



Article

Effects of Different Oxygen Levels with High-Carbon Dioxide Atmosphere on Postharvest Quality of Fresh Fig under Palliflex Storage Systems

Adem Dogan ^{1,2}

¹ Department of Horticulture, Faculty of Agriculture, Akdeniz University, Antalya 07058, Turkey; ademdogan@akdeniz.edu.tr

² Department of Plant and Animal Production, Elmalı Vocational School, Akdeniz University, Antalya 07700, Turkey

Abstract: Regulation of storage atmosphere composition with high carbon dioxide (CO₂) is a highly effective and alternative approach to control quantity and quality losses in many horticultural crops. The aim of the study was to determine the effects of different O₂ with constant high-level CO₂ on the postharvest quality of fig cv. Bursa Siyahi in a new practical approach. For this purpose, 6% O₂ + 15% CO₂ (PL1), 9% O₂ + 15% CO₂ (PL2) and 21% O₂ + 0.03% CO₂ (Control) compositions were tested under a palliflex storage system during the cold storage and shelf-life. PL1 and PL2 were found to be more effective than the control for investigated parameters in general. After 28 days of cold storage and +3 days shelf-life, PL1 was also effective in controlling weight loss, ethylene production, antioxidant activity, decay incidence, decay severity, and total microorganisms. However, there were no significant differences between PL1 and PL2 for total soluble solids, titratable acidity, taste, visual appearance, firmness, respiration rate, and anthocyanin content. PL1 could be an effective composition for controlling decay and maintaining the postharvest quality of fresh figs during cold storage and shelf-life without any side effects on visual appearance and taste.

Keywords: atmosphere composition; *Ficus carica*; pallet storage; shelf-life; quality



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1. Introduction

Fig (*Ficus carica* L.) is one of the oldest cultivated and demanded fruits by consumers with high appreciation [1]. Demand for exotic fruit like figs is increasing nowadays due to their rich biochemical properties and positive effects on human health and delicious taste. Fresh figs are rich in phenolic, flavonoid [2], anthocyanin [3] and antioxidant compounds [4]. Fig is one of the most precious fruits with high economic value, and its total production was 1,264,943 tons in 2020, and approximately 75% of the production was met by Turkey (25.3%), Egypt (15.9%), Morocco (11.4%), Iran (8.5%), Algeria (9.2%) and Spain (4.7%), respectively [5]. Moreover, Turkey is the world leader in the exportation of fresh figs, with 20,334 tons in 2019 [6]. The handling, storage, shipping and marketing process of fresh figs requires professional expertise and diligence due to the pomological properties and short postharvest life [7]. Despite the high demand for fresh figs in the market, year-round availability is limited due to its short shelf-life period, and postharvest losses of fresh figs can reach up to 40–50% under inappropriate storage conditions and even higher during shelf-life [8]. Therefore, it is extremely important to develop new postharvest technologies for perishable horticultural crops like fresh fig, especially the commodities having short storage and shelf-life periods. There are several studies conducted to decrease postharvest losses and maintain fruit quality of fresh figs using different postharvest techniques, including low temperature and high CO₂ [9], low O₂ [10], modified atmosphere packaging [11–14], controlled atmosphere [15,16], 1-MCP [17], UV-C [18], SO₂ [19], calcium chloride [20], chlorine dioxide [21], sodium carbonate, acetic acid [22] and different coating

treatments such as aloe vera gel [23], chitosan-based [24] and chitosan combined with thymol essential oil [25]. Among these techniques, applications to regulate compositions of the storage atmosphere have gained popularity all over the world in recent years. Increasing the CO₂ level [26] and decreasing the O₂ level [27] had positive results on fresh produce during storage. However, although the postharvest approaches summarized above resulted in promising findings, none of them are, unfortunately, widely used in the storage of fresh fig. To maintain fruit quality of fresh fig, the atmosphere composition must be stably regulated not only during storage but also during transportation. Therefore, recently, the palliflex storage system, which is a modification of controlled and modified atmosphere storage systems, has commercially been used for the storage and transportation of some produce [28–30]. In this storage system, produces are stored on a pallet basis, and each pallet can be controlled independently with different atmospheric compositions. This study aimed to investigate the effects of different atmospheric compositions on fruit quality of fresh fig (cv. Bursa Siyahi) using a palliflex storage system.

2. Materials and Methods

Fresh fig fruits belonging to cv. Bursa Siyahi were harvested from a commercial orchard in Bursa, Turkey. The fruits were immediately transported with a refrigerated truck to the postharvest physiology laboratory of the Department of Horticulture of Akdeniz University in Antalya, Turkey. After eliminating damaged fruits, fruits were harvested commercially at the mature stage and uniformly selected for size and color. Selected fruits were placed into commercial cardboard boxes with 22 inserts, and the boxes containing the fruits were stored in three different ways. The first group was stored in palliflex containing the gas composition 21% O₂ + 0.03% CO₂ as control. The second group was stored in palliflex containing the gas composition 6% O₂ + 15% CO₂ (PL1), and the last group was stored in palliflex containing 9% O₂ + 15% CO₂ (PL2). Fig fruits were stored at 0 ± 0.5 °C at $90 \pm 5\%$ RH for 28 days and sampled on 0, 14 and 28 days. Moreover, the fruits were kept for 3 days at 20 °C to evaluate shelf-life performance under ambient atmosphere composition after sampling. For each atmosphere composition, three palliflex storage units were used. In this storage, O₂ and CO₂ levels for each unit were adjusted by a flow-through system, mixing N₂ supplied from a generator, CO₂, and O₂ supplied from gas bottles. The atmosphere inside each unit was measured at ten-minute intervals until the desired atmosphere compositions were set, and then the compositions were hourly checked and adjusted by the automation during storage.

2.1. Weight Losses and Fruit Firmness

Weight loss was determined with a digital scale (Denver TP-214, Denver Instruments, Bohemia, NY, USA) with a sensitivity of 0.01 g at the beginning of the experiment and the end of certain storage periods. Weight loss was calculated as the percentage loss of the initial weight. The firmness of fruits was determined by using a penetrometer (Chatillon DFI 10, Largo, FL, USA) to measure the peeled equatorial region on 3 different sides of fruits. Fruit firmness was shown as an average of these measurements, and results were given in Newton (N).

