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Impact of Modified Atmosphere Packaging and Controlled Atmosphere Applications on 'Seval F1' Tomato Fruit Quality and Marketability

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ABSTRACT: This study was carried out at the Postharvest Physiology Laboratory of the Department of Horticulture of Isparta University of Applied Sciences with the 'Seval F1' table tomato variety. Tomato fruits are stored in normal atmospheric storage (NA), modified atmosphere packages (MAPs) (MAP1 and MAP2) and in controlled atmosphere (CA) cabinets (5% O_2+5% CO_2) at 12±1°C temperature and 90% ± 5 relative humidity (RH) conditions. After removing the fruits from cold storage at each analysis period they were kept at room conditions for 2 days for shelf life evaluation. Weight loss, peel color, fruit firmness, soluble solids content, pH, titratable acidity, respiration rate (RR), ethylene production (EP), MAPs' gas composition and sensorial analyzes were carried out for fruits taken randomly from cold storage and subsequent 2 days in shelf life conditions. According to the mean values, CA and MAPs maintained fruit firmness better than NA. The lowest RR (11.3 mLCO_2 kg $^{-1}$ h $^{-1}$) was recorded in NA followed by MAP1 (13.2 mLCO_2 kg $^{-1}$ h $^{-1}$). EP values of NA and CA were closer to each other's and lower than those of the others (2.7 and 2.8 µL.kg^{-1}h^{-1}, respectively). CA had the highest taste-aroma value at 25+2 days of storage, followed by MAP1 and NA. The highest O_2 (18.98 %) and the lowest CO_2 (2.90 %) values were recorded in MAP1. In conclusion, CA and MAP1 storage conditions successfully extended the postharvest life of 'Seval F1' tomato fruits and maintained their marketable quality for 25+2 days.

Keywords: Cold storage, controlled atmosphere, modified atmosphere packaging, postharvest, shelf life, quality

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INTRODUCTION

The tomato (*Solanum lycopersicum* L.) is a fresh vegetable in great demand worldwide (Black-Solis et al., 2019). Tomato is one of the most consumed vegetables worldwide, with a global production of 180.766.329 t ranked by China (62.764.671 t), India (19.007.000 t), and Türkiye (12.841.990 t) respectively (FAOSTAT, 2021). Organic acids, β-carotene, vitamins C and E, secondary metabolites, nutrients and mineral content of tomato make it essential for human health and prevent the formation and neutralizing various forms of free radicals by the antioxidative property (Dyshlyuk et al., 2020). The rate of oxidative stress-related diseases including atherosclerosis and cardiovascular disease decreases by regular consumption of tomatoes (Choi et al., 2015).

The fruit of tomato is known as a climacteric fruit and continues to ripen after harvest (Panjai et al., 2017). The rapid acceleration of alterations associated with ripening limits tomato fruit's postharvest life. One of the most crucial subject for the fresh tomato industry is the managing tomato fruit ripening (Candir et al., 2017). The broken cold chain, unsuitable storage conditions, and packaging materials are responsible for the production deterioration by increasing physiological activities. Other metabolic processes results the increase in postharvest losses (Choi et al., 2015).

Implementing the suitable storage conditions for the tomatoes harvested in red stages has high importance because of their high sensitivity to deterioration decreasing consumer acceptance and increasing economic loss (Cozmuta et al., 2016). The storage at low temperature maintains freshness and extends the shelf life due to reduced respiration and thermal decomposition. However, the chilling injury may develop under the storage conditions below 12.5°C temperature and this results poor quality fruits (Ali et al., 2010). The fruit quality is influenced negatively under the storage conditions below 10°C more than 2 weeks or 6-8 days at 5°C (Gonzalez et al., 2015). Chilling injury symptoms occur under low temperature conditions and this is a reversible response of products to low temperature with a cascade of secondary effects defined as chilling injury (CI) (Affandi et al., 2020). CI symptoms in tomatoes could be unbalanced ripening, extreme softening, surface pitting, increase in fungal decay, loss of flavor and color (Affandi et al., 2020) and browning of seeds (Candir et al., 2017). Consumer acceptance is decreased and the economic loss increases because of those injurious changes (Affandi et al., 2020).

The public tends to question current practices still in use due to the risk of carcinogenic by-products, residues and environmental damage (Ahmed et al., 2013). The controlled atmosphere (CA) storage (Fagundes et al., 2015) and modified atmosphere packaging (MAP) are the techniques used to prolong the postharvest life of vegetables and fruits by suppressing respiratory activity (Kyriacou and Rouphael, 2018; Ozturk and Ozer, 2019). The inner package CO_2 and O_2 levels are changed by passive or active way to suppress the respiration and ethylene production, slowing down the ripening related changes and prolonging the shelf life (Fagundes et al., 2015). The excellent barrier properties, low cost, and ease of production of polymeric packaging materials make it widely used to maintain the quality and safety of foods in the food industry (Guo et al., 2020).

