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Maintaining the Quality and Storage Life of Strawberries (*Fragaria* × *ananassa* Duch.) with Melatonin and Methyl Jasmonate

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Abstract

In this study, the effects of post-harvest applications of melatonin and methyl jasmonate (MeJA) on the quality parameters of Albion strawberries during the storage process were examined. The results showed a continuous increase in pH values during storage; The highest value was recorded in the 1 µmol L^{-1} MeJA group and the lowest value was observed in the 0.5 mMol L^{-1} Melatonin group. TSS content decreased in all treatments during storage due to increased respiration. Similarly, titratable acidity initially increased but decreased at the end of storage. In particular, it has been observed that administration of 0.5 mMol L^{-1} melatonin slows down the decrease in titratable acidity. There were fluctuations in color parameters (L*, a*, b*, C*, h°) during storage, and both melatonin and MeJA applications were effective in maintaining the L* value. MeJA application showed superior results in preserving overall color values. Respiratory rate increased initially and decreased after storage day 12; both melatonin and MeJA administrations contributed to the reduction in respiratory rate. The tanning index fluctuated across all treatments; Melatonin-treated groups showed the highest index at the end of storage. MeJA applications were more effective in protecting pH, TSS, L* value and color tone value. In conclusion, it can be said that post-harvest treatments of melatonin and MeJA have significant effects on quality parameters during the storage process of Albion strawberries and contribute to the understanding of post-harvest management strategies to increase the shelf life and quality of strawberry fruits

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1.Introduction

Belonging to the Fragaria genus of the Rosales family, strawberries exhibit unique characteristics such as the ability to thrive in a variety of climates, from desert regions to cold environments (Ağaoğlu, 1986). Known for its exquisite taste and aroma, strawberries have significant health benefits attributed to their high content of ellagic acid and L-ascorbic acid, which contribute to antioxidant properties and various anti-disease effects. However, despite their popularity and nutritional value, strawberries are susceptible to microbial spoilage, resulting in significant post-harvest losses (Cvetkovic and Jokanovic, 2009). Cold storage plays a crucial role in maintaining strawberry quality, but challenges remain due to their delicate nature and susceptibility to spoilage factors such as microorganisms, enzymes and biochemical reactions (Süleymanoğlu, 2009). Various interventions, including hormone administrations such as melatonin and methyl jasmonate (MeJA), have been investigated to reduce spoilage and extend shelf life (Yakupoğlu et al., 2018). Melatonin synthesized from tryptophan acts as a stress-responsive hormone, while MeJA derived from linoleic acid maintains food quality by modulating enzymatic activity. Despite the effectiveness of cold storage, the effect of melatonin and MeJA on post-harvest strawberries during cold storage remains relatively unexplored. This study aims to investigate the effects of exogenous melatonin and MeJA doses on strawberry quality parameters during post-harvest storage. By examining the effectiveness of these substances, valuable information is obtained on optimizing storage conditions and extending the shelf life of strawberries, thus increasing their marketability and reducing post-harvest losses (Vick and Zimmerman., 1984).

2.Materials and Methods

2.1. Materials

The fruits of the Albion strawberry variety harvested at the same maturity in the Sason district of Batman province were used as the research material. The harvested fruits were promptly delivered to the laboratory on the same day. Initially, the strawberry fruits were pre-cooled at 0°C for 12 hours. The selected strawberries were then randomly divided into three groups for the following treatments: Methyl Jasmonate (MeJal 0.5, 1.0, 1.5 μM), Melatonin (MLT 0.5, 1.0, 1.5 mM), and pure water applied as a control. The methodology for the specific packaging treatments was as follows: each group of strawberries was divided into three replicas, each containing 500 g of strawberries. Finally, all samples were stored at a temperature of 0°C and 80-85% relative humidity conditions.

2.2. Methods

2.2.1. pH

Calculation of pH in Albion strawberry variety is obtained by taking the supernatant part obtained after the samples are divided and centrifuged (Beckman Coulter, Allegra X-300R Brea, CA, USA) with the help of a homogenizer (IKA Ultra-Turrax T-25) and directly in the pH meter (Mettler-Toledo, Columbus, OH, USA) is determined by reading.

2.2.2. Total soluble solids content (TSS)

Calculation of total soluble solid (TSS) content in the Albion strawberry variety was measured using a digital hand refractometer from the supernatant part obtained (IKA Ultra-Turrax T-25) after the samples were divided and centrifuged with the help of a homogenizer (Beckman Coulter, Allegra X-300R) (Atago, Pal. -1, Pocket) and values are given in % (Elgar et al., 1997).

2.2.3. Titratable acidity (TA)

The method developed by modifying the method specified by Elgar et al. (1997) was used. Strawberry samples were crushed and centrifuged with the help of a homogenizer (IKA Ultra-Turrax T-25) (Beckman Coulter, Allegra X-300R Brea, CA, USA), 10 ml of fruit juice sample was taken from the supernatant portion, 20 ml of ultrapure water was added and diluted. In a pH meter, the juice was titrated with 0.1 N NaOH until the pH was

8.1 and the amount of titratable acidity was calculated as approaches 100 citric acid. (Karaçalı, 2009).

2.2.4. Colour (L, a*, b*, C*, h°)

Fruit color measurements in Albion variety strawberries were measured from 3 opposing regions from the middle axis of the fruit with the help of Minolta CR-410 colorimeter (Konica Minolta Sensing Inc., Osaka, Japan), and color values were determined as L*, a*, b* C* and hue angle values expressed. Colors represent a* (+red, -green), b* (+yellow, -blue) and L* (brightness) color values. It shows that the brightness increases as the L* value approach 100. The chroma value expresses the vitality and dullness of the fruit skin. While the chroma values are low in matte colors, the chroma value increases in vivid colors. The Hue angle represents the angle between the X-axis and the line passing through the intersection of a* and b* values. It corresponds to red when the angle is 0º, yellow when it is 90º, green when it is 180º, and blue when it is 270º.