2.2. Total Soluble Solids (TSS) and Titratable Acidity (TA)

Total soluble solid content was measured by a digital refractometer (Atago, Tokyo, Japan) and given as percentage. To determine titratable acidity (TA), the purees were diluted ten times with distilled water and measured through a method described by Bahar and Lichter [16]. TA content was given as the percentage of citric acid.

2.3. Visual Appearance and Taste

Visual appearance and taste parameters were evaluated by five trained judges. For each fruit sample, the judges were asked to taste and visualize it and then asked how they felt about the fruit sample on a five-point hedonic scale described by Selcuk and Erkan [29].

In addition, bottled water was given to cleanse their palate in between fruit samples. The hedonic scale was: 1 = very poor; 2 = poor (limit of marketability); 3 = good; 4 = very good; 5 = excellent.

Equation (1) was used to calculate the visual appearance and taste score:

$$\text{Visual appearance or taste score} = \text{Total score} / \text{Maximum score} \quad (1)$$

where the total score is an overall of scores given by five panelist and maximum score is the highest scale point (5).

2.4. Respiration Rate and Ethylene Production

The respiration rate and ethylene production were determined by using gas chromatography (GC; Thermo Electron S.p.A., Strada Rivoltana, Milan, Italy). Fruit samples with known weight and volume were initially stored in 3 L gas-tight jars at 20 °C for 1 h. Then, the gas samples of 1 mL were taken out of the jar with a gas-tight syringe to measure respiration rate and ethylene production. Thermal conductivity detector (TCD), Supelco 80/100 alumina F-1 column, flame ionization detector (FID) and GS-GasPro 113-4362 capillary column were used to measure CO₂ and ethylene production, respectively. For respiration measurements, the oven temperature, detector temperature, hydrogen and dry airflow rates were set as 130 °C, 275 °C, 45- and 400 mL min^{−1}, respectively. Whereas, in the ethylene analysis, oven temperature, detector temperature, and hydrogen, dry air and helium flow rates were set as 35-, 350- and 25 mL min^{−1}, respectively. The external standards of ethylene and carbon dioxide were used to evaluate the obtained findings.

Equation (2) was used to calculate the respiration rate and ethylene production:

$$\text{Respiration rate or ethylene production} = A \times (V_j - V_p) / (t \times g) \quad (2)$$

where *A* is the sample area (ppm)/standard area (ppm), *V_j* is the jar volume (L), *V_p* is the product volume (L), *t* is the time (hour) and *g* is the fruit weight (kg).

2.5. Total Antioxidant Activity and Anthocyanin Content

Antioxidant activity (AA) was determined based on the inhibition of 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical, described by Fernández-León et al. [31]. According to their method, 50 µL of the sample extract was diluted with 950 µL of DPPH solution (6×10^{-5} mol L^{−1} in methanol). The mixture was kept at room temperature for 30 min and then measured at a wavelength of 515 nm in a spectrophotometer (Specord 40, Analytik-Jena, Jena, Germany). Trolox was used as standard, and AA was calculated as mg of Trolox (6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid) equivalent 100 g^{−1} of fresh weight. Total monomeric anthocyanin content was determined using the pH-differential method described by Lee et al. [32]. According to their method, the pH of the extract was adjusted to pH 1.0 and 4.5 with the potassium chloride (0.025 M, pH 1.0) and sodium acetate buffers. The absorbance of each equilibrated solution was read at 510 and 700 nm in a spectrophotometer (Specord 40, Analytik-Jena, Germany). Distilled water was used as a blank, and total anthocyanins were calculated as µg cyanidin-3-glucoside g^{−1} of fresh weight.

2.6. Decay Incidence, Decay Severity and Total Microorganisms

Decay incidence was recorded by counting the number of fruits with visible symptoms and expressed as a percentage of total fruits. Decay severity was estimated by visualizing the decay area on the surface of the fruit using a scale from 0 (sound fruit) to 5 (81–100% of rotted fruit surface) [33]. The total microorganisms were examined according to the method described by Cantín et al. [19] in both cold storage and shelf-life conditions. To measure the total microorganism, 1 cm² pieces were taken from the surface of the fruits and put into microtubes. Then, 1 mL of sterile water was added to the samples in microtubes, and the samples were vortexed for 30 s; 100 µL of the suspension was placed in a Petri

dish containing potato dextrose agar (PDA) medium. Microorganisms were counted after incubation for 5 days at 25 °C.

2.7. Statistical Analysis

The experiment was conducted by completely randomized design with three replicates, and each replication included 22 fruits. Basic statistical parameters such as mean and standard error of the mean were calculated, and one-way analysis of variance (ANOVA) was performed for each parameter. The data were analyzed by using the SAS 9.0 statistical software (SAS Institute, Cary, NC, USA), and means were compared using Duncan's multiple range test ($p \leq 0.05$).

3. Results and Discussion

3.1. Weight Loss

Different atmosphere compositions significantly affected the weight loss of fig fruits and increased with prolonging storage duration of both cold storage and shelf-life conditions (Figure 1A,B). The atmosphere compositions, PL1 (1.81%) and PL2 (1.82%), significantly reduced weight loss in comparison to control (2.37%) after 14 days of cold storage (Figure 1A). Similar results were found in the cold storage period of 28 days, and the highest weight loss reached 3.99% (control). A considerable increase was determined during shelf-life conditions in all atmosphere compositions. After 14 days of cold storage at 0 °C + 3 days of shelf-life at 20 °C, while the highest weight loss was determined as 6.24% in control, and the lowest was 4.63% in PL1 (Figure 1B). Similarly, after 28 days of cold storage + 3 days shelf-life at 20 °C, whereas the weight loss reached 8.14% in control, it was 6.26% in PL1 (Figure 1B). Weight loss of horticultural crops during storage affects many biochemical processes and metabolic activity as well as loss of income [34]. In addition, high weight loss in figs can negatively influence the postharvest quality of fruit due to surface wrinkle, desiccation and reduced visual appearance [35]. The current findings illustrated that weight loss of fruits during storage was lower in PL1 and PL2 compared to control. Moreover, the effects of atmospheric composition on weight loss were more evident under shelf-life conditions. However, Tsantili et al. [10] reported that there were no significant differences between control and 2% O₂ (balanced with N₂) treated fruit stored at −1 °C.