As consumers in developed economies have been conditioned to a bounty of fruits and vegetables from across the globe and seasons, emphasis on shelf-life characteristics has been an inevitable necessity for furnishing this supply and demand cycle (Kyriacou and Rouphael, 2018). The postharvest diseases, senescence and transpiration confine the storage life of fresh tomatoes (Aguiló-Aguayo et al., 2013). Appearance is one of the most crucial quality attributes because the product's acceptance or rejection is determined by this criterion (Pathmanaban et al., 2019). Furthermore the organoleptic quality is an important attribute to determine the marketable quality and is composed of the combination of aroma, taste and texture (Oms-Oliu et al., 2011). Aroma ascribes to the smell of the products, whereas flavor comprises both taste and aroma (Pathmanaban et al., 2019). Flavor heavily relies on the balance between free amino acids, organic acids, volatile compounds and sugars. The senses of mouth feel, odor, and taste are essential in its perception (Oms-Oliu et al., 2011). Commercially, tomatoes are harvested different maturity stages, depending on the proximity between production and market place (Thole et al., 2020). Liu (2014) suggested 10-13 ± 1°C temperature and 90-95% relative humidity for the storage conditions of tomatoes.

Studies on the storage conditions and shelf life of the 'Seval F1' tomato variety are very limited. This study aimed to determine the effects of different modified atmosphere packages and controlled atmosphere conditions on the quality and shelf life of 'Seval F1' tomato variety.

MATERIALS AND METHODS

This study was carried out at Postharvest Physiology Laboratory of the Department of Horticulture of Isparta University of Applied Sciences with 'Seval F1' tomato variety in 2014. Tomatoes harvested at early hour in the morning on December 9 at the mature pink stage, placed in cardboard boxes and transported immediately to the laboratory by a covered pickup truck at 7°C atmospheric temperature. The fruits were grown in a greenhouse located in the Kumluca district of Antalya province. 'Seval F1' tomato variety's average fruit diameter is 65.16 mm, average fruit length is 52.15 mm, and fruit weight is between 180-200 g and has a flattened-round slightly sliced fruit shape. Although the planting of this tomato variety varies according to the region, it is carried out between 20 August and 20 September in the autumn season on the Mediterranean coastline where greenhouse cultivation is carried out (Anonymous, 2021). Fruits with a stem, healthy and without any defect were selected for the research. Tomato fruits are stored in normal atmospheric storage (20.9% O_2 + 0.03% CO_2), imported polyethylene (MAP1) and local polyethylene (MAP2) modified atmosphere packages and in controlled atmosphere (CA) insulated cabinets with a composition of 5% O_2 + 5% CO_2 at 12±1°C temperature and 90± 5% relative humidity conditions. After removing the fruits from cold storage at each analysis period they were kept at room conditions (20°C temperature and 65-70% relative humidity) for 2 days for shelf life evaluation.

a b

Figure 1. View of tomato cv. 'Seval F1' fruits on the plant (a) and after the harvest (b)

All analyzes mentioned below were carried out at 5-day intervals at cold storage period and the end of 2 days storage in room conditions.

Weight loss: At the beginning of the experiment, 15 fruits were labeled separately for each storage condition (NA, CA, MAP) and for each analysis period, and the measurements were made in these samples. In addition, the weights of the fruits were taken at the beginning and end of the shelf life analysis, and the changes during the shelf life were recorded. The obtained data were calculated with the following formula and evaluated as %:

Weight loss (%) = (Initial weight-Last weight) / (Initial weight) × 100 (1)

Peel color: Fruit peel color measurements were made using a Minolta CR-400 model color measuring device according to the CIE $L^*a^*b^*$ scale under the label where the fruit numbering is done in the equatorial region. Before the measurements, the device was calibrated.

Fruit firmness: Measurements were made using the Lloyd Instruments LF Plus texture device and the Nexygen package program installed on a computer to which it was connected. At the beginning of the experiment and in each analysis period, measurements were made on fruits removed from cold storage and at the end of their shelf life. 15 fruits, 5 fruits in each replication, were used and measurements were made from both sides of the fruit but not mutually. A 5.1 mm diameter cylindrical tip descending at a constant speed of 100 mm/min with a 50 N Loadcell was used. The maximum force obtained was used as the fruit firmness value in Newton (N).

Respiration rate and ethylene production: Fruits were weighed 1 kg into 4 L completely gas-tight jars and kept at room temperature (20°C) for 4 hours. Respiration rate and ethylene production were measured simultaneously in a single gas sample from each jar. Measurements in S/SL inlet split mode, using a fused silica capillary column (GS-GASPRO, 30 m x 0.32 mm ID) in a 1 mL gas sample with a gas sampling valve, a thermal conductivity detector (TCD) for respiratory rate measurement, a flame ionization detector for ethylene production amount (FID), Agilent brand GC-6890N model gas chromatography and Chemstation A.09.03 [1417] package program loaded on a computer to which it is connected. The carrier gas flow is 1.7mL/min in constant flow mode. The temperatures of the furnace, TCD and FID detectors are 40°C (isothermal), 250°C and 250°C, respectively. Gas flows for high purity hydrogen (H2) and dry air used as carrier gas in FID are 30 and 300 mL/min, respectively. High purity helium (He) (makeup) and Reference flow rates used as carrier gas in TCD are 7.0 and 20 mL/min, respectively. Respiration rate and ethylene production of fruits were evaluated according to the following formulas (Dilmaçünal, 2009):

$$\text{Respiration rate } (mLCO_2.kg^{-1}h^{-1}) = CO_{2(produced)}{}^{*} + CO_{2(absorbed)}{}^{**}.\ h^{-1***}.\text{fruit weight}^{-1} \quad (2)$$

$$\text{Ethylene } (\mu L.kg^{-1}.h^{-1}) = C_2H_4 \text{ x } (Volume_{jar} - Volume_{fruit}) \text{ x } (h \text{ x fruit weight x } 1000)^{-1} \quad (3)$$