2.2.5. Browning index

The following formula was used to determine the darkening of strawberry fruits during the storage period.

2.2.6. In-Pack gas composition

The CO_2 and O_2 gas levels in the packages of Albion variety strawberries were determined by Headspace Gas Analyzer GS3/L device from the packages removed from the warehouse in each period.

2.2.7. Respiration rate

Respiration rate measurements in fruit samples of Albion strawberry variety, strawberry fruits were placed in gas-tight containers and the amount of CO_2 they gave to the environment at the end of 2 hours was determined by Headspace Gas Analyzer GS3/L analyzer device. Respiration rate values were calculated by using fruit weight and volume values (Çavuşoğlu, 2020).

3.Results and Discussion

3.1. pH, total soluble solids content (TSS), titratable acidity (TA)

Descriptive statistics and comparison results for changes in pH value, TSS, and Titratable acidity (TA) contents in Albion strawberries are shown in Table 1.

When the changes in the pH value during the storage of Albion strawberry variety fruits are examined; It has been observed that there is an increase in all applications from the beginning to the end of storage. At the end of storage, the highest pH value was 3.790 in the 1 µmol L^{-1} MeJA group, and the lowest was 3.690 in the 0.5 mmol L^{-1} melatonin group (Table 1). Respiration is one of the most important factors affecting to pH (Kader and Ben-Yehoshua, 2000). It is in agreement with the findings that the pH values of strawberry fruits increase with ripening as the storage period increases. Çavuşoğlu (2018) reported that the MeJa application applied to the mushroom cap kept the pH value at a higher level at the end of storage compared to the control group. In the current study, it is thought that a 1 µmol L^{-1} MeJa dose prevents the decrease in pH during storage due to its effect on the respiration rate in strawberry fruits.

When the changes in the TSS content of Albion strawberry cultivar fruit samples were examined; A decrease in TSS content was observed in all applications throughout the storage period. It has been determined that there is a decrease in all applications from the beginning of storage to the end of storage. During the ripening period of horticultural crops, it increases due to the activity of the sucrose phosphate synthesis enzyme, which has an important role in TSS sucrose biosynthesis, and this enzyme becomes active on the ethylene side (Özgan et al., 2018). Strawberry fruit is harvested after fully ripening due to its non-climacteric nature. It is thought that the decrease in TSS content at the end of storage is due to the increase in respiration rate in strawberry fruits (Gil et al., 1997; Cordenunsi et al., 2005; Öz and Kafkas, 2015). It has been reported that TSS level has a positive effect with ripening and ripe fruits have higher TSS values than unripe fruits (Kondo et al., 2001; Kücüker and Öztürk, 2014). It has been reported that MeJA application prevents the decrease in TSS content in postharvest grape (Jiang et al., 2018) and mushroom (Çavuşoğlu, 2018) fruits. Similar to the studies on its storage, the MeJA application is thought to be effective in preventing decreases in the TSS content due to the consumption of sugars during the storage period. When the changes in the titratable acidity ratio are examined; Although an increase was noticed in all applications compared to the beginning of storage on the 6th day of storage, it was determined that there was a decrease in all applications at the end of storage. At the end of storage, it was determined that the highest titratable acidity ratio was between 0.685 and 0.5 mMol L^{-1} Melatonin group, and the lowest was 0.494 in the control group (Table 3). In the titratable acidity ratio, both the difference between applications and the difference between storage times were found to be statistically significant (Table 1).

Table 1. Changes in pH, TSS (%) and TEA (gl^{-1}) values in fruits of Albion strawberry variety during storage