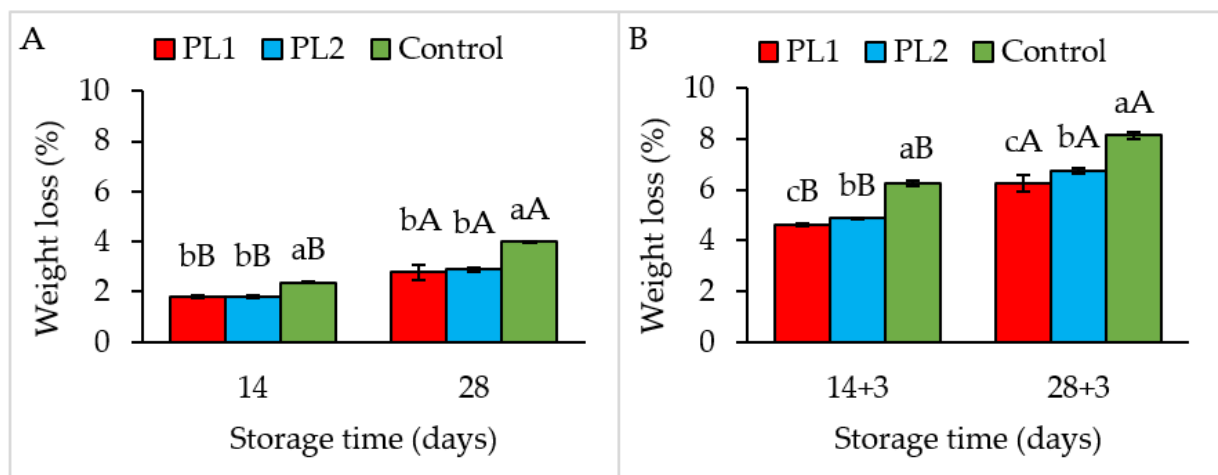


Figure 1. Weight loss changes during the cold storage (A) and shelf life (B). Data are the mean $\pm$ SE of three replicates of twenty-two fruit. Different uppercase letters indicate significant differences for each atmosphere composition during storage, and different lowercase letters indicate significant differences between atmosphere compositions for each sampling date at $p < 0.05$.

Differences between current findings can be caused by cultivar differences, storage systems and especially the combined effect of low O₂ and high CO₂. It is known that the

low O₂ and high CO₂ levels could affect the respiration rate and metabolism of fruits and vegetables [26,27]. In another similar study, the ‘Ottomanit’ fig variety fruits were stored in different atmosphere compositions such as 5/5, 5/10 and 5/15 (O₂/CO₂%), resulting in lower weight loss compared to the control [16].

3.2. Firmness

Fruit firmness was also influenced by cold storage and decreased nearly two-fold during the first 14 days of cold storage in all atmosphere compositions; however, there were no significant differences between PL1 and PL2 (Figure 2A). Moreover, the lowest fruit firmness was determined in control (3.02 N) during the first 14 days of storage compared to PL1 (3.79 N), and it remained lower in control (2.81 N) in comparison to PL1 (3.45 N) after 28 days of storage (Figure 2A). Furthermore, fruit firmness decreased in all atmospheric compositions during the first 14 + 3 days of cold storage, and shelf-life and the highest fruit firmness was determined in PL1 (3.46 N) compared to tested atmosphere compositions (Figure 2B). At the end of 28 + 3 days of storage and shelf-life, the fruit firmness gradually decreased in PL1 (2.42 N) and PL2 (2.35 N), while the lowest fruit firmness was observed in control (1.94 N). In general, fruit firmness was diminished by 48.73%, 53.04% and 58.24% compared to the initial value at harvest after 28 days of cold storage in PL1, PL2 and control, respectively (Figure 2A).

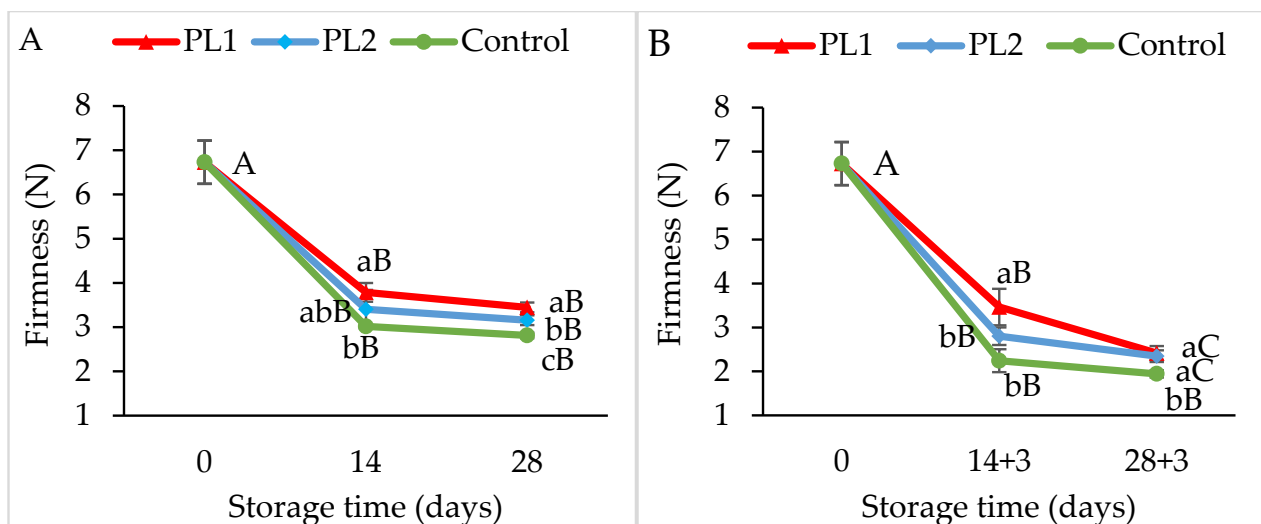


Figure 2. Fruit firmness changes during cold storage (A) and shelf life (B). Data are the mean $\pm$ SE of three replicates of twenty-two fruit. Different uppercase letters indicate significant differences for each atmosphere composition during storage, and different lowercase letters indicate significant differences among atmosphere compositions for each sampling date at $p < 0.05$.

