantly ($P \leq 0.01$) affected apricot weight loss (Figure 2). The highest weight loss was obtained in control (4.7 g) and the lowest (0.7 g) in high-N_2 treatment. However, there was no statistically significant ($P > 0.05$) difference between high-N_2 and high-O_2 treatment. Apricot fruit has a thin skin that increases weight loss, damage and financial losses of this product, so limiting weight loss is important (Muzzaffar et al., 2018). The lower weight loss in treated apricot might be attributed to the stabilization or maintenance of cell integrity and the permeability of the tissues with these applications (Thompson et al. 2018). Besides, the suppressing effect of these treatments on the metabolic activity of fruit after harvest can be responsible for lower weight losses. Comparing the effects of treatments, high-N_2 in storage was more effective for weight loss than other treatments. This reduction in weight loss can be explained by reducing oxygen (like the vacuum) and the strong delaying effect of high-N_2 on the senescence process of fruit. Similar results have been reported by other researchers on different fruits such as fig (Piga et al., 1997), pomegranate (Koyuncu et al., 2019), and apple (Serban et al., 2019).

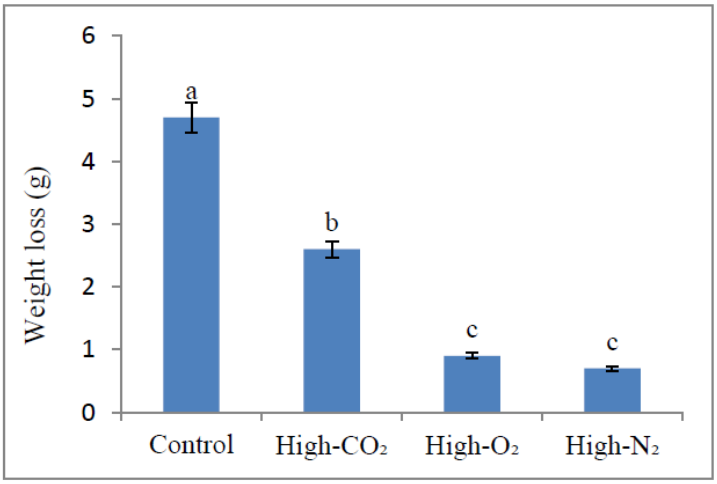

Figure 2. Weight loss of apricots under air (control) and MAP after 6 weeks of storage at 2˚C. Error bars represent the error deviation. Symbols with the same letter are not significantly different between them, at $P \leq 0.01$ (LSD test).

Firmness

Texture firmness of fruit is one of the most important characteristics of postharvest. As shown in Figure 3, all treatments used significantly ($P \leq 0.01$) maintained the apricot fruit firmness stored at 2 °C for six weeks. The results showed that fruits treated with high-N_2 had the highest firmness. Also, high-O_2 and high-CO_2 treatments maintained fruit firmness compared to the untreated (control) samples. Fruit softening is associated with cell wall degradation, which is positively correlated with pectin break down. They showed the expression of pectin breakdown–related genes was associated with ethylene production and apricot softening (Fan et al., 2018). Correlation showed increased firmness fruit is in agreement with the low fruit weight loss registered under high-N_2 treat (r: -0.8**). As mentioned before, it is well known that fruit weight loss is mainly due to respiration, which causes softening and firmness increase. Wu et al. (2015) observed that apricot firmness tended to decrease as respiration rates increased. Similar results have been reported on pineapples (Mubarak et al., 2018), pears (Yan et al., 2016) and mango (Ali et al., 2019).

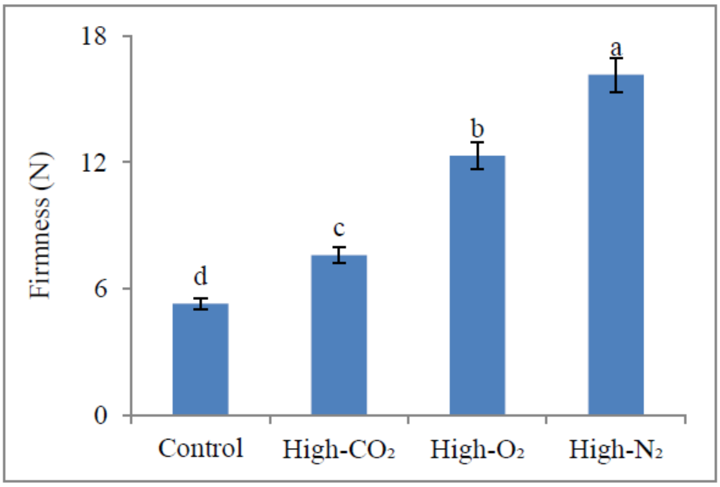

Figure 3. Firmness of apricots under air (control) and MAP after 6 weeks of storage at 2˚C. Error bars represent the error deviation. Symbols with the same letter are not significantly different between them, at $P \leq 0.01$ (LSD test).

