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Effects of Methyl Jasmonate and Modified Atmosphere Packaging on Physical and Mechanical Characteristics of Apricot Fruit During Cold Storage

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ABSTRACT

In this study, the effects of methyl jasmonate [MeJA (0.5 and 1.0 mmol L^{-1})] and modified atmosphere packaging (MAP) applications on the physical and mechanical properties of 'Precoce de Thyrinthe' apricot variety during cold storage were investigated. Fruit were stored at 0±0.5°C and 90±5% relative humidity for 20 days. Physical properties of apricot such as geometric mean diameter, sphericity, surface area, bulk and fruit densities; mechanical properties such as puncture-compression forces and friction coefficient were determined. It was observed that MeJA application did not produce a significant difference on the size characteristics of apricot compared to the harvest period. Regarding the storage time, decreases were observed in the change of compression force results obtained from the X-, Y- and Z- axes according to the increase in the storage time. Effect on the puncture force on three axes showed a lower tendency to decrease in MAP application than in the harvest period compared to the application without MAP. The coefficient of friction on laminate and galvanized sheet surfaces was lower than PVC, plywood and rubber surfaces.

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Metil Jasmonat ve Modifiye Atmosfer Paketleme Uygulamalarının Soğukta Muhafaza Süresince Kayısı Meyvesinin Fiziksel ve Mekanik Özelliklerine Etkileri

ÖZET

Bu çalışmada, metil jasmonat (MeJA) için, 0.5 ve 1.0 mmol L^{-1} dozları ile modifiye atmosfer paketleme (MAP) uygulamalarının soğukta muhafaza süresince 'Precoce de Thyrinthe' kayısı çeşidinin fiziksel ve mekanik özellikleri üzerine etkileri incelenmiştir. Meyveler, 0±0.5˚C ve % 90±5 oransal nemde 20 gün boyunca muhafaza edilmiştir. Kayısı meyvesinin fiziksel özellikleri olarak; geometrik ortalama çap, küresellik, yüzey alanı, ağırlık, yığın hacim ağırlığı, meyve hacim ağırlığı, mekanik özellikleri olarak; delme ve sıkıştırma kuvvetleri ve sürtünme katsayısı incelenmiştir. MAP uygulamasının istatistiksel olarak uzunluk, genişlik ve kalınlık parametreleri üzerindeki etkileri önemli bulunmuştur. MeJA uygulamasının kayısı meyvesinin boyut özellikleri üzerinde, hasat dönemine göre önemli bir farklılık meydana getirmediği görülmüştür. Depolama süresinin boyutsal parametreler üzerine etkisi istatistiksel olarak önemli bulunmuştur. Genel olarak, MAP uygulanan meyvelerde hasat dönemine göre yığın hacim ağırlığı değerlerindeki azalmanın daha az olduğu tespit edilmiştir. Depolama süresiyle ilgili olarak depolama süresi artışına göre sıkıştırma testi sonucu X-, Y- ve Z- ekseninden elde edilen sıkıştırma kuvveti sonuçlarının değişiminde azalmalar gözlenmiştir. X-, Y- ve Z- eksenlerindeki delme kuvvetine etkisi MAP'sız uygulamaya göre, MAP'lı uygulamada, hasat dönemine göre daha düşük düzeyde bir azalma eğilimi göstermiştir. Laminant ve galvaniz sac yüzeylerindeki sürtünme katsayısının, PVC, kontrplak ve lastik yüzeylerine göre daha düşük değerler vermiştir.

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INTRODUCTION

Having high β-carotene and lycopene activity, apricot may prevent heart diseases. It regulates digestive conditions such as constipation and diverticulitis and is an excellent food for anemia due to its rich and valuable fiber source and high iron content (Vardi et al., 2008). However, quality losses occur after harvest due to many factors. In order to reduce these losses, growth regulators are used as a tool (Karaman et al., 2013).

Plant growth regulators are natural or synthetic compounds capable of controlling multiple physiological events within the plant, which are natural or synthetic compounds that affect fruit yield and quality, ripening process and post-harvest storage and shelf life. One of these compounds is methyl jasmonate (Öztürk 2012; Karaman et al., 2013; Öztürk et al., 2014).

Methyl jasmonate (MeJA), is an inducer of plant defense, regulation of certain cellular events such as aging, fruit ripening and ethylene synthesis and an inhibitor in cellular development, such as seed germination, pollination, and root development (Rohwer and Erwin, 2008). In a research carried out on apricot fruit (Ezzat et al., 2017), MeJA has been observed to significantly delay fruit quality losses during storage and shelf life. There are also studies reporting that MeJA has a significant effect on post-harvest quality preservation in fruit species such as cherry, mango, guava and pomegranate (Gonzalez-Aguilar et al., 2003; Sayyari et al., 2011; Saracoglu et al., 2017).

Modified atmosphere packaging (MAP) is a post-harvest technology used to reduce fruit quality loss during cold storage. The fruit placed in the packaging breathe carbon dioxide and use the oxygen in the environment. In this process, respiration is suppressed due to decreased oxygen and increased carbon dioxide and losses are reduced. With the spread of this method, quality losses in fresh fruit and vegetables are reduced and market value increases (Ozturk et al., 2019).