App.		pH (Day) 0	3	6	9	12	14	Ort.
Cont.	0	3.61 ±0.07 c	3.71 ±0.04 Ab	3.66 ±0.09 bc	3.74 ±0.09 a	3.72 ±0.06 ab	3.74 ±0.01 BCa	3.69 ±0.01 A
MeJa (µM)	0.5	3.61 ±0.07 b	3.64 ±0.02 Ab	3.70 ±0.01 a	3.72 ±0.02 a	3.72 ±0.02 a	3.72 ±0.01 CDEa	3.69 ±0.01 AB
	1	3.61 ±0.07 c	3.66 ±0.01 Ac	3.65 ±0.02 c	3.75 ±0.03 ab	3.71 ±0.09 b	3.79 ±0.01 Aa	3.69 ±0.01 A
	1.5	3.61±0.07 b	3.61 ±0.02 Bb	3.66 ±0.02 ab	3.65 ±0.04 ab	3.67 ±0.07 ab	3.71 ±0.09 DEa	3.65 ±0.01 B
MEL (mM)	0.5	3.61 ±0.07 c	3.65 ±0.01 Ac	3.69 ±0.01 ab	3.71 ±0.03 ab	3.72 ±0.09 a	3.69 ±0.02 Eab	3.68 ±0.01 AB
	1	3.61 ±0.07 d	3.70 ±0.01 ABc	3.67 ±0.01 cd	3.73 ±0.03 ab	3.73 ±0.02 ab	3.76 ±0.03 ABCa	3.70 ±0.01 A
	1.5	3.61 ±0.07 c	3.70 ±0.03 Ab	3.65 ±0.01 bc	3.69 ±0.01 b	3.67 ±0.03 bc	3.77 ±0.07 ABa	3.68 ±0.01 AB
	Ort.	3.61 ±0.02 d	3.67 ±0.01 c	3.67 ±0.07 c	3.71 ±0.01 b	3.70 ±0.08 b	3.74 ±0.09 a	
		$p^{Aplication}$ = 0.003		$p^{S.T.}$ = 0.001			$p^{Aplication\ x\ S.T.}$ = 0.051	
App.		TSS (%) (Day) 0	3	6	9	12	14	Ort.
Cont.	0	9.46 ±0.17 a	7.73 ±0.03 ABb	7.30 ±0.26 ABbc	7.50 ±0.20 ABb	6.16 ±0.26 d	6,66 ±0,21 cd	7,47 ±0,26
MeJa (µM)	0.5	9.46 ±0.17 a	7.30 ±0.32 BCb	6.76 ±0.23 Bb	6.23 ±0.38 Db	6.73 ±0.94 b	6,93 ±0,36 b	7,07 ±0,32
	1	9.46 ±0.17 a	7.00 ±0.20 Cc	7.76 ±0.37 Ab	7.30 ±0.05 ABCbc	6.06 ±0.06 d	6,06 ±0,16 d	7,27 ±0,29
	1.5	9.46 ±0.17 a	8.10 ±0.37 Ab	8.00 ±0.17 Ab	7.06 ±0.21 A-Dc	6.83 ±0.18 c	6,46 ±0,13 c	7,65 ±0,25
MEL (mM)	0.5	9.46 ±0.17 a	8.03 ±0.12 Ab	7.60 ±0.32 Ab	6.56 ±0.32 CDc	6.66 ±0.16 c	6,26 ±0,16 c	7,43 ±0,28
	1	9.46 ±0.17 a	7.56 ±0.13 ABCbc	7.53 ±0.20 ABbc	7.73 ±0.27 Ab	6.73 ±0.46 cd	6,36 ±0,23 d	7,56 ±0,25
	1.5	9.46 ±0.17 a	7.93 ±0.08 ABb	7.86 ±0.08 Ab	6.63 ±0.26 BCDc	6.60 ±0.17 c	6,36 ±0,17 c	7,47 ±0,27
	Ort.	9.46 ±0.05 a	7.66 ±0.10 b	7.54 ±0.11 b	7.00 ±0.14 c	6.54 ±0.14 d	6,30 ±0,08 d	
		$p^{Aplication}$ =0.010			$p^{S.T.}$ =0.001			$p^{Aplication\ x\ S.T.}$ = 0.070
App.		TEA(gL^{-1}) (Day) 0	3	6	9	12	14	Ort.
Cont.	0	0.73 ±0.01 a	0.69 ±0.01 Db	0.66 ±0.01 Bc	0,56 ±0,09 Cd	0,52 ±0,02 De	0,49 ±0,01 Ef	0,61 ±0,02 D
MeJa (µM)	0.5	0.73 ±0.01 a	0.74 ±0.00 BDa	0.79 ±0.01 Aa	0,64 ±0,04 A-Cb	0,59 ±0,01 BCbc	0,57 ±0,01 CDc	0,68 ±0,02 BC
	1	0.73 ±0.01 a	0.70 ±0.01 CDab	0.75 ±0.03 ABa	0,62 ±0,05 BCbc	0,54 ±0,01 CDc	0,55 ±0,03 Dc	0,65 ±0,02 CD
	1.5	0.73 ±0.01 b	0.83 ±0.03 Aa	0.83 ±0.02 Aa	0,68 ±0,04 ABbc	0,63 ±0,01 ABc	0,61 ±0,01 BCc	0,72 ±0,02 AB
MEL (mM)	0.5	0.73 ±0.01 cd	0.79 ±0.02 ABab	0.84 ±0.03 Aa	0,75 ±0,01 Abc	0,68 ±0,01 Ad	0,68 ±0,01 Ad	0,74 ±0,01 A
	1	0.73 ±0.01 ab	0.73 ±0.02 BCab	0.80 ±0.05 Aa	0,72 ±0,03 ABab	0,61 ±0,04 ABCb	0,61 ±0,01 Bb	0,70 ±0,02 ABC
	1.5	0.73 ±0.01 bc	0.76 ±0.01 BCab	0.83 ±0.02 Aa	0,74 ±0,02 ABb	0,67 ±0,02 Acd	0,62 ±0,01 Bd	0,72 ±0,01 AB
	Ort	0.73 ±0.03 b	0.75 ±0.01 ab	0.78 ±0.01 a	0,67 ±0,01 c	0,61 ±0,01 d	0,59 ±0,01 d	
		$p^{Aplication}$ = 0.001		$p^{S.T.}$ = 0.001			$p^{Aplication\ x\ S.T.}$ = 0.026	

A,B,C : ↓ The difference between applications that receive different capitalizations within the same storage period is significant ($p<0.05$).
a, b, c : → The difference between storage times that have different lowercase letters within the same application is significant ($p<0.05$).
MeJA: Metil jasmonate
MEL: Melatonin

Since the titratable acidity value of fruits is affected by the metabolic activity and the respiration value that consumes organic acids, it has been reported that the amount of acidity decreases with the increase in respiration (Jin et al., 2012). Liu et al. (2016); in a study similar to the results of their study on strawberry fruit, it was determined that melatonin application slowed down the decrease in titratable acidity value in strawberry fruit during storage. As a result of the study, it is thought that 0.5 mMol L^{-1} melatonin dose treatment slows down the decrease in TA level due to slowing respiration in strawberry fruits.

3.2. Colour (L, a*, b*, C*, h°)

When the changes in L* values during storage of Albion strawberry cultivar fruit samples at 4°C and 85±5% were examined; It was determined that there were fluctuations in all applications during storage (Table 2).