Total soluble solids

The results showed that the application of all MAP treatments had a significant ($P \leq 0.01$) effect on TSS of apricot fruits during cold storage. Table 2 shows that the highest TSS (18%) was found in control. On the other hand, a significant reduction in TSS of juice observed in high-N_2 and high-CO_2 treatment. This decrease in TSS during storage may be due to the low O_2 concentration in high-N_2 and high-CO_2 treatment, which likely restricts ethylene synthesis and finally reduces the respiration rate of apricot fruits (Álvarez-Hernández et al., 2020). Zhebentyayeva et al. (2012) reported that TSS in apricot fruit should be more than 10% for acceptable quality, but high levels of TSS, due to the over-ripening of the fruit cause unpleasant taste and texture for the consumer. According to the results, high-N_2 and high-CO_2 atmospheres maintained better the soluble solids content of apricot fruit than high-O_2 treatment. There were a strong positive correlation between TSS and weight loss ($r=0.7^{**}$), and a negative correlation between TSS and firmness ($r= -0.8^{**}$). Similar results have been reported by previous studies on nectarine (Bal, 2016) and jujube fruit (Reche et al., 2019).

Total phenol content

Phenolic compounds are considered a positive quality of crops. In general, their nutritional benefits are often attributed to their substantial antioxidant activity (Karaat & Serçe, 2020). The TPC of treated apricot fruits significantly ($P \leq 0.01$) increased during storage (Table 2). The lowest TPC (62.3 mg/g) was observed in control, although no significant ($P > 0.05$) difference was found between the control and high-O_2 (62.5 mg/g) treated samples (Table 2). High-N_2 treatment caused the highest level (63.1 mg/g) of TPC in during cold storage. However, no statistically significant ($P > 0.05$) difference was observed between high-N_2 and high-CO_2 (63.0 mg/g) treatment. TPC is known as an antioxidant and causes scavenger free radical in cells, possibly reducing stress (over-ripening and pathogen, etc.), causing the accumulation of phenolic compounds in the cells, which in turn reduced decay incidence and extended storage and shelf life of apricot. The phenolic compounds in plants such as tannin, flavonoids and phenolic acids are directly involved in defense mechanisms by preventing pathogen growth, and strengthening the host tissues (Chalker-Scott & Fuchigami, 2018). Also, the antioxidant activity of phenolic compounds may be one of their important biological roles (Chalker-Scott & Fuchigami, 2018). Therefore maintaining a high level of phenolic compounds in fruits during storage and shelf life period is important (Łysiak et al., 2020). According to the results of the present study, the increase of TPC in response to high-N_2 treatment compared to the control

Table 2. Effect of pre-storage MAP treatments on the total soluble solids (TSS), total phenolic compound (TPC), total carotenoids (TC), and surface color of apricot fruit after 6 weeks of storage at 2°C.

Treat	TSS (%)	TPC (mg GA/100g.FW)	TC (mg /100g.FW)	Fruit color		
				*L**	*a**	*b**
Control	18.0±0.5[a]	62.3±0.1[b]	1.3±0.1[d]	62.9±1.3[b]	-1.9±0.5[a]	28.8±0.6[a]
High-CO_2	13.7±0.4[c]	63.0±0.2[a]	5.2±0.5[b]	68.0±0.5[a]	-1.6±0.2[a]	29.2±0.9[a]
High-O_2	14.6±0.1[b]	62.5±0.1[b]	2.6±0.3[c]	67.5±0.6[a]	-5.1±0.4[a]	27.1±0.7[a]
High-N_2	12.2±0.3[c]	63.1±0.3[a]	6.6±0.7[a]	67.9±0.5[a]	-2.3±0.2[a]	27.7±0.9[a]
Level of significant (1%)	**	**	**	**	ns	ns
LSD	0.93	0.10	1.06	1.86	0.84	1.80

Means followed by different letters in the same column for the same evaluated parameter are significantly different ($P \leq 0.01$) according to the LSD test.). GA: Gallic acid.

samples may be due to the reduction of oxygen and delayed ripening of apricot fruits. Similar reports have been provided by other researchers that agree to the results of this study (Yang et al., 2019; Shen et al., 2019).