During the period until the transportation of agricultural materials to the market after harvest and post-harvest technological processes; significant changes in physical and mechanical properties are observed. Physical, mechanical and chemical properties of agricultural materials may vary depending on species and varieties, aquaculture system, environmental conditions such as light and temperature, harvest time, storage conditions and cultural processes in development regulators (Shin et al., 2008).

In this study, it was aimed to determine the effect of MeJA and modified atmosphere packaging applications on some physical and mechanical properties of 'Prococe de Thyrinthe' apricot variety during cold storage.

MATERIALS and METHODS

The material of the study consisted of fruit of 12 year-olds 'Precoce de Thyrinthe' cultivar grafted on wild apricot (*Prunus armeniaca* L.) grown in orchard of Malatya Apricot Research Institute in Turkey. Irrigation, fertilization, pruning and other cultural processes during the development of trees (weed, disease and pest control etc.) were regularly conducted.

The fruit were hand-harvested (19 June 2018) at a stage of uniform size and color, and the SSC content was approximately 11% and placed in 5 kg plastic box and transferred to post-harvest physiology laboratory.

The research was designed as a randomized plot with 3 replications according to factorial design. Fruit were first divided into 3 groups. The first group (1st group) fruit (control group) were immersed only in a distilled water solution containing solvent [Triton X- 100 (0.077%), Sigma-Aldrich, Germany]. The 2nd group fruit were immersed into 0.5 mmol L^{-1} and 3rd group fruit into 1.0 mmol L^{-1} MeJA (Sigma-Aldrich, Germany) solution for 1 minute. Then fruit were kept in the laboratory until the surface got dry. After that, the 1st, 2nd and 3rd group fruit were separated into 2 and one of them was packaged in a [(code: 815-AT 10 / R), (patent no. 6190710), StePac, Xtend] modified atmosphere packaging of 65 cm height, 53 cm width, 5 kg capacity, designed especially for apricot fruit; and the other one was not exposed to any application. Each case represented a repetition and 1 kg of fruit was placed.

Finally, the fruit were pre-cooled with air cooling (4±0.5°C ve 90±5% relative humidity) for 24 hours, and then the packages were closed with clips, and at 0±0.5 °C and 90±5% relative humidity stored for 20 days. In addition to fruit harvest, on the 5th, 10th, 15th and 20th days; physical properties such as geometric mean diameter, sphericity, surface area, mass, bulk and fruit densities, and mechanical properties such puncture and compressive forces and friction coefficient were determined.

All physical measurements were made on 30 fruit with 10 parallels per repetition. Fruit length, width and thickness were measured by digital caliper (Tronic, Turkey) with a precision of 0.01 mm. The fruit mass were measured with a digital scale (Radwag, Poland) with a sensitivity of 0.001 g. Geometric mean diameter

(D_g), sphericity (ϕ), surface area (S) ve volume (V); calculated with the following equations (Mohsenin, 1980).

$$D_g = (LWT)^{1/3} \quad (1)$$

$$\Phi = (D_g/L).100 \quad (2)$$

$$S = D_g^2.\pi \quad (3)$$

$$V = [(\pi/6).(LWT)] \quad (4)$$

D_g = Geometric mean diameter (mm), Φ: Sphericity (%), S: Surface area (mm^2), V: Volume (mm^3), L: Lenght (mm), W: Width (mm), T: Thickness (mm).

Bulk density was determined in kg m^{-3} by taking into account the mass of the samples by filling the fruit samples into a ¼ liter hectolitre container by heaping from a certain height (Altuntaş and Yıldız, 2007). Liquid displacement method was used to determine fruit density. Pure water was added to the tare-grade cup and the liquid displacement value was determined in terms of fruit density, fruit mass and fruit volume values in kg m^{-3} (Mohsenin, 1980).

For mechanical measurements (fruit compaction and perforation forces), a biological material tester was used. In the tests, compression and puncture tests were carried out on the fruit shell. The tester consists of 3 main components. These are fixed plates, moving plate and data acquisition unit, PC card and computer software. The movable plate is in the form of a circular table in compression tests, and in the form of a cylindrical needle in puncture tests (Yaldız, 2014). The biological material tester used in the study consists of a draw-off dynamometer with manual movement and digital display (Sundoo, SH-50, China), a digital draw-off dynamometer and a stand with measuring scale, fixed plate and a wired computer connection. Puncture and compression tests were performed. The reading values are given in N (Newtons). In the experiments, 11.1 mm steel cylindrical table with constant compression speed in compression tests and 1.2 mm steel needle in puncture tests were used with the biological material tester. The mechanical behavior of the fruit which were punctured and compacted in 3 different axes (X-, Y-, Z-) were determined by using biological material tester on apricot fruit (F) (Figure 1). Different surfaces (PVC, rubber, plywood, galvanized sheet, laminate) were used for the friction coefficient measurements of apricot fruit. For the friction measurement of fruit, the inclined table was used. The inclined table was moved with a screw arm to allow the movement of the fruit on the different friction surfaces and the inclination angle of the inclined table was used to determine the static friction coefficient when the first movement was performed (Yaldız, 2014).

For determination of moisture content of apricot fruit, the fruit were divided into two parts and kept in the oven at 105±1° C for 24 h to reach a constant mass and moisture content (% wb) was determined according to wet base (Darıcı and Şen, 2012). The moisture content measurement value of apricot fruit harvested before the experiments was determined as 80.48% according to wet mass. Statistical analysis of the data obtained from all parameters was performed using the SPSS (V.13.0) statistical package program.