Table 2. Changes in color parameters (L*, a*, b*, Chroma and h°) values during storage of Albion strawberry variety at 4°C and 85±5%

	App.	L* (Day) 0	3	6	9	12	14	Ort.
Cont.	**0**	30.73 $_{\pm0.41}$ ab	30.59 $_{\pm0.12}$ ab	29.48 $_{\pm0.35}$ b	30,22 $_{\pm0,55}$ b	31,53 $_{\pm0,42}$ Aa	31,69 $_{\pm0,31}$ Aa	30,70 $_{\pm0,22}$
MeJa (µM)	**0.5**	30.73 $_{\pm0.41}$	29.87 $_{\pm0.25}$	30.51 $_{\pm0.33}$	30,41 $_{\pm0,37}$	30,73 $_{\pm0,49}$ AB	31,18 $_{\pm0,48}$ AB	30,57 $_{\pm0,17}$
	1	30.73 $_{\pm0.41}$	30.45 $_{\pm0.53}$	30.69 $_{\pm0.59}$	30,58 $_{\pm0,39}$	31,31 $_{\pm0,45}$ A	31,07 $_{\pm0,33}$ AB	30,80 $_{\pm0,17}$
	1.5	30.73 $_{\pm0.41}$ ab	29.78 $_{\pm0.52}$ b	30.20 $_{\pm0.35}$ b	30,61 $_{\pm0,12}$ ab	31,72 $_{\pm0,24}$ Aa	31,70 $_{\pm0,61}$ Aa	30,79 $_{\pm0,22}$
MEL (mM)	**0.5**	30.73 $_{\pm0.41}$	30.62 $\pm_{0.35}$	29.85 $_{\pm0.94}$	30,01 $_{\pm0,38}$	30,55 $_{\pm0,21}$ AB	30,89 $_{\pm0,26}$ AB	30,44 $_{\pm0,19}$
	1	30.73 $_{\pm0.41}$ ab	30.20 $_{\pm0.12}$ b	29.73 $_{\pm0.14}$ b	29,95 $_{\pm0,49}$ b	29,94 $_{\pm0,30}$ Bb	31,50 $_{\pm0,27}$ A a	30,34 $_{\pm0,23}$
	1.5	30.73 $_{\pm0.41}$ ab	29.84 $\pm_{0.60}$ ab	29.72 $_{\pm0.57}$ ab	29,46 $_{\pm0,18}$ b	31,06 $_{\pm0,35}$ ABa	30,10 $_{\pm0,45}$ Bab	30,15 $_{\pm0,21}$
	Ort	30.73 $_{\pm0.13}$	30.19 $_{\pm0.15}$	30.02 $_{\pm0.19}$	30,18 $_{\pm0,15}$	30,98 $_{\pm0,17}$	31,16 $_{\pm0,17}$	
		$p^{Aplication}$ = 0.068		$p^{S.T.}$ = 0.001			$p^{Aplication\ x\ S.T.}$ = 0.541	

	App.	a* (Day) 0	3	6	9	12	14	Ort.
Cont.	**0**	30.62 $_{\pm0.25}$ a	29.62 $_{\pm0.42}$ Aab	28.04 $_{\pm0.66}$ ABc	28,02 $_{\pm0,16}$ Bc	28,80 $_{\pm0,63}$ bc	26,33 $_{\pm0,53}$ BCd	28,57 $_{\pm0,37}$
MeJa (µM)	**0.5**	30.62 $_{\pm0.25}$ a	30.99 $_{\pm0.43}$ Aa	29.78 $_{\pm0.31}$ Abc	29,42 $_{\pm0,13}$ ABc	29,76 $_{\pm0,49}$ bc	28,30 $_{\pm0,32}$ ABd	29,81 $_{\pm0,24}$
	1	30.62 $_{\pm0.25}$ a	28.56 $_{\pm0.74}$ Bab	28.12 $_{\pm0.64}$ ABab	28,76 $_{\pm1,17}$ ABa	28,91 $_{\pm0,28}$ a	26,06 $_{\pm1,18}$ Cb	28,51 $_{\pm0,43}$
	1.5	30.62 $_{\pm0.25}$ a	29.03 $_{\pm0.75}$ Bab	28.14 $_{\pm0.88}$ ABb	29,38 $_{\pm0,49}$ ABab	28,33 $_{\pm0,15}$ b	26,33 $_{\pm0,40}$ BCc	28,64 $_{\pm0,37}$
MEL (mM)	**0.5**	30.62 $_{\pm0.25}$ a	28.57 $_{\pm0.82}$ Bab	27.03 $_{\pm1.24}$ Bb	29,69 $_{\pm0,59}$ ABa	29,02 $_{\pm0,70}$ ab	28,48 $_{\pm0,43}$ Aab	28,90 $_{\pm0,37}$
	1	30.62 $_{\pm0.25}$ a	29.09 $_{\pm0.32}$ Bab	28.93 $_{\pm0.59}$ ABab	30,29 $_{\pm0,84}$ Aab	29,96 $_{\pm0,73}$ ab	28,54 $_{\pm0,51}$ Ab	29,57 $_{\pm0,27}$
	1.5	30.62 $_{\pm0.25}$ a	29.06 $_{\pm0.21}$ Bb	29.10 $_{\pm0.28}$ ABb	29,44 $_{\pm0,50}$ ABb	29,78 $_{\pm0,38}$ ab	26,98 $_{\pm0,45}$ ABc	29,16 $_{\pm0,29}$
	Ort	30.62 $_{\pm0.08}$	29.27 $_{\pm0.25}$	28.41 $_{\pm0.29}$	29,29 $_{\pm0,25}$	29,22 $_{\pm0,21}$	27,290±0,30	
		$p^{Aplication}$ = 0.001		$p^{S.T.}$ = 0.001			$p^{Aplication\ x\ S.T.}$ = 0.220	