$^{*}CO_{2(produced)}$: ($Volume_{jar}$-$Volume_{fruit}$) x (($CO_{2measured}$ - CO_{2air}) x 100^{-1})
$^{**}CO_{2(absorbed)}$: (k^{****} x $CO_{2produced}$) x ($Volume_{fruit}$ x 0.9^{*****}) ***h: Waiting time in jar (hours)
****k= 0.878 $mLCO_2$ $mL_{water}{}^{-1}$: Solubility in water of 100 percent of CO_2 at 20°C
****0.9 = Water content in fruit (according to % dry matter)

Titratable acidity and pH: For titratable acidity and pH measurements, 5 fruit pulps from each replication were made. From the juice obtained, 10 mL of two parallel fruit juices were prepared for analysis with a micropipette for each repetition. The pH value was measured by dipping the Hanna Instruments HI 9321 microprocessor model digital pH meter probe into the prepared fruit juice, and 0.1 N NaOH was titrated until the reading value reached 8.1. The amount of titratable acidity was calculated in terms of citric acid over the spent base, according to the formula below (Karaçalı, 2009):

$$\text{Citric acid } (\%) = ((SxNxFxE) \text{ x } C^{-1}) \text{ x } 100 \quad (4)$$

(S: amount of sodium hydroxide used (mL); N: normality of sodium hydroxide used; F: factor of sodium hydroxide used; C: amount of sample taken (mL); E: equivalent value of the corresponding acid (0.064 g for citric acid))

Soluble solid content: 5 fruits from each replication were made into pulp by squeezing in a juicer. The amount of SSC in the obtained fruit juice was determined as % (Brix°) using Atago Pocket PAL-1 digital refractometer.

Sensorial evaluations: In each analysis period, the fruits removed from the cold storage room were evaluated by the panelists in terms of visual quality (1-4:unmarketable, 5:marketable, 6-8:good, 9:excellent), taste and aroma (1:very poor, 2:poor, 3:moderate, 4:good, 5:excellent), calyx desiccation (1:healthy, 2:very little, 3:little, 4:moderate, 5:severe) and rupture (1:very difficult, 2:difficult, 3:moderate, 4:easy, 5:very easy).

Atmosphere composition in modified atmosphere bags: The gas compositions in the bags were made with the Systec Instrument Gaspace brand infrared gas analyzer in the bags taken out of the warehouse at each analysis period and at the end of the shelf life. The needle tip of the device was inserted into the bag and gas sample was taken from the bags. Obtained results are given as %.

TUKEY TEST was applied in multiple comparison methods to determine the differences between group means.

RESULTS AND DISCUSSION

The visual quality of the tomatoes decreased in all storage conditions and temperatures and the decrease was more dramatically in fruits stored in MAP2 than those of the others (Table 1). All the samples remained their marketable quality till 25+2 days of storage except for MAP2. The samples stored in MAP2 lost their quality after the 15th day of storage. The taste-aroma values decreased in all conditions with an extended storage period. CA fruits had the highest value at 25+2 days of storage, followed by MAP1 and NA. Tomatoes stored in MAP2 lost their edibility after the 15+2 days of storage. Calyx desiccation increased during the storage period and was higher at the shelf life than cold storage in all conditions. After 15 days of storage, calyx rupture increased with the increase in calyx desiccation (Table 1). Ayomide et al. (2019) reported that unpacked tomatoes could be stored with higher sensorial quality throughout 13 days in cold conditions, compared to 5 days for room conditions. Nunes et al. (1996) reported that storing of pink ‘Buffalo’ tomatoes at 4% O_2 + 2% CO_2 and 12°C extended their shelf life. Ayomide et al. (2019) indicated that perforated polyethylene bags extended the storage life for 20 days compared to 13 days at ambient. Our findings are in agreement with previous studies. It is stated that the characteristics of packaging materials required to be appraised to determine their eligibility for an individual cultivar of tomato (Mekonnen, 2017).

Table 1. Sensorial attributes of tomato cultivar 'Seval F1' in four storage conditions during cold storage and shelf life