RESULTS and DISCUSSION

Dimensional Properties

There was no significant change in general in the dimensional properties of the fruit during cold storage. However, on day 5 measurements of storage, the length (L) value of the fruit stored in MAP and treated with MeJA was found to be significantly higher than the control fruit. When the overall means of MAP application were compared, it was found that the length, width and thickness values of fruit stored in MAP were significantly higher than those not stored in MAP (Table 1). Altuntas et al., (2012), reported that the length values of 'Fuji' apple fruit treated with MeJA before harvest were 62.56 mm to 62.52 mm; width values from 79.99 mm to 79.13 mm; the thickness values ranged from 75.45 mm to 75.56 mm. As a result of single and two applications of 0, 2000 and 4000 ppm doses 'Alar' application on 'Hasanbey' apricot cultivar 15 and 30 days after flowering, Bolat and Güleryüz (1992), determined that 'Alar' application decreased fruit length from 53.00 mm to 49.02 mm, width values of 39.50 mm to 40.94 mm. Altuntas et al., (2013), reported that MeJA applications in plum fruit (control, 1120 mg L^{-1} and 2240 mg L^{-1}) showed that the length values decreased from 56.76 mm to 54.40 mm according to doses, and the thickness value was 46.00 mm to 44.96 mm decreased.

In this context, it can be stated that MeJA can affect the dimensional properties of the fruit. However, in our study, it was found that MeJA did not have a negative effect on dimensional properties of the fruit during storage and wasn't even different from control group in general. It is thought that the difference that occurred on the 5th day of storage may have occurred due to the loss of water in the fruit.

Geometric mean diameter, sphericity and surface area

In Precoce de Thryinthe apricot cultivar, significant effect of MAP application on geometric mean diameter (Dg), sphericity (ϕ) and surface area (SA) was observed. In particular, a significantly higher geometric diameter, sphericity and surface area were obtained (P <0.01) from the fruit stored in MAP. However, the effect of MeJA applications on all these properties during storage was generally found to be no different from control. At the end of the storage period (day 20), the effect of MeJA application was not significant for all properties (Table 2).

Table 1. Effects of MAP and MeJA applications, and stroge times on size dimensions of 'Precoce de Thyrinthe' apricot fruits

Çizelge 1. MAP ve MeJA uygulamaları ile muhafaza sürenin 'Precoce de Thyrinthe' *kayısı meyvelerinin boyut özelliklerine etkileri*

Size dimension	MAP	MeJA application	Harvest	Storage period (days) 5	10	15	20	Mean
L (mm)	With	Control	35.63±0.49	34.56±0.38b**	34.46±0.38^{ns}	34.01±0.43^{ns}	35.29±0.08^{ns}	34.45±0.25a**
		0.5 mmol L^{-1}	35.63±0.49	35.25±0.27a	33.72±0.33^{ns}	33.12±0.18^{ns}	35.19±0.12^{ns}	
		1.0 mmol L^{-1}	35.63±0.49	35.45±0.39a	33.71±0.25^{ns}	33.31±0.25^{ns}	35.36±0.47^{ns}	
	Without	Control	35.63±0.49	35.04±0.44^{ns}	33.06±0.10^{ns}	32.10±0.22^{ns}	34.59±0.16^{ns}	33.77±0.39b
		0.5 mmol L^{-1}	35.63±0.49	35.39±0.12^{ns}	32.83±0.07^{ns}	32.36±0.32^{ns}	35.16±0.30^{ns}	
		1.0 mmol L^{-1}	35.63±0.49	35.27±0.13^{ns}	32.99±0.26^{ns}	31.95±0.26^{ns}	34.55±0.27^{ns}	
W (mm)	With	Control	34.86±0.21	33.80±0.32^{ns}	34.13±0.05^{ns}	34.54±0.21a**	34.43±0.36^{ns}	34.03±0.15a**
		0.5 mmol L^{-1}	34.86±0.21	34.36±0.38^{ns}	33.91±0.41^{ns}	33.65±0.10b	34.24±0.03^{ns}	
		1.0 mmol L^{-1}	34.86±0.21	34.02±0.23^{ns}	33.46±0.27^{ns}	32.71±0.07c	34.12±0.55^{ns}	
	Without	Control	34.86±0.21	33.60±0.17b*	32.98±0.24^{ns}	32.19±0.16^{ns}	32.65±0.20^{ns}	32.84±0.25b
		0.5 mmol L^{-1}	34.86±0.21	33.93±0.25ab	33.25±0.24^{ns}	31.69±0.22^{ns}	32.80±0.43^{ns}	
		1.0 mmol L^{-1}	34.86±0.21	34.61±0.19a	31.98±0.70 ^{ns}	32.04±0.21^{ns}	32.31±0.28^{ns}	
T (mm)	With	Control	32.30±0.11	31.70±0.39^{ns}	32.07±0.02a*	32.12±0.16a**	30.12±1.15^{ns}	31.50±0.19a**
		0.5 mmol L^{-1}	32.30±0.11	31.95±0.21^{ns}	31.44±0.14b	30.59±0.35b	32.05±0.09^{ns}	
		1.0 mmol L^{-1}	32.30±0.11	31.89±0.27^{ns}	31.41±0.25b	30.85±0.20b	31.79±0.15^{ns}	
	Without	Control	32.30±0.11	31.53±0.19^{ns}	31.16±0.15^{ns}	30.04±0.11a*	29.95±0.12b*	30.47±0.30b
		0.5 mmol L^{-1}	32.30±0.11	31.80±0.26^{ns}	30.50±0.19^{ns}	29.65±0.57a	30.70±0.22a	
		1.0 mmol L^{-1}	32.30±0.11	32.18±0.06^{ns}	29.49±0.66^{ns}	28.61±0.48b	29.96±0.13b	