Similar findings were obtained in shelf-life conditions; however, it was determined that PL1 effectively delayed the softening process after 14 + 3 days storage at 20 °C. Fruit firmness in control was diminished by 66.71% and 71.17% after 14 + 3 days and 28 + 3 days of shelf-life compared to harvest. During the ripening-related loss of firmness, it is considered that structural changes in pectin, hemicellulose and cellulose are responsible for altering the structure of the cell wall [36]. It was reported that lowering the O₂ level decreases enzyme activities related to cell modification resulting in delaying the fruit softening [37]. Tsantili et al. [10] also reported that low O₂ level and low temperature slowed firmness loss in fresh fig fruit. Furthermore, Villalobos et al. [13] examined the firmness of ‘San Antonio’ and ‘Banane’ figs packaged in microperforated films under low O₂ and high CO₂ and the loss of fruit firmness was prevented due to the reduction in respiration rate and ethylene production. Similar results were obtained in ‘Cello Dama Blanco’, ‘Cuello Dama Negro’ and ‘San Antonio’ fig varieties packaged in different microperforated films [14].

3.3. Total Soluble Solids (TSS) and Titratable Acidity (TA)

Although TSS content was slightly increased during cold storage in all atmosphere compositions, control fruit had significantly higher TSS than PL1 and PL2 both after 14- and 28-days storage durations (Table 1). However, 14-day cold storage + 3-day shelf-life did not significantly affect the TSS content, while it was higher in control than in PL1 and PL2 after 28-day cold storage + 3-day shelf-life (Table 2). TSS content was closely linked with fresh weight loss and TA content in fresh fig [38]. In this study, control fruit had high-level weight loss in comparison to the PL1 and PL2 due to the slowdown effects of atmosphere composition on metabolism. In parallel to the current findings, Bahar and Lichter [16] determined that a controlled atmosphere delayed ripening and slowed down the increased rate in TSS both in cold storage and shelf-life and in ‘Ottomanit’ figs. In addition, the atmosphere compositions did not significantly affect the TA content during the cold storage and shelf-life (Tables 1 and 2). Similarly, Ayhan and Karacay [12] also reported no significant differences between passive and active MAP (10% O₂ + 20% CO₂) application except for the 20th day of storage for the ‘Bursa Siyahi’ fig variety in terms of the TA. However, Özkaya et al. [17] reported a slight decrease in TA among control and 1-MCP treated ‘Bursa Siyahi’ fruits. The different findings obtained from the studies above can be caused by the treatments, harvest maturity stages and storage conditions.

Table 1. Total soluble solids (TSS), titratable acidity (TA), taste and visual appearance of Bursa Siyahi fig cultivar under palliflex storage system during cold storage.

Atmosphere Composition	Storage Time (Days)	TSS (%)	TA (% Citric Acid)	Taste	Visual Appearance
Initial	0	18.6 B ¹	0.23	5.0 A	5.0 A
PL1	14	18.8 b	0.20	4.8 A	4.9 A
PL2		18.7 b	0.21	4.8 A	4.9 A
Control		20.1 aA	0.21	4.5 B	4.6 A
PL1	28	19.2 b	0.20	4.4 B	4.6 aB
PL2		19.5 b	0.20	4.3 B	4.5 aB
Control		20.5 aA	0.21	4.1 C	4.1 bB

¹ Significant differences in each atmospheric composition depending on storage time are indicated by different uppercase letters, and significant differences among the atmosphere compositions for each sample date are shown by different lowercase letters ($p < 0.05$). Non-significant differences ($p \geq 0.05$) in the atmosphere composition and storage time not shown by any letters. The values are the means of three replicates of twenty-two fruit.

Table 2. Total soluble solids (TSS), titratable acidity (TA), taste and visual appearance of Bursa Siyahi fig cultivar under palliflex storage system during cold storage + 3 days at shelf-life.

Atmosphere Composition	Storage Time (Days)	TSS (%)	TA (% Citric Acid)	Taste	Visual Appearance
Initial	0	18.6 C ¹	0.23	5.0 A	5.0 A
PL1	14 + 3	19.5 a	0.20	4.6 aB	3.9 aB
PL2		19.5 a	0.20	4.5 aB	3.9 aB
Control		21.2 aA	0.21	4.0 bB	2.7 bB
PL1	28 + 3	19.2 b	0.19	4.0 aC	3.5 aB
PL2		18.9 b	0.19	3.9 aC	3.3 aC
Control		19.8 aB	0.18	3.8 aB	1.7 bC

¹ Significant differences in each atmospheric composition depending on storage time are indicated by different uppercase letters, and significant differences among the atmosphere compositions for each sample date are shown by different lowercase letters ($p < 0.05$). Non-significant differences ($p \geq 0.05$) in the atmosphere composition and storage time not shown by any letters. The values are the means of three replicates of twenty-two fruit.

3.4. Visual Appearance and Taste

Visual appearance score was not significantly different during the first 14-day storage either in storage time or tested atmosphere compositions (Table 1). However, after the 28-day storage, visual appearance scores decreased in all atmosphere compositions

compared to the initial values, and they were lower in control (4.1) in comparison to PL1 (4.6) and PL2 (4.5). Furthermore, shelf-life statistically affected the visual appearance of the fruits (Table 2). Both after 14 + 3 days and 28 + 3 days, the visual appearance scores decreased in all atmosphere compositions compared to the initial value, and the lowest values were recorded in the control (2.7 and 1.7). The fruit taste decreased during storage; however, there were no significant differences among the atmospheric compositions (Table 1). Significant differences occurred in PL1 and PL2 compared to the initial value of taste after 14 days of storage. On the other hand, the fruit taste score significantly decreased after 14 + 3-days and 28 + 3-days of storage in all, compared to the initial value of the fruits (Table 2). However, the lowest taste score was observed in the control fruit compared to PL1 and PL2 after 14 + 3-days storage, and the atmosphere compositions were not significantly different after 28 + 3-days storage.