S.C.	Storage Duration (days)											
	Visual quality (1-9 scale)											
	0	5	5+2	10	10+2	15	15+2	20	20+2	25	25+2	30
NA	9.0^{Aa*}	9.0^{Aa}	9.0^{Aa}	8.0^{Aa}	7.8^{ABab}	6.8^{Ba}	6.3^{BCa}	6.7^{Ba}	5.7^{Ca}	5.5^{Ca}	5.7^{Ca}	4.5^{Ca}
CA	9.0^{Aa}	9.0^{Aa}	8.8^{Aa}	7.2^{Ba}	8.8^{Aa}	4.9^{Cb}	6.2^{Ba}	4.8^{Cab}	6.0^{Ba}	5.0^{Cb}	5.0^{Ba}	2.0^{Db}
P1	9.0^{Aa}	9.0^{Aa}	9.0^{Aa}	7.0^{Ba}	6.5^{Bab}	5.7^{Bab}	5.8^{Ba}	5.6^{Ba}	5.8^{Ba}	5.6^{Ba}	5.8^{Ba}	5.3^{Ba}
P2	9.0^{Aa}	9.0^{Aa}	9.0^{Aa}	7.3^{Aa}	6.0^{Bb}	5.0^{Bb}	3.0^{Cb}	2.0^{Cb}	1.0^{Db}	1.0^{Cc}	1.0^{Db}	1.0^{Cc}
	Taste and aroma (1-5 scale)											
NA	5.0^{Aa}	4.7^{Aa}	5.0^{Aa}	5.0^{Aa}	5.0^{Aa}	4.5^{ABc}	4.8^{Aa}	4.3^{ABa}	4.2^{Ba}	3.7^{Ba}	3.0^{Cb}	2.3^{Ca}
CA	5.0^{Aa}	5.0^{Aa}	5.0^{Aa}	5.0^{Aa}	5.0^{Aa}	5.0^{Ab}	4.7^{Aab}	4.2^{Ba}	4.0^{Aa}	4.3^{Ba}	4.0^{Aa}	2.8^{Ca}
P1	5.0^{Aa}	4.7^{ABa}	5.0^{Aa}	4.7^{ABa}	4.5^{Bb}	5.0^{Aa}	3.8^{Cb}	3.7^{BCa}	3.8^{Ca}	3.7^{BCa}	3.5^{Cab}	2.8^{Ca}
P2	5.0^{Aa}	5.0^{Aa}	5.0^{Aa}	5.0^{Aa}	4.2^{Ab}	3.0^{Bd}	2.7^{Bc}	2.3^{BCb}	2.0^{BCb}	1.7^{Cb}	1.3^{Cc}	1.3^{Cb}
	Calyx desiccation of fruits (1-5 scale)											
NA	1.0^{Ca}	1.0^{Cb}	2.7^{Ba}	2.7^{Ba}	3.7^{ABa}	2.7^{Bab}	4.0^{Aab}	3.7^{Ab}	4.0^{Ab}	3.8^{Ab}	4.2^{Aab}	4.0^{Aab}
CA	1.0^{Ca}	1.3^{BCab}	2.3^{Ba}	1.3^{BCa}	3.3^{ABa}	2.3^{ABb}	3.7^{Ab}	3.2^{Ab}	3.8^{Abc}	3.3^{Ab}	4.5^{Aa}	3.5^{Ab}
P1	1.0^{Ca}	2.0^{BCa}	2.3^{Aa}	2.7^{ABCa}	3.2^{Aa}	3.5^{ABab}	3.3^{Ab}	3.8^{ABb}	3.3^{Ac}	3.8^{ABb}	3.3^{Ab}	4.0^{Aab}
P2	1.0^{Da}	1.0^{Db}	2.2^{Ca}	2.2^{Ca}	3.3^{Ba}	4.2^{Ba}	4.7^{Aa}	4.8^{Aa}	4.8^{Aa}	5.0^{Aa}	5.0^{Aa}	5.0^{Aa}
	Calyx rupture of fruits (1-5 scale)											
NA	1.0^{Ca}	1.0^{Ca}	1.3^{Ca}	1.5^{Cab}	1.7^{BCa}	2.5^{Ba}	2.7^{Bb}	2.8^{Bab}	2.7^{Bb}	3.0^{Bb}	4.0^{Ab}	4.5^{Aa}
CA	1.0^{Ca}	1.0^{Ca}	1.0^{Ba}	1.0^{Cb}	1.7^{Ba}	2.5^{Ba}	3.0^{Ab}	3.0^{Bab}	3.2^{Aab}	3.3^{Bab}	3.0^{Ac}	4.8^{Aa}
P1	1.0^{Da}	1.0^{Da}	1.3^{Ba}	2.0^{CDa}	2.0^{Ba}	2.3^{BCa}	2.8^{ABb}	2.7^{BCb}	3.0^{ABb}	3.2^{Bb}	4.7^{Aa}	4.8^{Aa}
P2	1.0^{Ea}	1.0^{Ea}	1.0^{Ca}	2.0^{Da}	2.0^{Ca}	3.3^{Ca}	3.7^{Ba}	3.8^{BCa}	4.0^{ABa}	4.2^{Ba}	5.0^{Aa}	5.0^{Aa}

*: Means followed by different letter in the same column are significantly different from each other at $P<0.05$ S.C.: Storage conditions, NA: Normal atmosphere, CA: Controlled atmosphere, P1: MAP1, P2: MAP2

Similar to Akbudak et al. (2007) and D'Aquino et al. (2016) CO_2 concentrations gradually increased while O_2 partial pressure decreased with increasing storage period in MAP1 and MAP2 packages. Modified atmosphere packages' inner O_2 concentration was lower while CO_2 was higher in MAP2 than MAP1 throughout the storage. The lowest O_2 (13.80%) and the highest CO_2 (4.57%) values were recorded in MAP2 (Table 2). It is thought that the reason for the low O_2 and high CO_2 values were the lower permeability of MAP2 than MAP1.