**: $p < 0.01$, *: $p<0.05$, ns: not significant. The difference between the same letters in the same column is insignificant. Number following ± are standard errors

Table 2. Effects of MAP and MeJA applications and stroge times on some geometric properties of 'Precoce de Thyrinthe' apricot fruits

Çizelge 2. MAP ve MeJA uygulamaları ile muhafaza süresinin 'Precoce de Thyrinthe' *kayısı meyvelerinin bazı geometrik özellikleri üzerine etkileri*

Geometric dimension	MAP	MeJA application	Harvest	Storage period (days) 5	10	15	20	Mean
Dg (mm)	With	Control	28.26±0.1	27.41±0.30^{ns}	28.00±0.15^{ns}	28.18±0.30a**	27.19±0.60^{ns}	27.41±0.13a**
		0.5 mmol L^{-1}	28.26±0.1	27.34±0.43^{ns}	27.50±1.41^{ns}	26.82±0.23b	27.72±0.16^{ns}	
		1.0 mmol L^{-1}	28.26±0.1	27.36±0.34^{ns}	27.24±0.51^{ns}	26.55±0.15b	27.57±0.40^{ns}	
	Without	Control	28.26±0.1	26.89±0.11b*	26.62±0.24a*	25.79±0.22^{ns}	25.87±0.22^{ns}	26.15±0.26b
		0.5 mmol L^{-1}	28.26±0.1	27.21±0.28ab	26.51±0.19a	25.10±0.23^{ns}	26.22±0.37^{ns}	
		1.0 mmol L^{-1}	28.26±0.1	27.82±0.05a	25.57±0.31b	24.64±0.47^{ns}	25.58±0.33^{ns}	
Φ (%)	With	Control	0.810±0.0	0.807±0.003^{ns}	0.808±0.006^{ns}	0.806±0.004^{ns}	0.808±0.010^{ns}	0.805±0.006a**
		0.5 mmol L^{-1}	0.810±0.0	0.799±0.004^{ns}	0.807±0.032^{ns}	0.797±0.005^{ns}	0.805±0.004^{ns}	
		1.0 mmol L^{-1}	0.810±0.0	0.806±0.005^{ns}	0.805±0.009^{ns}	0.870±0.007^{ns}	0.808±0.002^{ns}	
	Without	Control	0.810±0.0	0.800±0.005^{ns}	0.807±0.001^{ns}	0.801±0.003^{ns}	0.794±0.003^{ns}	0.797±0.002b
		0.5 mmol L^{-1}	0.810±0.0	0.801±0.002^{ns}	0.797±0.002^{ns}	0.794±0.006^{ns}	0.799±0.006^{ns}	
		1.0 mmol L^{-1}	0.810±0.0	0.804±0.003^{ns}	0.789±0.028^{ns}	0.781±0.010^{ns}	0.793±0.003^{ns}	
SA (mm^2)	With	Control	2513.6±35	2363.9±53.7^{ns}	2469.2±26.5^{ns}	2490.2±51.9^{ns}	2328.9±102.0^{n}	2366.9±21.9a**
		0.5 mmol L^{-1}	2513.6±35	2359.1±71.7^{ns}	2383.0±42.7^{ns}	2266.9±37.4^{ns}	2422.2±26.9^{ns}	
		1.0 mmol L^{-1}	2513.6±35	2358.1±59.1^{ns}	2338.4±87.4^{ns}	2222.9±30.0^{ns}	2400.4±64.7^{ns}	
	Without	Control	2513.6±35	2278.8±15.8b*	2230.7±40.0a*	2094.1±36.3^{ns}	2109.8±39.3^{ns}	2160.9±42.8b
		0.5 mmol L^{-1}	2513.6±35	2338.7±48.7ab	2214.9±30.0a	1989.2±35.6^{ns}	2176.8±70.4^{ns}	
		1.0 mmol L^{-1}	2513.6±35	2437.7±7.2a	2078.4±67.8b	1918.6±70.4^{ns}	2062.8±49.7^{ns}	

**: $p < 0.01$, *: $p<0.05$, ns: not significant. The difference between the same letters in the same column is insignificant. Number following ± are standard errors.

Altuntas et al., (2012), explained that by applying MeJA control, 1120 mg L^{-1}, 2240 mg L^{-1} and 4480 mg L^{-1} in post-harvest period, the geometric mean diameter values were in the range of 71.36 mm to 69.97 mm in 'Fuji' apple cultivar; the sphericity value according to the control application was ranging between 2.53 and 7.99% respectively; the surface area values increased initially due to increased doses of MeJA, then decreased and the values changed to 161.32 cm^2, 168.16 cm^2 and 158.11 cm^2 through MeJA applications, respectively. In the literature, it has been observed that the geometric mean diameter values have decreased with MeJA applications, while the results obtained in the literature are similar to those obtained in the literature, it is seen that there is a decrease in the surface area values in general in terms of MeJA and therefore there is a difference compared to the literature findings.