	App.	b* (Day) 0	3	6	9	12	14	Ort.
Cont.	**0**	17.38 $_{\pm0.65}$	17.41 $_{\pm0.47}$	16.17 $_{\pm0.85}$	16,01 $_{\pm0,64}$	17,75 $_{\pm0,23}$	17,07$_{\pm0,36}$ BC	16,968$_{\pm0,25}$
MeJa (µM)	**0.5**	17.38 $_{\pm0.65}$	17.47 $_{\pm0.56}$	16.61 $_{\pm0.40}$	17,24 $_{\pm0,68}$	17,48 $_{\pm0,52}$	18,03 $_{\pm0,75}$ AB	17,37 $_{\pm0,23}$
	1	17.38 $_{\pm0.65}$	16.33 $_{\pm0.66}$	15.62 $_{\pm0.35}$	16,31 $_{\pm0,23}$	17,38 $_{\pm0,78}$	15,50 $_{\pm0,85}$ C	16,42 $_{\pm0,28}$
	1.5	17.38 $_{\pm0.65}$	16.62 $_{\pm1.27}$	15.85 $_{\pm0.57}$	16,84 $_{\pm0,30}$	18,14$_{\pm0,55}$	17,75 $_{\pm0,25}$ AB	17,10 $_{\pm0,30}$
MEL (mM)	**0.5**	17.38 $_{\pm0.65}$ ab	16.37 $_{\pm0.72}$ ab	15.27 $_{\pm0.99}$ b	16,43 $_{\pm0,36}$ ab	16,78 $_{\pm0,57}$ ab	17,75 $_{\pm0,09}$ ABa	16,66 $_{\pm0,290}$
	1	17.38 $_{\pm0.65}$ ab	16.69 $_{\pm0.13}$ b	16.10 $_{\pm0.44}$ b	17,33 $_{\pm0,66}$ ab	17,05 $_{\pm0,96}$ ab	18,84 $_{\pm0,3}$ Aa	17,23 $_{\pm0,29}$
	1.5	17.38 $_{\pm0.65}$ ab	16.20 $\pm_{0.08}$ c	15.72 $_{\pm0.44}$ c	16,71 $_{\pm0,26}$ bc	18,03 $_{\pm0,24}$ a	15,76 $_{\pm0,41}$ Cc	16,63 $_{\pm0,23}$
	Ort	17.38 $_{\pm0.20}$	16.73 $_{\pm0.24}$	15.91 $_{\pm0.21}$	16,70 $_{\pm0,18}$	17,51 $_{\pm0,21}$	17,24 $_{\pm0,30}$	
		$p^{Aplication}$ = 0.063		$p^{S.T.}$ = 0.001			$p^{Aplication\ x\ S.T.}$ = 0.516	

	App.	C* (Day) 0	3	6	9	12	14	Ort.
Cont.	**0**	35.30 $_{\pm0.55}$ a	34.46 $_{\pm0.58}$ Aab	32.46 $_{\pm0.99}$ b	32,34 $_{\pm0,46}$ Bbc	33,97 $_{\pm0,55}$ ab	31,50 $_{\pm0,60}$ BCc	33,34 $_{\pm0,39}$
MeJa (µM)	**0.5**	35.30 $_{\pm0.55}$ ab	35.65 $_{\pm0.39}$ Aa	34.16 $_{\pm0.46}$ a	34,27 $_{\pm0,37}$ ABab	34,59 $_{\pm0,67}$ ab	33,69 $_{\pm0,70}$ ABb	34,60 $_{\pm0,25}$
	1	35.30 $_{\pm0.55}$ a	32.99 $_{\pm0.97}$ Bab	32.23 $_{\pm0.71}$ a	33,14 $_{\pm1,10}$ ABab	33,89 $_{\pm0,63}$ a	30,45 $_{\pm1,48}$ Cb	33,00 $_{\pm0,49}$
	1.5	35.30 $_{\pm0.55}$ a	33.36 $_{\pm1.13}$ ABa	32.37 $_{\pm0.95}$ b	33,93$_{\pm0,49}$ ABab	33,76 $_{\pm0,18}$ ab	31,89 $_{\pm0,33}$ BCb	33,43 $_{\pm0,36}$
MEL (mM)	**0.5**	35.30 $_{\pm0.55}$ a	33.03 $_{\pm0.10}$ Bab	31.13 $_{\pm1.54}$ b	34,01 $_{\pm0,68}$ ABab	33,57 $_{\pm0,86}$ ab	33,69 $_{\pm0,39}$ ABa	33,45 $_{\pm0,44}$
	1	35.30 $_{\pm0.55}$	33.61 $_{\pm0.34}$ AB	33.17 $_{\pm0.74}$	34,98 $_{\pm1,04}$ A	34,55 $_{\pm1,15}$	34,38 $_{\pm0,68}$ A	34,33 $_{\pm0,33}$
	1.5	35.30 $_{\pm0.55}$ a	33.36 $_{\pm0.17}$ ABb	33.12 $_{\pm0.28}$ b	33,94 $_{\pm0,55}$ ABab	34,92 $_{\pm0,46}$ a	31,34 $\pm_{0,45}$ BCc	33,66 $_{\pm0,35}$
	Ort.	35.30 $_{\pm0.17}$	33.78 $_{\pm0.31}$	32.66 $_{\pm0.34}$	33,79 $_{\pm0,29}$	34,18 $_{\pm0,25}$	32,42 $_{\pm0,39}$	
		$p^{Aplication}$ = 0.003		$p^{S.T.}$ = 0.001			$p^{Aplication\ x\ S.T.}$ = 0.340	