Table 2. Modified atmosphere packages' inner oxygen (O_2) and carbon dioxide (CO_2) values

MAPs	MAPs' G.C.	Storage Duration (days)						
		0	5	10	15	20	25	30
P 1	O_2 (%)	20.9^{Aa*}	19.83^{ABCa}	19.87^{ABCa}	20.02^{ABa}	19.42^{BCa}	18.82^{Ca}	18.98^{BCa}
P 2	O_2 (%)	20.9^{Aa}	15.03^{Bb}	15.00^{Bb}	13.38^{Bb}	12.97^{Cb}	13.27^{Bb}	13.80^{Bb}
P 1	CO_2 (%)	0.40^{Ba}	2.73^{Aa}	2.27^{Ab}	2.30^{Ab}	2.28^{Bb}	3.12^{Ab}	2.90^{Ab}
P 2	CO_2 (%)	0.40^{Da}	$3.05B^{Ca}$	2.98^{Ca}	3.53^{BCa}	3.60^{BCa}	3.97^{ABa}	4.57^{Aa}

*: Means followed by different letter in the same column are significantly different from each other at P<0.05 MAPs: Modified atmosphere packages, P1: MAP1, P2: MAP2, MAPs'G.C.: Modified atmosphere packages' gas composition

Although recent information on the crucial limits of water loss is not enough, generally wilting and shriveling and loss of quality begins with 5-10 % of water loss compared to initial weight in most vegetables. It makes them unmarketable (Lufu et al., 2020). Similar with Şen et al. (2004) weight loss of tomatoes increased with the extended storage period. In this study the storage condition with the highest weight loss was the normal atmosphere, while MAP2 limited weight loss in the best way, followed by CA and MAP1 at cold storage. The tomatoes reached 5.7 % at the 20th day of storage in NA while the samples stored in CA (5.3 %) and P1 (5.8 %) exceeded 5% on the 30th day of the storage. Low values were recorded in shelf life evaluation for all four conditions (Table 3). The respiration and transpiration levels of fruits increase with the combination of high temperature and low humidity conditions resulting in higher water loss (Lufu et al., 2020). The CA and MAPs are more controlled conditions in terms of humidity than NA. That is why higher water loss occurred in NA than in the other conditions. Abd Allah et al. (2011) reported 3.34 % weight loss in light pink tomatoes stored in cardboard boxes at the end of the 10th days at 12°C. Affandi et al. (2020) indicated that extended cold storage causes an increase in weight loss at the subsequent shelf-life evaluation. Our results are in accordance with the literature.

Soluble solid content (SSC) of the tomatoes were close to each other and a decrease was observed at the end of the storage compared to initial values. According to the mean values (data were not given) the highest SSC was recorded in NA (3.6 %), MAP1 (3.6 %) and CA (3.6 %). The lowest was in MAP2 (3.5 %) ($P<0.05$). Şen et al. (2004), Cheema et al. (2014), D'Aquino et al. (2016), Pagno et al. (2017), Bruijn et al. (2020) reported a decrease in the SSC of the tomatoes during the postharvest storage at respectively, 5±1 and 20±1°C, 15°C, 20°C, 20°C, 20°C. Abd Allah et al. (2011) reported 4.85 % SSC at the end of the 10th day at 12°C + 5 days at 20°C storage.

Titratable acidity (TA) of tomato fruits decreased at the end of the storage compared to initial values in both of two storage temperature and all conditions. Similar to Taye et al. (2017), there was no significant difference ($P<0.05$) in TA of fruits of cv. 'Seval F1' among storage conditions, although the acidity values of the fruits decreased with increasing storage period. Also Hernández-Yépez et al. (2013), Pagno et al. (2017) and Zhang et al. (2019) reported a decrease in TA of the tomatoes. Bruijn et al. (2020) reported that TA and soluble solids content are vital quality parameters for tomatoes showing a similar behavior with a significant decrease during the second half of postharvest storage.

The maximum desirable pH level is 4.4 for safety, and the optimum target pH should be 4.25 to maintain food safety (Teka, 2013). The pH of the tomatoes fluctuated during the storage period and samples stored in NA, CA and MAP1 were recorded as 4.4 while MAP2 (4.7) was above the limit values. So, it can be said that MAP2 was not successful as the other storage conditions to protect the safety of the fruits.

The firmness and weight loss of fruits are the physical parameters generally evaluated during storage period because of their important impact on the appearance of tomatoes (Cozmuta et al., 2016). Similar to Şen et al. (2004) the firmness values of tomatoes decreased with increasing storage period in all storage conditions. Similar to Majidi et al. (2014) CA and MAPs maintained fruit firmness better than NA according to the mean values (data were not given) and the highest value recorded in MAP2 (2.59 N), followed by MAP1 (2.45 N), CA (2.28 N) and NA (2.05 N) (Table 3).

Ripening is a very organized process attached to ethylene's behavior (Steelheart et al., 2019). Therefore, most tomato postharvest storage technologies are focused on managing the action of ethylene and respiration (Fagundes et al., 2015). In all conditions and storage temperatures ethylene production (EP) showed fluctuations throughout the storage. Generally EP was lower at cold storage than shelf life in all storage conditions. The highest EP was recorded in MAP2 (7.1 $\mu L.kg^{-1}h^{-1}$) followed by MAP1 (4.4 $\mu L.kg^{-1}h^{-1}$) on the 30th day of storage. It is thought that high relative humidity created a suitable environment for decay development and deteriorated fruits caused an increase in ethylene production of samples stored in MAP1 and MAP2. Ahmad et al. (2006) declared that diseases increase by high RH. According to Nunes (2008), when the vegetables and fruits are exposed to high humidity and temperature levels it may cause an increase in fungal decay. Likewise, the rate of deteriorated fruits was higher in MAP1 and MAP2 than in the others (data were not given). Delaying the loss of cellular integrity, which enhances fungi's ability to grow, will be possible by maintaining ethylene concentration as low as possible, which will extend the postharvest life of products (Pristijono et al., 2018).