Volumetric properties

When the overall averages of MAP application were evaluated, the effect of MAP on mass (M, g) and volume (V, mm^3) values of apricot fruit was found to be significant (P <0.01). However, the effect of MAP on bulk and fruit densities was insignificant. When the effect of MeJA applications was examined, it was observed that the values of the applications were generally at the same level as the control group. Looking at the data obtained in the last measurement period, it was seen that the volumetric properties of the MeJA treated fruit were similar to those of the control fruit (Table 3).

Table 3. Effects of MAP and MeJA application and storage time on volumetric properties of 'Precoce de Thyrinthe' apricot fruits

Çizelge 3. MAP ve MeJA uygulamaları ile muhafaza süresinin 'Precoce de Thyrinthe' *kayısı meyvelerinin hacimsel özellikleri üzerine etkileri*

Volumetric properties	MAP	MeJA application	Harvest	Storage period (days)				Mean
				5	10	15	20	
M (g)	With	Control	20.27±0.27	19.66±0.42^{ns}	19.85±0.34^{ns}	20.10±0.44a*	19.86±0.42^{ns}	19.45±0.11a**
		0.5 mmol L^{-1}	20.27±0.27	19.12±0.57^{ns}	19.43±6.28^{ns}	19.03±0.28b	19.65±0.26^{ns}	
		1.0 mmol L^{-1}	20.27±0.27	19.30±0.42^{ns}	19.20±0.78^{ns}	18.77±0.25b	19.43±0.45^{ns}	
	Without	Control	20.27±0.27	18.56±0.12^{ns}	18.59±0.26^{ns}	17.93±0.31^{ns}	17.91±0.34^{ns}	18.19±0.22b
		0.5 mmol L^{-1}	20.27±0.27	18.90±0.31^{ns}	18.59±0.22^{ns}	17.54±0.11^{ns}	18.17±0.55^{ns}	
		1.0 mmol L^{-1}	20.27±0.27	19.58±0.07^{ns}	18.34±0.44^{ns}	16.64±0.53^{ns}	17.51±0.44^{ns}	
V (mm^3)	With	Control	12007.8±2600	10946.7±387.2^{ns}	11698.8±198.2^{ns}	11845.1±365.2a**	10718.7±702.3^{ns}	10992.3±150.9a**
		0.5 mmol L^{-1}	12007.8±2600	10953.0±483.8^{ns}	11094.3±590.3^{ns}	10320.8±240.6b	11378.1±186.2^{ns}	
		1.0 mmol L^{-1}	12007.8±2600	10914.1±418.5^{ns}	10795.1±609.6^{ns}	10005.4±227.1b	11255.4±418.6^{ns}	
	Without	Control	12007.8±2600	10382.1±89.3b*	10032.0±268.4^{ns}	9133.6±237.8^{ns}	9243.4±275.3^{ns}	9618.1±283.6b
		0.5 mmol L^{-1}	12007.8±2600	10823.6±345.4ab	9949.2±195.7^{ns}	8483.2±220.9^{s}	9775.0±543.2^{ns}	
		1.0 mmol L^{-1}	12007.8±2600	11478.9±41.26a	9117.1±237.1^{ns}	8053.3±425.4^{ns}	8946.2±302.6^{ns}	
ρ_b (kg m^{-3})	With	Control	489.92±11.40	466.7±5.74^{ns}	452.1±3.33a*	444.0±2.58^{ns}	431.7±15.73^{ns}	441.7±3.13^{ns}
		0.5 mmol L^{-1}	489.92±11.40	448.9±4.91^{ns}	432.6±5.08b	435.3±1.91^{ns}	426.6±11.49^{ns}	
		1.0 mmol L^{-1}	489.92±11.40	445.9±6.08^{ns}	438.2±3.91ab	442.1±6.41^{ns}	436.7±0.42^{ns}	
	Without	Control	489.92±11.40	458.4±2.33^{ns}	432.3±1.50^{ns}	427.4±28.64^{ns}	396.2±11.49^{ns}	434.5±5.78^{ns}
		0.5 mmol L^{-1}	489.92±11.40	471.4±1.58^{ns}	448.3±0.42^{ns}	438.9±4.91^{ns}	431.7±4.25^{ns}	
		1.0 mmol L^{-1}	489.92±11.40	445.4±8.74^{ns}	428.8±8.07^{ns}	420.1±6.83^{ns}	415.2±9.41^{ns}	
ρ_f (kg m^{-3})	With	Control	1025.75±34.10	778.0±6.96c**	1036.7±20.58a*	938.3±15.84b*	956.6±10.64^{ns}	953.1±20.13^{ns}
		0.5 mmol L^{-1}	1025.75±34.10	890.0±38.34b	935.0±26.13b	985.0±16.88ab	934.6±13.68^{ns}	
		1.0 mmol L^{-1}	1025.75±34.10	1031.7±10.76a	972.5±26.01ab	1008.9±15.48a	970.0±18.24^{ns}	
	Without	Control	1025.75±34.10	1011.3±22.94ab*	965.0±11.07^{ns}	873.3±7.13^{ns}	995.4±18.43^{ns}	951.5±15.9^{ns}
		0.5 mmol L^{-1}	1025.75±34.10	945.4±29.64b	897.0±44.63^{ns}	965.6±38.22^{ns}	929.7±35.50^{ns}	
		1.0 mmol L^{-1}	1025.75±34.10	1040.0±12.65a	868.8±14.86^{ns}	925.6±16.74^{ns}	1000.7±23.34^{ns}	

**:$p < 0.01$, *: $p<0.05$, ns: not significant. The difference between the same letters in the same column is insignificant. Number following ± are standard errors.