	App.	Hue (h°) (Day) 0	3	6	9	12	14	Ort.
Cont.	**0**	29.36 $_{\pm0.68}$ b	30.29 $_{\pm0.45}$ b	29.78 $_{\pm0.79}$ b	29.62 $_{\pm0.80}$ b	31.35 $_{\pm0.56}$ ABab	32.97 $_{\pm0.51}$ ABa	30.56 $_{\pm0.38}$
MeJa (µM)	**0.5**	29.36 $_{\pm0.68}$ b	29.29 $_{\pm0.87}$ b	29.07 $_{\pm0.32}$ b	30.19 $_{\pm0.94}$ ab	30.33 $_{\pm0.43}$ ABab	32.30 $_{\pm0.79}$ ABCa	30.09 $_{\pm0.36}$
	1	29.36 $_{\pm0.68}$	29.46 $_{\pm0.437}$	28.94 $_{\pm0.30}$	29.55 $_{\pm0.69}$	30.60 $_{\pm0.88}$ AB	30.73 $_{\pm0.32}$ CD	29.77 $_{\pm0.26}$
	1.5	29.36 $_{\pm0.68}$ b	29.07 $_{\pm0.84}$ b	29.22 $_{\pm0.73}$ b	29.68 $_{\pm0.47}$ b	32.33 $_{\pm0.93}$ Aa	33.84 $_{\pm0.67}$ Aa	30.58 $_{\pm0.51}$
MEL (mM)	**0.5**	29.36 $_{\pm0.68}$ b	29.63$_{\pm0.85}$ b	29.27 $_{\pm0.69}$ b	28.77 $_{\pm0.09}$ b	29.92 $_{\pm0.51}$ Bab	31.66 $_{\pm0.21}$ BCDa	29.77 $_{\pm0.30}$
	1	29.36 $_{\pm0.68}$ b	29.61$_{\pm0.11}$ b	29.03 $_{\pm0.24}$ b	29.60 $_{\pm0.51}$ b	29.48 $_{\pm0.68}$ Bb	33.19 $_{\pm0.21}$ ABa	30.04 $_{\pm0.38}$
	1.5	29.36 $_{\pm0.68}$ abc	28.88$_{\pm0.14}$ bc	28.32 $_{\pm0.13}$ c	29.38 $_{\pm0.09}$ ab	30.88 $_{\pm0.10}$ ABa	30.26 $_{\pm0.90}$ Dab	29.51 $_{\pm0.26}$
	Ort.	29.36$_{\pm0.21}$	29.46$_{\pm0.21}$	29.09 $_{\pm0.18}$	29.54 $_{\pm0.21}$	30.70 ±0.28	32.14 ±0.33	
		$p^{Aplication}$ = 0.020		$p^{S.T.}$ = 0.001			$p^{Aplication\ x\ S.T.}$ = 0.251	

A,B,C : ↓ The difference between applications that receive different capitalizations within the same storage period is significant (p<0.05).
a, b, c : → The difference between storage times that have different lowercase letters within the same application is significant (p<0.05).
MeJA: Metil jasmonate; MEL: Melatonin

Colors; are one of the most important factors affecting the consumer perspective of strawberry fruit. The L* value has experienced decreases from the beginning to the end of storage (Şen et al., 2022). Liu, et al. (2018); Çavuşoğlu (2018) reported that the MeJa application was effective in preserving the L* value, and in the same way Liu et al (2018) in their study, MeJa application was effective in preserving the L* value of strawberry fruit. Similarly Zhang et al. (2018) reported that melatonin application applied to lychee fruit after harvest was effective in keeping the color parameters (a*, b*, C*, h°) at the desired level in terms of marketability. In the current study, it was noticed that the melatonin and MeJa applications applied after the harvest had positive effects on the color parameters of the strawberry fruits, and the MeJA application applied after the harvest was more effective in preserving the color values of fruits and vegetables.

3.3. In-pack gas composition (CO_2), respiration rate

Descriptive statistics and comparison results for changes in respiration rate (mL CO_2 kg h-^{1}) and CO_2 (%) gas composition during storage of Albion strawberry variety fruits are shown in Table 3.

Table 3. Changes in respiratory rate (mL CO_2 kg h^{-1}) and CO_2 (%) rates during the storage of Albion strawberry variety fruits.