Cantín et al. [39] reported that the visual appearance of fig fruit decreased during the storage due to the senescence process and increasing deterioration. On the contrary, the current study findings showed that low O₂ and high CO₂ had positive effects on inhibiting metabolic activity, decay incidence, decay severity and amount of microorganisms during prolonged cold storage and shelf-life conditions. Similar results were reported by Waghmare and Annapure [40], who studied the single and combined effects of irradiation (0.5 and 1 kGy) and MAP (5% O₂ + 10% CO₂) on the taste and visual appearance of 'Poona' fig variety stored at 5 °C for 15 days. The results indicated that poor visual appearance occurred in control fruit compared to MAP and other treatments. Similarly, Ayhan and Karacay [12] reported that active MAP [high O₂ (70%) and low O₂ (10%) with 20% CO₂] had a protective effect on the taste and appearance of the 'Bursa Siyahi' fig variety. Similarly, MAP was effective in maintaining the taste and overall appearance in stored 'Black Mission' figs both at 1 °C and 25 °C [41].

3.5. Ethylene Production and Respiration Rate

At harvest, the ethylene production of the 'Bursa Siyahi' fruit was determined as 3.23 µL C₂H₄ kg⁻¹ h⁻¹, and the respiration rate was 21.71 mL CO₂ kg⁻¹ h⁻¹ (Figure 3). Ethylene production significantly increased during both cold storage and shelf-life (Figure 3A,B). However, high CO₂ and low O₂ levels slowed down ethylene synthesis in fig fruit. On the 14th day of cold storage, the ethylene production in the control fruit was higher in comparison to in fruits stored in PL1 and PL2. A low amount of oxygen solidly decreased the ethylene production in fruits stored in cold storage after 28 days. The highest ethylene production was in control, and the lowest was in PL1 (Figure 3A). The trend was also similar during shelf-life conditions. While the highest ethylene production reached 8.08 µL C₂H₄ kg⁻¹ h⁻¹ in control, the lowest was reached 6.16 µL C₂H₄ kg⁻¹ h⁻¹ in PL1 after 28 + 3-days storage. In general, respiration rate slightly increased during 14-days storage, and it declined during 28-days storage in control. Although the respiration rate was higher at 25.49 mL CO₂ kg⁻¹ h⁻¹ in control in comparison to PL1 and PL2, there was no significant difference between the PL1 and PL2 for the respiration rate during 14-day storage (Figure 3C), and a similar trend was observed at the end of the 14 + 3-day storage (Figure 3D). On the other hand, respiration rate significantly decreased in control fruit (18.83 mL CO₂ kg⁻¹ h⁻¹) compared to PL1 and PL2 (21.16 and 22.73 mL CO₂ kg⁻¹ h⁻¹) at the end of the 28-day storage. Furthermore, respiration rate sharply decreased to 21.61 mL CO₂ kg⁻¹ h⁻¹ in control and was significantly lower than PL1 and PL2 after 28 + 3-days storage; however, PL1 and PL2 were not statistically different (Figure 3D). Crisosto et al. [42] reported that the ethylene production of fresh fig fruit generally increased from 4.0 to 6.0 µL C₂H₄ kg⁻¹ h⁻¹ when respiration rate increased from 20 to 30 mL CO₂ kg⁻¹ h⁻¹ at 20 °C. Similar results were found in the current study, where ethylene production changed between 3.23 and 8.08 µL C₂H₄ kg⁻¹ h⁻¹ while respiration rate changed from 18.83 to 27.60 mL CO₂ kg⁻¹ h⁻¹ based on treatments and storage times.