It was seen in our study that fruit mass and volume were better preserved in MAP treated fruit. However, the effect of MeJA applications was generally insignificant. In particular, the loss of water in fruit and the limitation of respirable products can be considered as the main reason for the losses in MAP application. Altuntas et al., (2013), stated that the effects of MeJA application on the mass value of plum fruit 0 (control), 1120 mg L^{-1} and 2240 mg L^{-1} were in the range of 70.86 g to 69.02 g. Again, in another study Altuntas et al., (2012), stated that in 'Fuji' apple cultivar, MeJA control, 1120 mg L^{-1}, 2240 mg L^{-1} and 4480 mg L^{-1} in post-harvest applications, fruit mass ranged between 196.53 g and 194.83 g fruit volume values were in the range of 192.93 cm^3 to 209.89 cm^3; with the application of MeJA, there was a 5.33% decrease in bulk density with increasing doses; bulk and fruit densities for 1120 mg L^{-1} and 4480 mg L^{-1} doses of MeJA ranged between 383.65 kg m^{-3} ile 364.22 kg m^{-3} , 967.96 kg m^{-3}, 954.63 kg m^{-3} respectively.

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Compression test

In the compression tests of apricot fruit; considering the general averages of MAP application, significant differences were found only for the compression test on the X-axis. In the X-axis compression test, the value of fruit in MAP was significantly higher ($P <0.05$) than those not stored in MAP. The effect of MAP on the other axes (Y- and Z-) was not significant. When the effect of MeJA was examined, it was seen that the values of the applications were similar to the values of the control fruit in general (Table 4).

Table 4. Effects of MAP, MeJA applications and storage times on compression force of 'Precoce de Thyrinthe' apricot fruits

Çizelge 4. MAP ve MeJA uygualamaları ile muhafaza sürelerinin 'Precoce de Thyrinthe' *kayısı meyvelerinin sıkıştırma kuvveti değerleri üzerine etkileri*

Loading axis	MAP	MeJA application	Harvest	Storage period (days) 5	10	15	20	Mean
X	With	Control	2.31±0.12	1.49±0.05b**	1.38±0.09^{ns}	1.62±0.12^{ns}	1.41±0.08b*	1.54±0.06a*
		0.5 mmol L^{-1}	2.31±0.12	1.72±0.12b	1.66±0.04^{ns}	1.49±0.02^{ns}	1.52±0.02a	
		1.0 mmol L^{-1}	2.31±0.12	2.21±0.09a	1.62±0.06^{ns}	1.47±0.06^{ns}	1.44±0.06a	
	Without	Control	2.31±0.12	1.46±0.18b**	1.37±0.08b*	1.55±0.11^{ns}	1.39±0.10^{ns}	1.49±0.06b
		0.5 mmol L^{-1}	2.31±0.12	1.32±0.01b	1.63±0.07a	1.45±0.13^{ns}	1.44±0.05^{ns}	
		1.0 mmol L^{-1}	2.31±0.12	2.06±0.13a	1.61±0.05ab	1.37±0.08^{ns}	1.26±0.10^{ns}	
Y	With	Control	2.63±0.18	1.49±0.04^{ns}	1.29±0.06^{ns}	1.39±0.04^{ns}	1.39±0.10^{ns}	1.37±0.03^{ns}
		0.5 mmol L^{-1}	2.63±0.18	1.25±0.08^{ns}	1.40±0.03^{ns}	1.27±0.06^{ns}	1.35±0.03^{ns}	
		1.0 mmol L^{-1}	2.63±0.18	1.45±0.10^{ns}	1.55±0.04^{ns}	1.35±0.06^{ns}	1.27±0.06^{ns}	
	Without	Control	2.63±0.18	1.71±0.08a**	1.20±0.10^{ns}	1.46±0.01^{ns}	1.36±0.10^{ns}	1.36±0.04^{ns}
		0.5 mmol L^{-1}	2.63±0.18	1.25±0.10^{ns}	1.38±0.05^{ns}	1.27±0.05^{ns}	1.32±0.10^{ns}	
		1.0 mmol L^{-1}	2.63±0.18	1.43±0.06^{ns}	1.37±0.09^{ns}	1.26±0.11^{ns}	1.26±0.06^{ns}	
Z	With	Control	2.39±0.07	1.53±0.04a**	1.22±0.08^{ns}	1.39±0.08^{ns}	1.23±0.07^{ns}	1.33±0.03^{ns}
		0.5 mmol L^{-1}	2.39±0.07	1.18±0.02b	1.32±0.04^{ns}	1.30±0.07^{ns}	1.42±0.06^{ns}	
		1.0 mmol L^{-1}	2.39±0.07	1.32±0.07ab	1.40±0.05^{ns}	1.37±0.09^{ns}	1.24±0.04^{ns}	
	Without	Control	2.39±0.07	1.76±0.06a**	1.16±0.04b**	1.35±0.05^{ns}	1.18±0.10^{ns}	1.31±0.05^{ns}
		0.5 mmol L^{-1}	2.39±0.07	1.17±0.06b	1.31±0.10a	1.26±0.09^{ns}	1.42±0.03^{ns}	
		1.0 mmol L^{-1}	2.39±0.07	1.17±0.03b	1.39±0.03a	1.12±0.09^{ns}	1.39±0.01^{ns}	