In all conditions and storage temperatures respiration rate (RR) showed fluctuations throughout the storage. Generally RR was lower at low temperature than shelf life in all storage conditions. Similar to EP, the highest RR was recorded in MAP2 (21.0 $mLCO_2kg^{-1}h^{-1}$) on the 30th day of storage. A high level of ethylene production is thought to promote an increase in respiratory rate. Likewise Rees et al. (2011) reported that ethylene co-ordinates the expression of genes in climacteric fruit responsible for increasing the rate of respiration.

Color, especially for tomatoes, is essential for consumer acceptability and quality (Ali et al, 2010). Similar to Ali et al. (2010) the lightness decreased in all storage conditions and temperatures compared to initial values. Considering that fruits generally lose their marketable quality after 25+2 days (Table 3), it is seen that the brightness (L^*) is best preserved in MAP1, followed by CA, MAP2 and NA at 25+2 days. The highest chroma (C^*) value (28.9) was recorded in MAP1, followed by MAP2 (27.7), NA (27.5) and CA (26.2) while the highest saturation (h°) was recorded in CA (50.3), followed by MAP2 (48.4), NA (47.8) and MAP1 (47.2). According to data, the vividness of the tomato fruits stored in MAP1 at low temperature was better than those of the others. On the other hand, the fruits' color stored in CA is more saturated than MAP2, NA and MAP1. MAP1 was found the fruits' color stored in CA is the brightness and vividness of the tomatoes (data were not given). Similar to Belović et al. (2015), red tone (a^*) values were >20, while hue angle (h°) values were in the range 40–50° for all storage conditions at 25+2 days of storage, indicating that they were ripe and ready for consumption.

Table 3. Physical and chemical quality attributes of tomato cultivar 'Seval F1' in four storage conditions during cold storage and shelf life