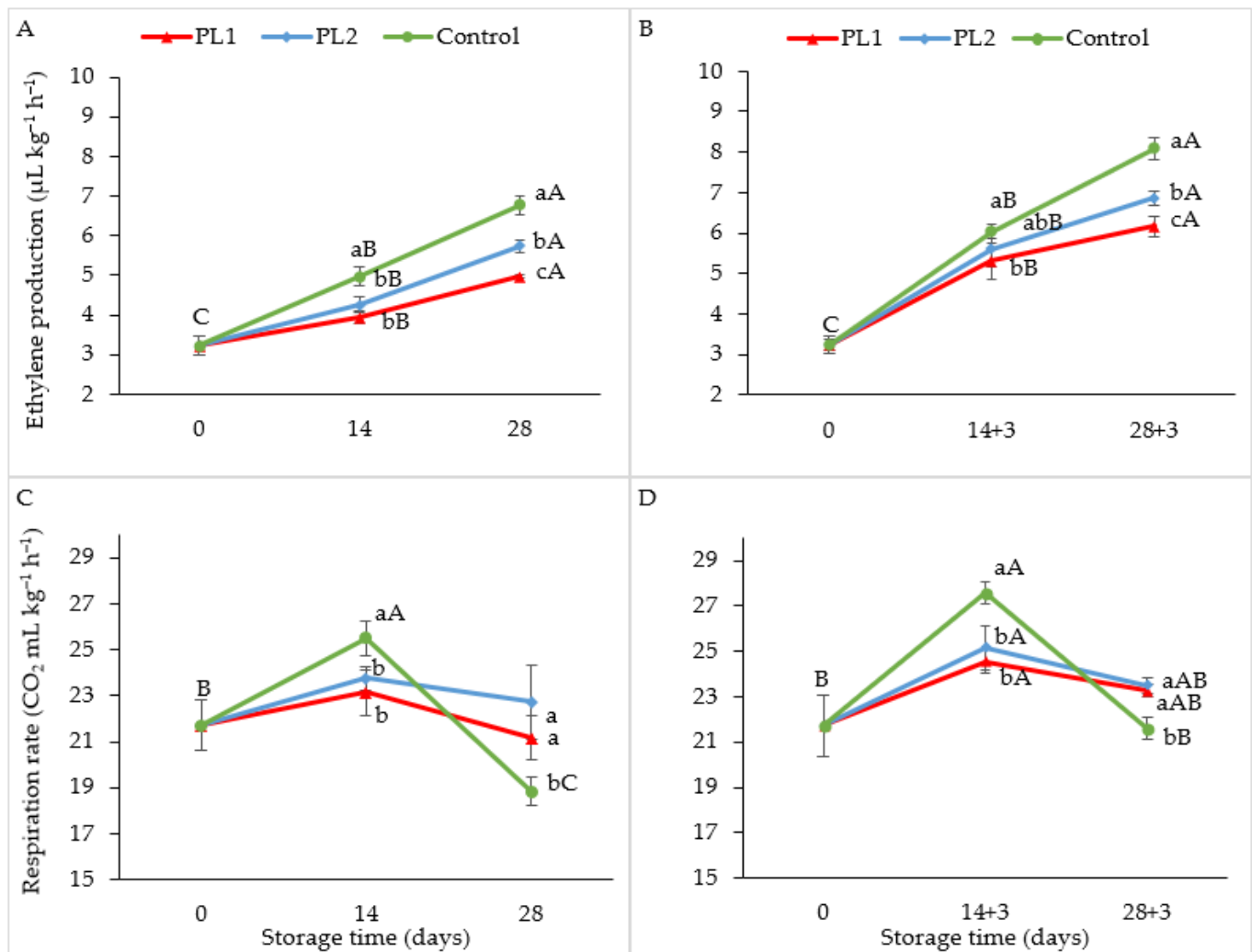


Figure 3. Ethylene production and respiration rate changes during cold storage (A,C), and ethylene production and respiration rate changes during shelf life (B,D). Data are the mean $\pm$ SE of three replicates of twenty-two fruit. Different uppercase letters indicate significant differences for each atmosphere composition during storage, and different lowercase letters indicate significant differences among atmosphere compositions for each sampling date at $p < 0.05$. Non-significant differences ($p \geq 0.05$) in atmosphere composition and storage time did not give any letters.

In this study, PL1 and PL2 were more successful in inhibiting ethylene production in comparison to control. Similarly, the enriched storage atmosphere of 15% and 20% CO₂ inhibited ethylene production in the ‘Mission’ fig due to the effects of autocatalytic ethylene biosynthesis [9]. In addition, many studies illustrated that low O₂ and high CO₂ reduced ethylene production and respiration rate [27,43] since they slow down fruit maturation by decreasing the expression of genes associated with ethylene synthesis [44]. On the other hand, although the respiration rate increased in the first period and then decreased, ethylene production in all atmosphere compositions showed an increasing trend during the storage periods. The increasing trend, especially in the first period, for both traits can be because fruits of cv. Bursa Siyahi show a certain amount of color change and maturation after harvesting. It was also stated by Freiman et al. [45] that there may be an increase in ethylene production in fig fruit with the progress of ripening. Similarly, Özkaya et al. [17] reported that an increase in ethylene production and respiration rate was determined in fruits of cv. Bursa Siyahi stored for 10 days. Moreover, it is considered that the decrease in respiration rate at the end of the storage can be caused by fruit senescence. Byeon and

Lee [38] also highlighted that the respiration of fig fruits increased during the first ten-day cold storage and then decreased sharply during the second half of cold storage.

3.6. Total Antioxidant Activity

It is acknowledged that fig fruit has rich antioxidant activity [4,46]. In the current study, the total antioxidant activity gradually decreased in all atmosphere compositions compared to the initial value during storage (Figure 4A). However, low O_2 and high CO_2 slowed the loss of antioxidant activities of fruits compared to control. During the 14-day storage, control fruit had significantly lower antioxidant activity than PL1 and PL2. At the end of the 28-days storage, while the highest antioxidant activity was detected in PL1 (428.2 mg Trolox 100 g⁻¹ fw), the lowest was in the control fruit (396.5 mg Trolox 100 g⁻¹ fw) (Figure 4A). Similar results were also obtained in shelf-life conditions (Figure 4B). Singh and Singh [47] stated that the antioxidative systems efficiently managed under low O_2 atmospheres to scavenge reactive oxygen species produced in response to gas stresses. In the current study, low O_2 combined with high CO_2 levels delayed the decrease in antioxidant activity of fresh figs. PL1 delayed loss of antioxidant activity, and therefore low O_2 can be prominent to reduce antioxidant loss in fresh figs at the end of the storage. The decrease in antioxidant activity can be caused by a decrease in polyphenol, vitamin C and other antioxidant-derivative biochemicals, as stated by Adiletta et al. [24]. On the other hand, Solomon et al. [1] also reported that total polyphenol and anthocyanin contents were positively correlated with antioxidant activity in ripe fig fruits as in this study. Therefore, decreased anthocyanin content in long-term storage may cause a decrease in antioxidant activity.