Total carotenoids

Carotenoids have a unique and important role in the human diet. An important function of some carotenoids is their role as vitamin A precursors (Pace et al., 2020). Table 2 shows that experimental treatments had a significant ($P \leq 0.01$) effect on the TC content of apricot fruit. The highest and lowest TC content were obtained in high-N_2 (6.6 mg/g FW) and control (1.3 mg/g FW). The reduction in TC retention observed in control samples and high-O_2 compared with the high-N_2 or high-CO_2 treatment suggested an obvious detrimental effect of oxygen on the stability of these pigments. The TC protects cellular membranes by scavenging free radicals (Xia et al., 2020). This increase in TC may be due to the reduction of free radicals in the treatments with less oxygen. By decreasing the amount of oxygen free radicals, the amount of carotenoid consumed in the tissue decreases, eventually leading to an increase and accumulation of TC in the product tissue. Sumual et al. (2017) found that total carotenoid content in stored (2 days at 21°C) mangoes in low oxygen (3%) was higher than fruit stored in the air. They suggested that this decrease in TC may be due to the oxidation of carotenoids in the presence of oxygen. The observations of the present study in terms of TC are consistent with the findings of Chauhan et al. (2011) on carrot.

Fruit color attributes

The surface color parameters L*, a*, and b* have been widely used to describe the color properties of fruit and vegetable products (Candir et al., 2018). In all treatments, the L * level was significantly ($P \leq 0.01$) higher than the control samples (Table 2). The L* represents lightness changes from 0, which, has no lightness (absolute black) to 100, which is maximum lightness (absolute white). In general, the control group had lower L* values than other treatments (high-N_2, high-CO_2, and high-O_2) and indicating all modified atmosphere protected lightness better. Selcuk and Erkan (2015) presented similar results, stating that the decrease in L* in control samples was due to the weight loss of the product. The results also showed that the MAP treatments had no significant ($p > 0.05$) effect on the a* and b* color components. Our result was in agreement with previous reports on apricot (Ayhan et al., 2009) and on pomegranate (Moradinezhad et al., 2018) fruits.

Microbial load

The results showed that the all MAP treatments significantly reduced the microbial load compared to control. All MAP treatments significantly ($P \leq 0.01$) reduced bacteria, yeast and mould growth compared to control samples. However, high-CO_2 and high-N_2 treatments had a greater effect on reducing the growth of microorganisms than high-O_2 treatment. The highest number of bacteria, yeast and mould was counted in control samples (22.5 log CFU mL^{-1} and 15.5 log CFU mL^{-1}, respectively), and the lowest was recorded in high-CO_2 (5.25 log CFU mL^{-1} and 4 log CFU mL^{-1}, respectively) samples (Table 3). Studies on fresh fruits and vegetables showed that they are highly perishable (Sinha et al., 2012). Controlled or modified atmosphere retards senescence, lowers respiration rates, and slows the rate of tissue softening or texture loss, and this retards fungal rotting of fruits probably by acting as a competitive inhibitor of ethylene action (Sinha et al., 2012). It has been proved that high concentration of CO_2 can reduce the microbial load of fruit likely associated with the penetration to the microbial membrane, leading to intracellular pH changes or formation of carbonic acid, which has bacteriostatic effects (Van de Velde et al., 2019). The present study also showed that high concentrations of N_2 reduced the microbial load of apricot

Table 3. Effect of pre-storage MAP treatments on the total bacteria counts and yeast and mould counts of apricot fruit after 6 weeks of storage at 2°C.