**:$p < 0.01$, *: $p<0.05$, ns: not significant. The difference between the same letters in the same column is insignificant. Number following ± are standard errors.

Altuntas et al., (2013), found that the effect of pre-harvest MeJA applications on the compressive force values of plum fruit changed depending on the time of harvest and the effect of MeJA applications on the Y-axis was in the range of 140 N to 129.6 N. In our study, no significant effect of MeJA in compression tests was observed. Çalışır and Aydın (2004), reported that the breaking force values of the dried black mulberry fruit ranged from 4.5 to 3.0 N at 9-77.5% moisture level and that the breaking force values decreased as a result of the compression test.

Puncture test

When the results of the puncture tests carried out in apricot fruit were examined, the puncture test values of MAP-treated fruit for all axes were found to be significantly higher than those not stored in MAP. In our study, the puncture test values of the fruit of MeJA applications were found to be similar to the control in all measurement periods (except 15th day measurements without MAP on Y- axis) (Table 5).

In the study, the reason why fruit stored in MAP give higher values in puncture test can be result of decrease of water loss in the fruit with MAP and as a result of this, cell wall structure's getting more resistant.

Kalyoncu (2016), stated that the puncture force values of the *Prunus laurocerasus* fruit showed decreasing tendency in the puncture tests along the X-, Y- and Z-axis of different harvest periods. He also stated that the decrease in force values was 12.90% for length (X-) axis, 46.43% for width (Y-) axis and 24.39% for thickness (Z-) axis depending on the ripening process from the 1st harvest period to the 3rd harvest period.

Table 5. Effects of MAP, MeJA and storage times on the puncture force of 'Precoce de Thyrinthe' apricot fruits
Çizelge 5. MAP ve MeJA uygulamaları ve muhafaza süresinin 'Precoce de Thyrinthe' *kayısı meyvelerinin delme kuvveti üzerine etkileri*

Loading axis	MAP	MeJA application	Harvest	Storage period (days) 5	10	15	20	Mean
X	With	Control	0.901±0.31	0.760±0.02ns	0.575±0.08ns	0.507±0.18ns	0.427±0.06ns	0.586±0.04a**
		0.5 mmol L-1	0.901±0.31	0.672±0.11ns	0.644±0.04ns	0.581±0.25ns	0.395±0.001ns	
		1.0 mmol L-1	0.901±0.31	0.866±0.10 ns	0.682±0.16ns	0.560±0.16ns	0.368±0.07ns	
	Without	Control	0.901±0.31	0.563±0.08ns	0.479±0.18ns	0.549±0.07ns	0.406±0.10ns	0.510±0.04b
		0.5 mmol L-1	0.901±0.31	0.440±0.04ns	0.592±0.18ns	0.581±0.07ns	0.284±0.05ns	
		1.0 mmol L-1	0.901±0.31	0.764±0.03ns	0.649±0.05ns	0.490±0.05ns	0.334±0.04ns	
Y	With	Control	0.741±0.32	0.402±0.01ns	0.574±0.02ns	0.566±0.05ns	0.178±0.03ns	0.434±0.04a**
		0.5 mmol L-1	0.741±0.32	0.565±0.09ns	0.669±0.04ns	0.439±0.13ns	0.282±0.042ns	
		1.0 mmol L-1	0.741±0.32	0.591±0.29ns	0.510±0.19ns	0.335±0.02ns	0.277±0.02ns	
	Without	Control	0.741±0.32	0.358±0.14ns	0.301±0.05b*	0.411±0.02a*	0.168±0.04ns	0.356±0.04b
		0.5 mmol L-1	0.741±0.32	0.517±0.08ns	0.613±0.05a	0.410±0.02b	0.103±0.04ns	
		1.0 mmol L-1	0.741±0.32	0.456±0.01ns	0.476±0.13a	0.272±0.02b	0.190±0.02ns	
Z	With	Control	0.696±0.26	0.490±0.07ns	0.522±0.14ns	0.588±0.05ns	0.373±0.02ns	0.508±0.04a*
		0.5 mmol L-1	0.696±0.26	0.620±0.12ns	0.654±0.02ns	0.541±0.13ns	0.338±0.09ns	
		1.0 mmol L-1	0.696±0.26	0.692±0.14ns	0.585±0.16ns	0.400±0.04ns	0.300±0.06ns	
	Without	Control	0.696±0.26	0.364±0.35ns	0.471±0.07ns	0.512±0.04ns	0.350±0.07ns	0.433±0.04b
		0.5 mmol L-1	0.696±0.26	0.480±0.05ns	0.561±0.07ns	0.492±0.04ns	0.212±0.03ns	
		1.0 mmol L-1	0.696±0.26	0.562±0.06ns	0.571±0.06ns	0.367±0.02ns	0.254±0.02ns	

**: $p < 0.01$, *: $p<0.05$, ns: not significant. The difference between the same letters in the same column is insignificant. Number following ± are standard errors.