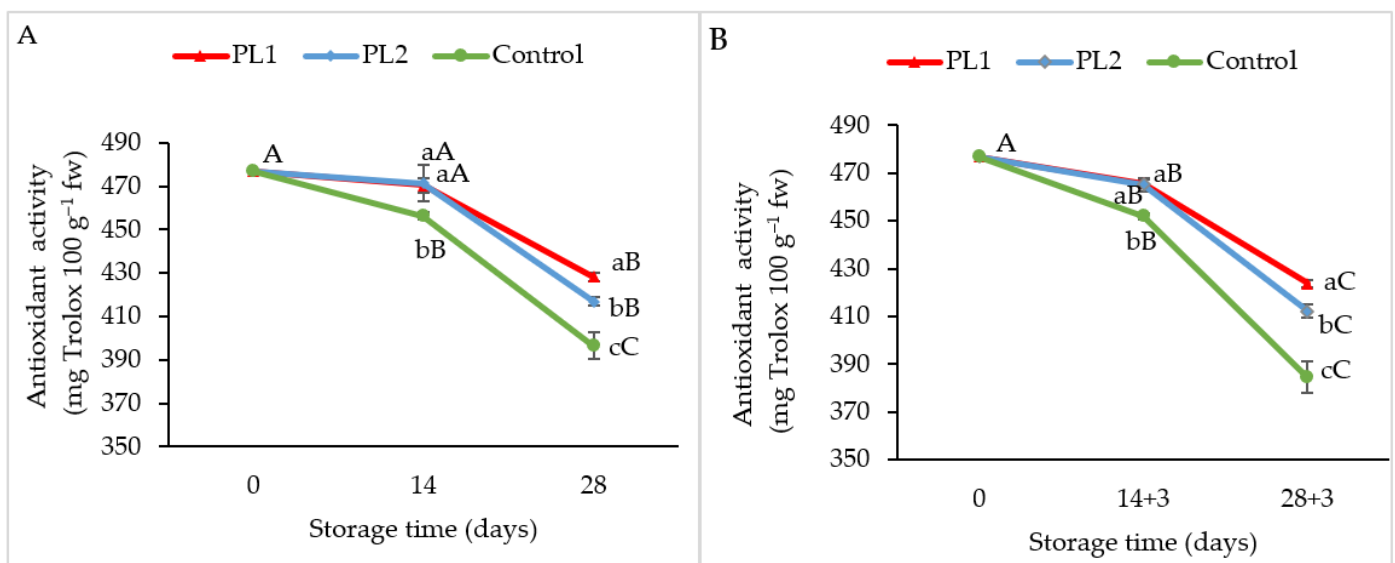


Figure 4. Antioxidant activity changes during cold storage (A) and shelf life (B). Data are the mean $\pm$ SE of three replicates of twenty-two fruit. Different uppercase letters indicate significant differences for each atmosphere composition during storage, and different lowercase letters indicate significant differences among atmosphere compositions for each sampling date at $p < 0.05$.

3.7. Total Anthocyanin Content (TAC)

At harvest, TAC was 122.7 μ g cy-3-rutinoside g⁻¹. TAC significantly increased during the 14-day storage period in all atmosphere compositions, and then it decreased in PL2 and control at the end of the 28-day storage (Figure 5A). The highest TAC was detected in control fruit (139.1 μ g cy-3-rutinoside g⁻¹) during the first 14-day storage, and the lowest TAC was in control (115.4 μ g cy-3-rutinoside g⁻¹) during the last 28-day storage. The storage of figs for 14 + 3-days significantly affected the TAC, where it was 143.3 μ g cy-3-

rutinoid g^{-1} in control and higher than PL1 and PL2 (Figure 5B). On the other hand, TAC was significantly higher in PL1 and PL2 than in control at the end of 28 + 3-days storage.

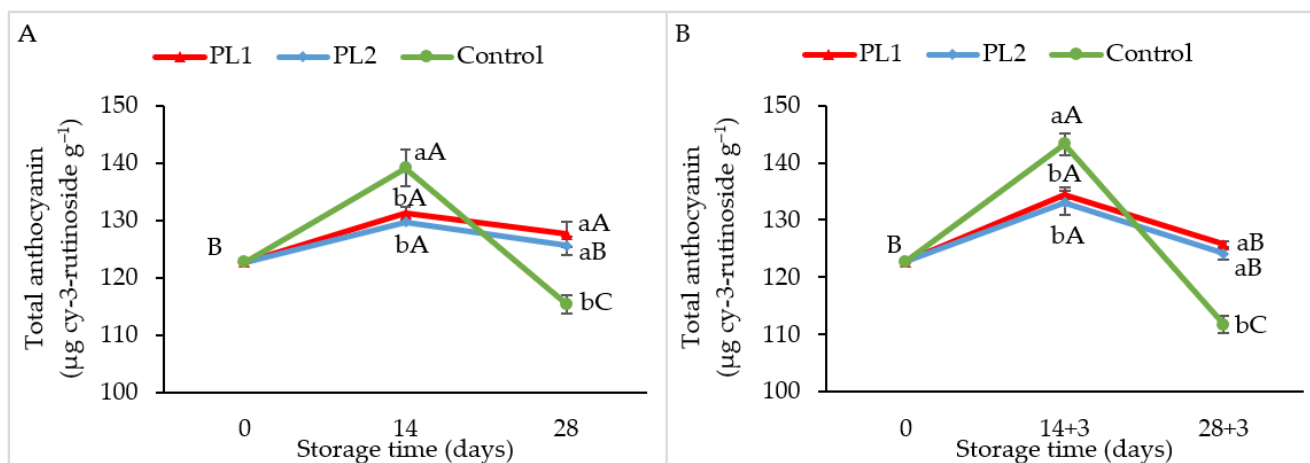


Figure 5. Total anthocyanin changes during cold storage (A) and shelf life (B). Data are the mean $\pm$ SE of three replicates of twenty-two fruits. Different uppercase letters indicate significant differences for each atmosphere composition during storage, and different lowercase letters indicate significant differences among atmosphere compositions for each sampling date at $p < 0.05$.

TAC showed an increase in the first 14-day cold storage period and then showed a decrease; however, these changes between periods were limited to PL1 and PL2. Saki et al. [25] reported that the anthocyanin content of coated and uncoated cv. ‘Siah’ fig fruit increased during the first five days and then decreased at the end of storage, as found in this study. Romero et al. [48] reported that high CO_2 levels as a pretreatment increased the anthocyanin content of the grapes, but this increase was lower in comparison to non-treated as found in the current study. Ali et al. [49] also claimed a decrease in the anthocyanin content of litchi fruit stored in a controlled atmosphere due to the slowing effects of the latter on metabolism and senescence. It can be because of the relatively high O_2 level since it is known as a destabilizing factor for polyphenolic compounds like total anthocyanins [50]. Khorshidi et al. [51] also support this hypothesis by acknowledging that a lower content of polyphenol and anthocyanin cherries stored in a normal atmosphere compared to fruits stored in a modified atmosphere was observed.