	App	Respiration Rate (mL CO_2 kg h^{-1}) (Day) 0	3	6	9	12	14	Ort.
Cont.	0	65.30 ±0.95 c	77.74 ±5.83 bc	73.39 ±5.62 bc	85.19 ±2.67 ABb	104.22 ±2.65 a	68,20 ±6,91 c	79,01 ±3,52
MeJa (µM)	0.5	65.30 ±0.95 cd	76.59 ±3.18 bc	72.96 ±1.42 c	86.70 ±0.77 ABab	98.74 ±2.82 a	60,01 ±8,49 d	76,72 ±3,42
	1	65.30 ±0.95 cd	74.66 ±3.15 bc	75.08 ±0.32 bc	87.16 ±1.25 ABab	92.30 ±8.51 a	58,48 ±6,63 d	75,50 ±3,24
	1.5	65.30 ±0.95 c	74.10 ±2.99 bc	70.26 ±2.18 bc	84.46 ±1.31 Bab	91.77 ±10.59 a	66,79 ±4,96 c	75,45 ±2,90
MEL (mM)	0.5	65.30 ±0.95 c	78.37 ±1.27 b	66.18 ±2.76 c	83.18 ±2.85 BCab	91.52 ±6.25 a	61,69 ±4,27 c	74,37 ±2,88
	1	65.30 ±0.95 bc	70.19 ±1.20 b	71.20 ±3.46 b	91.77 ±2.51 Aa	92.31 ±4.24 a	59,34 ±4,45 c	75,02 ±3,24
	1.5	65.30 ±0.95 c	73.59 ±3.65 bc	68.20 ±2.87 bc	77.08 ±1.69 Cb	89.22 ±3.01 a	54,42 ±5,42 d	71,30 ±2,83
	Ort.	65.30 ±0.30	75.03 ±1.21	71.0 ±1.167	85.08 ±1.12	94.30 ±2.23	61,27 ±2,15	
		$p^{Aplication}$ = 0.081		$p^{S. T.}$ = 0.001		$p^{Aplication\ x\ S.\ T.}$ = 0.896		
	App	In-Pack Gas Composition (CO_2) (Day) 0	3	6	9	12	14	Ort.
Cont.	0	0.30 ±0.01 c	0.36 ±0.03 ABbc	0.36 ±0.03 bc	0.43 ±0.03 b	0.40 ±0.01 Bb	0,56 ±0,03 a	0,40 ±0,02
MeJa (µM)	0.5	0.30 ±0.01 c	0.40 ±0.01 Ab	0.40 ±0.01 b	0.40 ±0.01 b	0.40 ±0.01 Bb	0,50 ±0,05 a	0,40 ±0,01
	1	0.30 ±0.01 c	0.36 ±0.03 ABb	0.40 ±0.01 b	0.40 ±0.01 b	0.40 ±0.01 Bb	0,46 ±0,03 a	0,38 ±0,01
	1.5	0.30 ±0.01 c	0.33 ±0.03 ABc	0.40 ±0.01 b	0.40 ±0.01 b	0.43 ±0.03 Bb	0,50 ±0,01 a	0,39 ±0,01
MEL (mM)	0.5	0.30 ±0.01	0.40 ±0.01 A	0.40 ±0.01	0.40 ±0.01	0.40 ±0.01 B	0,50 ±0,01	0,40 ±0,01
	1	0.30 ±0.01 c	0.40 ±0.01 Ab	0.40 ±0.01 b	0.43 ±0.03 b	0.43 ±0.03 Bb	0,56 ±0,03 a	0,42 ±0,02
	1.5	0.30 ±0.01 d	0.30 ±0.01 Bd	0.40 ±0.01 c	0.46 ±0.03 b	0.50 ±0.01 Ab	0,56 ±0,03 a	0,42 ±0,02
	Ort.	0.30 ±0.01	0.36 ±0.01	0.39 ±0.01	0.41 ±0.01	0.42 ±0.01	0,52 ±0,01	
		$p^{Aplication}$ = 0.035		$p^{S. T.}$ = 0.001		$p^{Aplication\ x\ S.\ T.}$ = 0.004		

A,B,C : ↓ The difference between applications that receive different capitalizations within the same storage period is significant ($p<0.05$).
a, b, c : → The difference between storage times that have different lowercase letters within the same application is significant ($p<0.05$).
MeJA: Metil jasmonate; MEL: Melatonin

When the changes in gas levels in respiration rate (mL CO_2 kg h^{-1}) and CO_2 (%) gas composition were examined during storage of Albion strawberry variety fruit samples at 4°C and 85±5%; Although an increase was observed in the respiratory rate from the beginning of the storage period to the 12th day of storage, it was determined that the respiratory rate decreased in all application groups after the 12th day of storage. When the changes in the gas values in the CO_2 gas composition were examined, it was observed that there was a fluctuating increase in all applications during the storage period. At the end of storage, it was determined that the highest CO_2 level was 0.567 in the Control, 1 mMol L^{-1} melatonin and 1.5 mMol L^{-1} melatonin group, the lowest CO_2 value was 0.467 and 1 µmol L^{-1} MeJa group (Table 5). The difference between storage times and applications was found to be statistically insignificant in respiration rate (Table 5). Although it differs according to species and cultivars, there is an interaction between respiration and maturation. The rate of respiratory activity is related to the speed of the maturation process. As the respiration rate increases in horticultural crops, the shelf life is shortened (Cemeroğlu et al., 2001). Slowing respiration rates during post-harvest storage of fruits and vegetables are one of the most important factors in maintaining quality. Because slowing the respiratory rate means a decrease in the metabolic rate. Therefore, it is necessary to slow down the respiratory rate as an important step to preserve quality characteristics (Kasım, 2021). Meng et al. (2012). reported that the postharvest MeJA application, which they applied to mushrooms, decreased the respiration rate rapidly compared to the initial level, increased to a certain extent in the middle of the storage, and then decreased the respiration rate again at the end of the storage. In mango fruits that were applied MeJA after harvest and kept at 7 °C, the respiratory rate decreased in both control and MeJA-treated fruits on the 7th day of storage, increased and reached the highest level on the 21st day of storage, and then at the end of the storage, the respiratory rate decreased in both application groups (González-Aguilar et al., 2012). In addition, it is thought that melatonin application applied to nectarine fruits after harvest is effective in reducing the respiration rate of the fruits compared to the control group, and exogenous melatonin application is effective in inhibiting respiration by reducing the presence of O_2 in the tricarboxylic acid cycle (Bal, 2021). In the current study, when compared to the control group fruits, it was observed that the respiration rate decreased at the end of storage in both melatonin-treated fruits and MeJA-treated fruits, however, melatonin application was more effective in reducing the respiration rate of the fruits.

3.4. Browning index

Descriptive statistics and comparison results for the changes in the significant browning index (%) during storage are shown in Table 3.7. When the changes in the browning index (%) of strawberry fruits were examined, it was observed that there were increases and decreases in the form of fluctuations in all applications during the storage period. It was determined that the application with the highest browning index rate at the end of storage was in the 1 mMol L^{-1} melatonin group with 146,588, and the lowest browning index value was 123.616 in the 1 µmol L^{-1} MeJa group (Table 4). While the difference between storage times was not found to be statistically significant, the difference between applications was found to be statistically significant (Table 4).