S. C.	Storage Duration (days)											
	0	5	5+2	10	10+2	15	15+2	20	20+2	25	25+2	30
	Weight loss (%)											
NA		1.6^{Ea*}	1.1^{B}	3.1^{DEa}	1.0^{Dc}	4.6^{CDa}	1.0^{Cbc}	5.7^{BCa}	0.9^{Ec}	7.1^{ABa}	1.8^{Ab}	8.5^{Aa}
CA	-	1.1^{Aa}	1.1^{B}	1.8^{Aab}	1.1^{Bc}	2.7^{Aab}	1.2^{Bb}	3.2^{Aab}	1.1^{Bbc}	3.8^{Aab}	1.8^{Ab}	5.3^{Aa}
P1	-	1.0^{Da}	2.1^{A}	2.0^{Ca}	1.3^{Cb}	2.5^{Cab}	1.0^{Ec}	3.7^{Bab}	1.2^{Db}	4.2^{Bab}	1.8^{Bb}	5.8^{Aa}
P2	-	0.1^{Fb}	1.2^{E}	0.2^{Eb}	1.7^{Da}	0.3^{Db}	2.0^{Ca}	0.5^{Cb}	2.0^{Aa}	0.6^{Bb}	2.0^{Ba}	0.7^{Ab}
	Soluble solid content (%)											
NA	3.8^{Aa*}	3.5^{Ba}	3.6^{A}	3.7^{ABa}	3.5^{ABa}	3.4^{Bb}	3.7^{Aa}	3.6^{ABa}	3.3Ba	3.6^{ABab}	3.5^{ABa}	3.6^{ABa}
CA	3.8^{Aa}	3.6^{Aa}	3.7^{A}	3.7^{Aa}	3.5^{Aa}	3.4^{Ab}	3.7^{Aa}	3.6^{Aa}	3.5^{Aa}	3.8^{Aa}	3.5^{Aa}	3.6^{Aa}
P1	3.8^{Aa}	3.5^{ABa}	3.7^{A}	3.4^{Ba}	3.5^{Ba}	3.6^{ABa}	3.8^{Aa}	3.6^{ABa}	3.6^{ABa}	3.7^{ABa}	3.4^{Ba}	3.4^{Ba}
P2	3.8^{Aa}	3.4^{Ba}	3.4^{B}	3.6^{ABa}	3.7^{ABa}	3.5^{Bab}	3.8^{Aa}	3.6^{ABa}	3.5^{ABa}	3.4^{Bb}	3.3^{Ba}	3.5^{ABa}
	Titratable acidity (%)											
NA	0.4^{Aa*}	0.4^{Aa}	0.4^{A}	0.4^{Aa}	0.3^{Aa}	0.4^{Aa}	0.5^{Aa}	0.4^{Aa}	0.3^{Aa}	0.3^{Aa}	0.3^{Aab}	0.4^{Aa}
CA	0.4^{Aa}	0.4^{Aa}	0.4^{A}	0.4^{Aa}	0.4^{ABa}	0.4^{Aa}	0.4^{ABa}	0.4^{Aa}	0.4^{ABa}	0.4^{Aa}	0.4^{Bab}	0.3^{Aa}
P1	0.4^{Aa}	0.3^{Ba}	0.4^{A}	0.3^{Ba}	0.3^{Aa}	0.3^{Ba}	0.4^{Aa}	0.4^{ABa}	0.3^{Aa}	0.4^{ABa}	0.4^{Aa}	0.4^{AaB}
P2	0.4^{Aa}	0.4^{ABa}	0.4^{A}	0.4^{ABa}	0.4^{Aa}	0.3^{ABa}	0.4^{Aa}	0.4^{ABa}	0.3^{Aa}	0.4^{ABa}	0.3^{Ab}	0.3^{Ba}
	pH											
NA	4.7^{Ca*}	4.8^{Bb}	3.5^{A}	4.3^{Fb}	3.5^{Aa}	5.1^{Aa}	3.7^{Aa}	4.9^{Ba}	3.3^{Aa}	4.4^{Eb}	3.4^{Ab}	4.5^{Da}
CA	4.7^{Ca}	4.9^{Bab}	3.7^{A}	4.4^{Eab}	3.6^{Aa}	5.1^{Aa}	3.7^{Aa}	4.8^{Ba}	3.5^{Aa}	4.4^{Eb}	3.5^{Ab}	4.6^{Da}
P1	4.7^{Ca}	4.9^{Bab}	3.7^{A}	4.4^{Ea}	3.5^{Ba}	5.1^{Aa}	3.8^{Aa}	4.8^{Ba}	3.6^{ABa}	4.4^{Eb}	3.4^{Bb}	4.6^{Da}
P2	4.7^{Aa}	4.9^{Aa}	3.4^{C}	4.4^{Aa}	3.7^{BCa}	5.1^{Aa}	3.8^{Ba}	4.8^{Aa}	3.5^{BCa}	4.7^{Aa}	4.7^{Aa}	5.0^{Aa}
	Firmness (N)											
NA	3.8^{Aa*}	2.4^{Ba}	2.0^{A}	2.0^{BCb}	2.0^{Aa}	2.0^{BCa}	2.4^{Aa}	1.7^{BCa}	2.0^{Aa}	1.8^{BCa}	1.2^{Bb}	1.3^{Ca}
CA	3.8^{Aa}	2.3^{BCa}	3.0^{A}	2.8^{ABab}	2.5^{ABa}	2.6^{ABa}	1.9^{ABa}	1.6^{BCa}	2.5^{Aa}	1.8^{BCa}	1.4^{Bb}	1.2^{Ca}
P1	3.8^{Aa}	3.2^{Aa}	2.8^{A}	2.9^{Aab}	2.9^{Aa}	1.7^{Ba}	3.1^{Aa}	1.5^{Ba}	3.0^{Aa}	1.7^{Ba}	1.5^{Bb}	1.6^{Ba}
P2	3.8^{Aa}	2.6^{BCa}	2.4^{A}	3.2^{ABa}	3.0^{Aa}	2.4^{BCDa}	3.2^{Aa}	1.8^{CDa}	2.7^{Aa}	1.7^{CDa}	2.8^{Aa}	1.4^{Da}
	Ethylene production ($\mu L.kg^{-1}h^{-1}$)											
NA	3.5^{Aa*}	3.0^{ABa}	1.7^{B}	2.1^{Bbc}	1.9^{BCd}	2.3^{ABc}	2.4^{Bb}	2.5^{ABb}	1.3^{Cd}	2.4^{ABd}	3.7^{Ac}	2.7^{ABc}
CA	3.5^{ABa}	1.2^{Cb}	1.5^{C}	3.3^{Bab}	8.3^{Bb}	4.7^{Ab}	8.6^{Ba}	3.2^{Bb}	8.5^{Bc}	3.5^{ABc}	10.8^{Aa}	2.8^{Bc}
P1	3.5^{BCa}	2.8^{Ca}	1.9^{C}	1.7^{Dc}	3.9^{Bc}	1.7^{Dc}	1.4^{Cc}	2.8^{CDb}	9.5^{Ab}	5.3^{Ab}	4.3^{Bc}	4.4^{ABb}
P2	3.5^{Da}	3.1^{Da}	1.4^{D}	3.8^{Da}	10.4^{Ba}	8.8^{Ba}	8.4^{Ca}	13.1^{Aa}	20.0^{Aa}	7.9^{BCa}	9.3^{Cb}	7.1^{Ca}
	Respiration rate ($mLCO_2kg^{-1}h^{-1}$)											
NA	5.0^{Da*}	10.3^{ABCa}	9.9^{A}	8.8^{Ca}	9.7^{Ab}	9.8^{BCb}	10.2^{Ac}	9.5^{BCc}	9.2^{Ac}	12.0^{Ab}	10.8^{Ac}	11.3^{A}
CA	5.0^{Ea}	8.9^{Db}	9.4^{C}	6.2^{Ec}	11.5^{Cb}	10.6^{Cb}	14.4^{Bb}	11.1^{Cb}	15.1^{Bb}	14.9^{Bab}	21.1^{Aa}	17.6^{Ab}
P1	5.0^{BCa}	11.4^{Ca}	12.0	6.8^{Dbc}	10.6^{Cb}	10.3^{Db}	10.6^{Cc}	13.2^{CDa}	14.6^{Ab}	13.2^{Ab}	11.7^{Bc}	13.2^{A}
P2	5.0^{Da}	10.6^{CDa}	9.6^{D}	8.0^{CDab}	15.3^{Ca}	14.7^{BCa}	23.4^{Aa}	12.3^{CDa}	19.6^{Ba}	22.8^{Aa}	17.2^{BC}	21.0^{Aa}
	L^*											
NA	40.9^{Aa*}	40.7^{Aa}	39.7	39.8^{Ba}	39.4^{Aa}	39.6^{Ba}	38.8^{Aa}	39.8^{BCa}	38.0^{Aa}	38.2^{CDa}	37.5^{Ba}	40.9^{Da}
CA	42.0^{Aa}	41.5^{Aa}	40.7	39.7^{Ba}	39.2^{ABa}	39.3^{Ba}	39.2^{ABa}	38.9^{BCa}	38.8^{Ba}	38.3^{BCa}	38.0^{Ba}	37.5^{Ca}
P1	41.4^{Aa}	40.5^{Aa}	39.9	38.8^{BCa}	40.4^{Aa}	39.4^{Ba}	32.9^{Bb}	38.4^{Ca}	39.5^{Aa}	37.9^{CDa}	38.1^{Aa}	37.0^{Da}
P2	41.2^{Aa}	40.6^{Aa}	40.2	39.1^{Aa}	39.9^{ABa}	39.3^{Aa}	38.1^{ABa}	28.7^{Aa}	38.9^{ABa}	11.2^{Bb}	38.0^{Ba}	11.2^{Bb}
	a^*											
NA	19.0^{Aa*}	20.1^{Aa}	19.4	19.8^{Aa}	19.7^{ABa}	20.2^{Aa}	20.6^{Aa}	20.0^{Aa}	20.3^{ABa}	19.5^{Aa}	18.5^{Bab}	19.3^{Aa}
CA	20.0^{ABa}	20.6^{Aa}	19.1	19.6^{ABa}	19.7^{Aa}	19.6^{ABa}	18.8^{ABab}	19.1^{ABa}	17.7^{ABb}	18.3^{Bb}	16.7^{Bb}	16.2^{Cb}
P1	19.5^{BCDa}	21.6^{Aa}	19.6	20.5^{ABa}	20.9^{Aa}	20.3^{ABCa}	17.5^{Bb}	19.2^{BCDa}	18.8^{ABab}	19.0^{CDab}	19.7^{ABa}	18.4^{Da}
P2	20.0^{Aa}	20.4^{Aa}	18.7	19.6^{Aa}	21.0^{Aa}	21.2^{Aa}	20.5^{ABa}	14.3^{Aa}	20.4^{ABa}	5.4^{Bc}	18.4^{Cab}	5.2^{Bc}
	b^*											
NA	23.0^{Aa*}	23.2^{Aa}	21.4^{A}	22.0^{ABa}	22.1^{Aab}	21.7^{Bab}	22.4^{Aa}	21.0^{BCa}	21.9^{Aa}	20.2^{CDa}	20.4^{Aa}	19.6^{Da}
CA	23.2^{Aa}	22.9^{Aa}	22.0^{A}	21.4^{Ba}	21.2^{Ab}	21.2^{Bb}	21.5^{Aa}	20.6^{BCa}	20.8^{Aa}	19.8^{Ca}	20.1^{Aa}	18.3^{D}
P1	22.8^{Aa}	22.8^{Aa}	21.9^{A}	22.2^{Aa}	23.0^{Aa}	21.7^{ABab}	18.5^{Bb}	20.6^{BCa}	21.2^{Aa}	20.2^{Ca}	21.2^{Aa}	19.6^{Ca}
P2	23.0^{Aa}	22.9^{Aa}	21.7^{B}	21.4^{Aa}	23.0^{Aa}	22.5^{Aa}	21.1^{Ba}	15.9^{Aa}	21.1^{Ba}	5.95^{Bb}	20.7^{Ba}	20.5^{Aa}