Treat	Total bacteria counts (log CFU mL^{-1})	Yeast and mould counts (log CFU mL^{-1})
Control (air)	22.50 ± 0.40[a]	15.50 ± 0.91[a]
High-CO_2	5.25 ± 0.67[c]	4.00 ± 0.57[c]
High-O_2	6.25 ± 0.35[b]	5.00 ± 1.00[b]
High-N_2	5.75 ± 0.35[c]	4.25 ± 0.35[c]
Level of significant (1%)	**	**
LSD	1.09	1.64

Means followed by different letters in the same column for the same evaluated parameter are significantly different (P ≤ 0.01) according to the LSD test.

fruit. Sandhya (2010) has concluded that nitrogen displaces O_2 and therefore helps to retard the growth of aerobic spoilage microorganisms. In addition, our results showed that in all MAP treatments, total aerobic bacteria, yeast and mould counted were lower than the maximum acceptable limit of 7 log CFU mL^{-1} and 5 log CFU mL^{-1}, respectively, for fresh fruit according to South African legislation (FCDA, Act 54, 1979). However, untreated samples (control) on day 42 of storage had an unacceptable limit on the amount of total aerobic bacteria, and the yeast and mould count. Similarly, Van de Velde et al. (2020) reported that high CO_2 (20%) application reduced the microbial load of blackberry fruits during 20 days of cold storage compared to control (air) samples. Also, Banda et al. (2015) found that high N_2 (85%) reduced yeast and mould of pomegranate arils during cold storage.

Shelf life

Shelf-life includes consumer acceptability by combining visual deterioration evaluation with the consumer's willingness to purchase, thus defining a minimum acceptable deterioration used to determine shelf-life (Casanovas, 2019). As shown in Figure 4, the effect of MAP treatments on apricot fruit survival in cold storage was significant at the 99% probability level. So that high-N_2 and had the highest shelf life (Figure 6). Overall, high-N_2 storage had a positive effect on quality for fresh apricot fruit, allowing extend shelf-life of apricots about 60 days in cold storage; however, control had only 17.5 days shelf life. Modified atmosphere packaging (MAP) refers to the deliberate manipulation of the atmosphere inside a package to maintain the nutritional appeal and increase the shelf life of fresh and minimally processed packaged

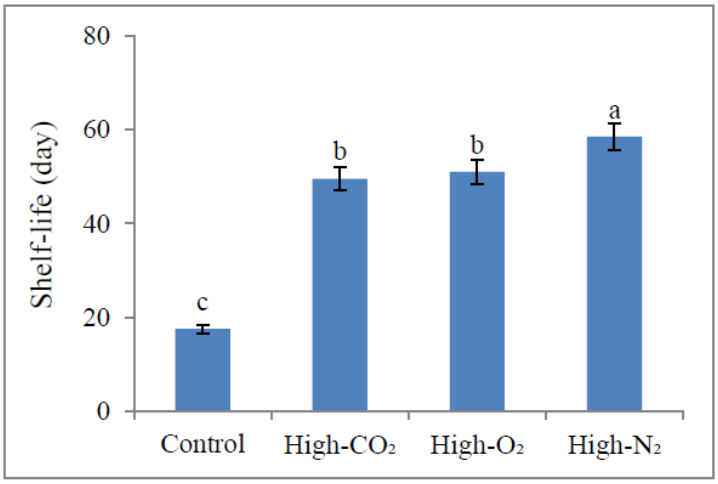

Figure 4. Shelf-life of apricots under air (control) and MAP after 8 weeks of storage at 2 ˚C. Error bars represent the error deviation. Symbols with the same letter are not significantly different between them, at P ≤ 0.01 (LSD test).

food products (Opara et al. 2019). The process of modification is generally conducted by lowering the concentration of oxygen, which is essential for aerobic respiration, lipid oxidation, and the growth of spoilage organisms that cause postharvest decay, and replacing it with relatively inert gases such as nitrogen. It was reported by Anon (1920) that the storage of plums in total N_2 almost completely inhibited ripening. A low level of O_2 is desired for fresh fruits and vegetables to reduce the respiration rate and suppress deteriorative activities such as lipid oxidation and growth of aerobic microorganisms (Makino et al., 2020). However, a minimum concentration of O_2 is required for fresh fruits and vegetables since it is mandatory for aerobic respiration (Thompson et al., 2018). MAP is usually combined with refrigeration. A storage temperature below 5˚C also increases the shelf life of fresh fruits and vegetables by reducing the respiration rate and minimizing microbial growth without chilling injury (Moradinezhad et al., 2019; Ho et al., 2020). The results of current report are in agreement with the findings of Moradinezhad and Jahani (2016) on apricot and Chen (2019) on lychee.

Sensory Evaluation

MAP treatments had a significant effect on all sensory traits (taste, texture, appearance, aroma, and general acceptance) of apricot fruit during storage.