Table 4. Changes in the browning index (%) of Albion strawberry variety fruit samples during storage at 4°C and 85±5%

	App.	Browning Index (%) (Day) 0	3	6	9	12	14	Ort.
Cont.	**0**	144 $_{\pm 2,83}$ a	144 $_{\pm 3,08}$ ABa	139 $_{\pm 4,95}$ ab	134 $_{\pm 3,34}$ Bab	139 $_{\pm 2,85}$ ab	130 $_{\pm 4,26}$ BCb	138 $_{\pm 1,75}$ BC
MeJa (µM)	**0.5**	144 $_{\pm 2,83}$ ab	150 $_{\pm 4,02}$ Aa	139 $_{\pm 1,46}$ b	143 $_{\pm 3,67}$ ABab	143 $_{\pm 2,24}$ ab	142 $_{\pm 3,72}$ ABab	144 $_{\pm 1,35}$ A
	1	144 $_{\pm 2,83}$ a	135 $_{\pm 2,79}$ Babc	129 $_{\pm 2,85}$ bc	135 $_{\pm 2,59}$ Babc	138 $_{\pm 3,15}$ ab	123 $_{\pm 7,80}$ Cc	134 $_{\pm 2,15}$ C
	1.5	144 $_{\pm 2,83}$	142 $_{\pm 7,01}$ AB	133 $_{\pm 4,76}$	139 $_{\pm 1,81}$ AB	140 $_{\pm 2,04}$	134 $_{\pm 2,09}$ ABC	139 $_{\pm 1,65}$ ABC
MEL (mM)	**0.5**	144 $_{\pm 2,83}$ a	135 $_{\pm 4,05}$ Bab	129 $_{\pm 4,97}$ b	140 $_{\pm 1,64}$ ABa	139 $_{\pm 3,79}$ ab	142 $_{\pm 2,40}$ ABa	138 $_{\pm 1,71}$ BC
	1	144 $_{\pm 2,83}$	140 $_{\pm 1,14}$ AB	138 $_{\pm 3,45}$	148 $_{\pm 6,16}$ A	145 $_{\pm 6,90}$	146 $_{\pm 2,28}$ A	144 $_{\pm 1,69}$ A
	1.5	144 $_{\pm 2,83}$ a	139 $_{\pm 3,27}$ ABab	136 $_{\pm 3,23}$ ab	145 $_{\pm 3,59}$ ABa	145 $_{\pm 2,94}$ a	131 $_{\pm 1,23}$ BCb	140 $_{\pm 1,64}$ AB
	Ort	144 $_{\pm 0,89}$	141 $_{\pm 1,67}$	135 $_{\pm 1,52}$	141 $_{\pm 1,55}$	142 $_{\pm 1,35}$	135 $_{\pm 2,11}$	
		$p^{Aplication}$ = 0.001			$p^{S.T.}$ = 0.001		$p^{Aplication \times S.T.}$ = 0.207	

A,B,C : ↓ The difference between applications that receive different capitalizations within the same storage period is significant ($p<0.05$).
a, b, c : → The difference between storage times that have different lowercase letters within the same application is significant ($p<0.05$).
MeJA: Metil jasmonate; MEL: Melatonin

Zheng et al. (2019) reported that when compared to the control group, it has been reported that the application of melatonin applied to freshly cut pear fruits after harvest has the highest browning index rate at the end of storage. Similarly, Zhang et al. (2018) reported that it was reported that the highest darkening index rate at the end of storage in Litchi fruit was in the fruit groups treated with melatonin. In addition, Cao et al. (2009) reported that it has been reported that the MeJA application applied to the loquat fruit after harvest has a lower browning index rate at the end of storage compared to the control group fruits and that MeJA application may be effective in preserving quality parameters such as the darkening index of the loquat fruit after harvest. In the current study, it was observed that there were increases and decreases in the darkening index in all applications and that the highest rate of the darkening index at the end of storage was in the groups treated with melatonin.

3. Conclusions

Strawberries are widely recognized for their ease of cultivation, delightful taste, high productivity per unit of land, and significant nutritional value. However, their vulnerability to spoilage post-harvest poses a challenge. Given their susceptibility to mechanical damage, water loss, and decay, strawberries quickly lose their quality and aroma. Their soft texture makes them prone to physical damage and hastens spoilage, resulting in a shortened shelf life. Extending the post-harvest shelf life of strawberries not only benefits producers economically but also encourages consumers to opt for healthier options. To address this issue, various approaches have been explored to preserve the fruit's nutritional value and prolong its shelf life. Among these, the utilization of substances like melatonin and methyl jasmonate has shown promise in enhancing strawberry resilience against decay and maintaining their marketable condition. Researchers prioritize criteria ensuring that post-harvest chemicals are safe for human consumption and meet commercial standards during storage. The application of melatonin and methyl jasmonate post-harvest has been found to have differing effects on the preservation of strawberry fruits during storage. Specifically, methyl jasmonate (MeJA) treatments have shown greater efficacy in safeguarding crucial quality parameters such as pH, total soluble solids (TSS), lightness (L* value), and color hue. Considering the limited shelf life and vulnerability of strawberries to post-harvest deterioration, enhancing their quality parameters and extending their shelf life through MeJA applications emerges as a viable and effective preservation method for commercial producers. This approach not only improves marketability but also ensures the delivery of high-quality strawberries to consumers, thereby benefiting both producers and consumers alike.

Declaration of Author Contributions

The authors declare that they have contributed equally to the article. All authors declare that they have seen/read and approved the final version of the article ready for publication.

Declaration of Conflicts of Interest

All authors declare that there is no conflict of interest related to this article.

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