*: Means followed by different letter in the same column are significantly different from each other at $P<0.05$ S.C.: Storage conditions, N: Normal atmosphere, C: Controlled atmosphere, P1: MAP1, P2: MAP2

CONCLUSION

According to the mean values, it was found that CA and MAPs maintained fruit firmness better than NA. The weight loss of tomatoes reached 5.7 % at the 20th day of storage in NA while the samples stored in CA (5.3 %) and MAP1 (5.8 %) exceeded 5% on the 30th day of the storage. The highest EP was recorded in MAP2 (7.1 $\mu L.kg^{-1}h^{-1}$) followed by MAP1 (4.4 $\mu L.kg^{-1}h^{-1}$) on the 30th day of storage. Similar to EP, the highest RR was recorded in MAP2 (21.0 $mLCO_2\ kg^{-1}h^{-1}$) on the 30th day of storage. All the storage conditions preserved marketable quality till 25+2 days of storage except for MAP2. The samples stored in MAP2 lost their quality after the 15th day of storage. CA had the highest taste-aroma value at 25+2 days of storage, followed by MAP1 and NA. The lowest O_2 (13.80%) and the highest CO_2 (4.57%) values were recorded in MAP2. When the data obtained from the study, especially weight loss and sensory analyzes were examined, it was concluded that CA and MAP1 storage conditions preserved the marketable quality of 'Seval F1' tomato variety for 25+2 days. It is thought that research should be done to determine the effects of different CA atmosphere compositions and MAPs on the quality of each different tomato variety. In conclusion, CA and MAP1 storage conditions successfully extended the postharvest life of 'Seval F1' tomato fruits and preserved their marketable quality for 25+2 days.

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Conflict of Interest

The article authors declare that there is no conflict of interest between them.

Author's Contributions

The authors declare that they have contributed equally to the article.

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