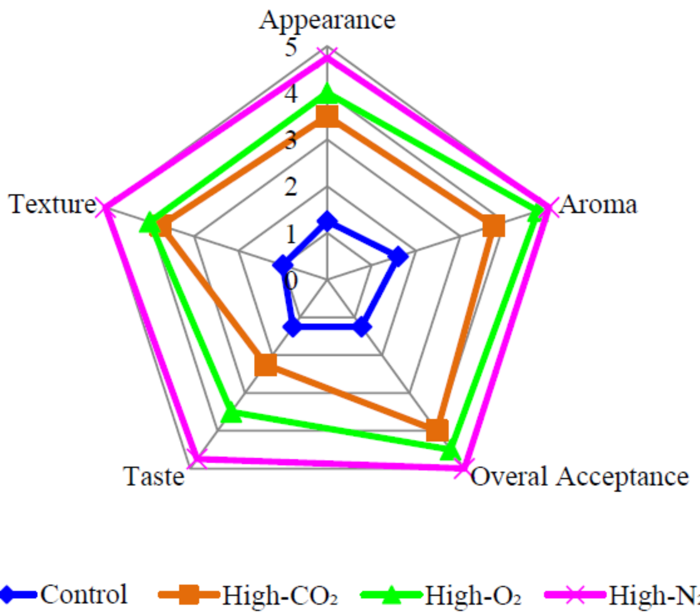

Figure 5. Effect of pre-storage MAP treatments on sensory evaluation of apricot fruits after 6 weeks of storage at 2˚C.

The best taste and texture were obtained from apricot fruits treated with high-N_2 (Figure 5) while the control samples were unpleasant to evaluate its taste. Because of the information obtained from other traits in the present experiment, such as firmness and soluble solids, it is concluded that the control samples have over-ripening, which had an undesirable taste and texture. Also, in the high-CO_2 treatment, fruit samples were unacceptable as judged by the panelists, probably because of the anaerobic respiration and production of substances such as alcohol and acetaldehyde, the taste of the fruits being undesirable. In high N_2-treated fruits, in addition to low oxygen concentration, high nitrogen inhibits anaerobic respiration in apricot fruit. It was in consistent with the findings of Moradinezhad and Jahani (2019) on apricot fruit. The aroma or odor in fruits is produced by several volatile compounds. As aroma is one of the most appreciated fruit characteristics, volatile flavor compounds are likely to play a key role in determining the perception and acceptability of products by consumers. This study showed that high-N_2, high-CO_2, and high-O_2 treatments were able to obtain acceptable scores for fruit aroma by the panelists. The highest score was related to high-N_2 treatment. Our observations also showed, when opening the lid of fruit packs. The aroma for the apricot fruit was detectable, while the control samples lacked this aroma. The results obtained in the present study were in accordance with the results of Klieber et al. (2002) on banana fruit. Appearance is one of the most important characteristics of fruits for consumer choice. As shown in Figure 6, all treatments were significantly better than the control group, but the high-N_2 treatment had the best overall acceptance and apparent in cold storage for six weeks at 2˚C. The most important attribute of any fruit's appearance is its color and decay. Figure 5 showing the differences in the appearance of apricot fruits in the treated and control samples after six weeks of storage. Other authors found similar results on mango (Ntsoane et al., 2020), on pear (Siddiq et al., 2020), and pomegranate (Moradinezhad et al., 2018) fruits.

Figure 6. Appearance of treated and untreated (control) apricot fruits, after 8 weeks of storage at 2˚C. A (air), B (high-CO_2: 90%), C (high-O_2: 90%), D (high-N_2: 90%).

CONCLUSIONS

The use of high-N_2 (90%) as a modified atmosphere packaging improves the physical properties (such as firmness, weight loss and color) of apricot fruit. Besides, by preserving chemical properties (such as total phenol content, and carotenoids), the nutritional value of treated fruit with high-N_2 maintained better than control during six weeks of cold storage at 2°C. Also, high N_2 reduced microbial load fruit appropriately. The results of this study show that the use of high-N_2 pre-storage treatment positively extended the shelf-life of fresh apricot fruit cv. ‘Shahroudi’ and is recommendable for commercial application as a simple and inexpensive postharvest method. Although the best treatment for this test was high N_2 treatment, the use of high CO_2 and high O_2 had a better performance than the control. Therefore, more studies are needed in this theme.

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