3.8. Decay Incidence, Decay Severity and Total Microorganisms

Appropriate storage conditions should be provided to avoid decay losses in fresh fig; if not, severe decay loss may appear within a short time. There was no decay during the first 14-day cold storage in low O_2 stored fruit, while a 5.6% decay incidence was found in control (Table 3). Whereas the highest decay incidence was determined in control (42.6%), the lowest was in PL1 (25.9%) during the 28-days of cold storage. However, decay incidences of fig fruit sharply increased during shelf-life conditions (Table 4). After 14 + 3-days storage, while the highest decay incidence (51.9%) was determined in control fruits, the lowest (28.0%) was determined in PL1. A similar trend was observed at the end of 28 + 3-days storage. When the decay incidence of control fruits increased up to 87.0%, it was 40.7% in PL1 (Table 4). Therefore, low O_2 and high CO_2 storage can be used effectively to control the decay incidence of fresh fig. The highest decay severities of 3.2 and 37.0 were detected in control for 14 and 28-days storage, respectively. Decay severity decreased based on the lowering oxygen level, and at the end of the storage, the lowest decay severity was 13.4 observed in PL1 (Table 3). During 14 + 3-days and 28 + 3-days shelf-life, while the highest decay severity was 44.0 and 69.5 in control, respectively, the lowest (14.4 and 28.2) was obtained from PL1 (Table 4). Moreover, a combination of low O_2 and high CO_2 significantly inhibited the total microorganism populations of fig fruits in

parallel to decay data. PL1 and PL2 had significantly fewer microorganisms than control during the first 14-day storage (Table 3). At the end of the 28-day storage, while the highest microorganism population was detected in control (4.37×10^5 cfu), the lowest was in PL1 (2.37×10^5 cfu). Similar results were also found in shelf-life (Table 4). The higher microorganism population was determined in control (5.90×10^5 cfu) followed by PL2 (4.10×10^5 cfu) and PL1 (3.20×10^5 cfu) after 28 + 3-days storage. The quality of fresh fig can be negatively affected by many pathogens such as *Alternaria* spp., *Botrytis* spp., *Fusarium* spp., *Aspergillus* spp., *Penicillium* spp. and *Rhizopus* spp. [8,19,52]. In the current study, most fresh figs decay occurred as mottling from the ostiole part of the fruit or start from the contact points with viols in packages. It was observed that low O₂ and high CO₂ had positive effects on lowering decay incidence and severity since they inhibit pathogen reproduction. Colelli et al. [9] reported that for controlling decay, 15% and 20% CO₂ levels were more effective than the normal atmosphere for cv. Mission fig. The 15% CO₂ or higher level was effective against *Botrytis* rot in Red Globe and Thompson Seedless grape [53]. Besides, 10% CO₂ + 6% O₂ level was suggested for Red Globe grapes for 4 weeks [54].

Table 3. Decay incidence, decay severity and total microorganisms of Bursa Siyahi fig cultivar under palliflex system during the cold storage.

Atmosphere Composition	Storage Time (Days)	Decay Incidence (%)	Decay Severity	Total Microorganisms (10 ⁵ cfu)
Initial	0	-	-	1.67 B, B, C *
PL1	14	0.0 bB ¹	0.0 bB	2.17 bA
PL2		0.0 bB	0.0 bB	2.27 bB
Control		5.6 aB	3.2 aB	3.03 aB
PL1	28	25.9 cA	13.4 cA	2.37 cA
PL2		33.3 bA	18.5 bA	3.40 bA
Control		42.6 aA	37.0 aA	4.37 aA

¹ Significant differences in each atmosphere composition depending on storage time are indicated by different uppercase letters, and significant differences among the atmosphere compositions for each sample date are shown by different lowercase letters ($p < 0.05$). Non-significant differences ($p \geq 0.05$) in the atmosphere composition and storage time did not show by any letters. * Capital letters show differences of means for PL1, PL2 and control, respectively. The values are the means of three replicates of twenty-two fruit.

Table 4. Decay incidence, decay severity and total microorganisms of Bursa Siyahi fig cultivar under palliflex system during the cold storage + 3 days at shelf-life.

Atmosphere Composition	Storage Time (Days)	Decay Incidence (%)	Decay Severity	Total Microorganisms (10 ⁵ cfu)
Initial	0	-	-	1.67 C
PL1	14 + 3	28.0 cB ¹	14.4 bB	2.37 bB
PL2		40.7 bB	25.0 bB	2.60 bB
Control		51.9 aB	44.0 aB	4.03 aB
PL1	28 + 3	40.7 cA	28.2 cA	3.20 cA
PL2		53.7 bA	44.4 bA	4.10 bA
Control		87.0 aA	69.5 aA	5.90 aA

¹ Significant differences in each atmosphere composition depending on storage time are indicated by different uppercase letters, and significant differences among the atmosphere compositions for each sample date are shown by different lowercase letters ($p < 0.05$). Non-significant differences ($p \geq 0.05$) in the atmosphere composition and storage time not shown by letters. The values are the means of three replicates of twenty-two fruit.

MAP, including low O₂ and high CO₂ storage, was effective in reducing decay development on ‘San Antonio’ and ‘Banane’ fig, while decay reached 98% in control fruit at the end of 21-day storage [13]. Likewise, positive effects of atmosphere compositions were also observed in ‘Cuello Dama Blanco’ and ‘Cuello Dama Negro’ fig cultivars reported by Villalobos et al. [14]. The total microorganisms in the current study varied from 1.67×10^5 to 5.90×10^5 cfu, and these findings agreed with the findings of Tepeli et al. [55], who

determined the total microorganisms to be between 1.00×10^5 and 9.50×10^5 cfu in 'Bursa Siyahi' fig stored with antimicrobial MAP. The ripening and senescence are delayed in a controlled atmosphere, and so decay incidence and susceptibility could be reduced [56]. These findings suggest that PL1 was more effective in controlling total microorganism burden both in cold storage and shelf-life.

4. Conclusions

A typical controlled atmosphere storage is not appropriate for fresh figs since commercial companies face many challenges regarding fruit circulation and management in a short season. Therefore, palliflex storage systems might be a useful alternative to overcome these problems. The current study revealed that the atmosphere composition of 6% O₂ + 15% CO₂ (PL1) was more effective in reducing ethylene production, respiration rate, antioxidant activity, decay incidence, decay severity and total microorganisms without any side effects on visual appearance and taste.

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