Coefficient of friction

When the general means of MAP applications were compared, it was found that the values of fruit stored in MAP were significantly higher only on PVC friction surface than those fruit without MAP. There was no difference between friction coefficient values of MAP applications on other surfaces. When the effect of MeJA applications in the last measurement period was examined, the friction coefficient of the fruit treated with MeJA in the non-MAP group on the PVC surface was found to be significantly lower than the control group. In contrast, galvanized sheet and plywood were higher than in the control group (Table 6).

In this study, as laminate and galvanized sheet surfaces are more smooth and slippery than PVC, plywood and rubber surfaces, it was observed that it gives lower coefficient of friction. Similar to this study, Öztürk (2012), stated that in the 'Braeburn' apple cultivar, the effect of AVG applications and harvest periods on the static coefficient of friction gave a lower coefficient of friction than the plywood and rubber surface on AVG applications (0, 100 and 300 mg L^{-1}); Yaldız (2014), stated that as a result of applying three different doses of 0, 100, 200 aminoethoxyvinylglycine (AVG) in the 'Santa Rosa' plum fruit in three different harvest periods, the lowest coefficient of friction was found on laminate and galvanized sheet surfaces.

CONCLUSIONS

In this study, it has been determined that modified atmosphere packaging applications have a significant effect on the preservation of dimensional properties, geometrical properties and partially volumetric properties. However, it would be a more accurate approach to state that the applied regulatory MeJA does not have a significant effect on physico-mechanical properties in general. Growth regulators, including MeJA, are now widely used in agricultural production. Therefore, detailed research is needed to fully demonstrate the effect of growth regulators on physico-mechanical properties.

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Credit Authorship Contribution Statement

Berrak Aslanturk: Methodology, Formal analysis, Data curation.
Ebubekir Altuntas: Methodology, Formal analysis, Validation, Review and editing.

Burhan Ozturk: Methodology, Investigation, Conceptualization, Formal analysis, Writing-original draft, Visualization.

Declaration of competing interest

The authors declare that they have no conflict of interest.

Table 6. Effects of MAP and MeJA applications and storage times on friction coefficient values of 'Precoce de Thyrinthe' apricot fruits

Çizelge 6. MAP ve MeJA uygulamaları ile muhafaza süresinin 'Precoce de Thyrinthe' *kayısı meyvelerinin sürtünme katsayısı özellikleri üzerine etkileri*

Friction surface	MAP	MeJA application	Storage period (days)					Mean
			Harvest	5	10	15	20	
PVC	With	Control	0.426±0.007	0.404±0.007b**	0.540±0.014a**	0.550±0.004a**	0.372±0.013^{ns}	
		0.5 mmol L^{-1}	0.426±0.007	0.412±0.003a	0.470±0.014b	0.361±0.006c	0.367±0.006^{ns}	0.424±0.020b**
		1.0 mmol L^{-1}	0.426±0.007	0.395±0.007b	0.437±0.003c	0.455±0.013b	0.336±0.006^{ns}	
	Without	Control	0.426±0.007	0.408±0.006^{ns}	0.518±0.017a**	0.563±0.003a**	0.447±0.023a**	
		0.5 mmol L^{-1}	0.426±0.007	0.416±0.010^{ns}	0.420±0.011b	0.450±0.003c	0.367±0.003b	0.453±0.022a
		1.0 mmol L^{-1}	0.426±0.007	0.412±0.006^{ns}	0.596±0.004a	0.503±0.007b	0.348±0.006b	
Plywood	With	Control	0.582±0.007	0.590±0.004^{ns}	0.687±0.004a**	0.498±0.010b**	0.522±0.007^{ns}	
		0.5 mmol L^{-1}	0.582±0.007	0.618±0.012^{ns}	0.529±0.014c	0.413±0.050a	0.538±0.007^{ns}	0.554±0.021^{ns}
		1.0 mmol L^{-1}	0.582±0.007	0.605±0.008^{ns}	0.630±0.008b	0.514±0.021a	0.520±0.003^{ns}	
	Without	Control	0.582±0.007	0.624±0.004a**	0.582±0.015b	0.550±0.007bc	0.538±0.007c	
		0.5 mmol L^{-1}	0.582±0.007	0.562±0.007a**	0.570±0.015a	0.404±0.033b	0.518±0.007a	0.553±0.020^{ns}
		1.0 mmol L^{-1}	0.582±0.007	0.567±0.004b**	0.695±0.016a	0.500±0.021b	0.536±0.003b	
Rubber	With	Control	0.612±0.016	0.531±0.014b**	0.700±0.029a**	0.667±0.008a**	0.529±0.007^{ns}	
		0.5 mmol L^{-1}	0.612±0.016	0.481±0.014c	0.692±0.012a	0.568±0.007b	0.554±0.029^{ns}	0.573±0.021^{ns}
		1.0 mmol L^{-1}	0.612±0.016	0.568±0.007a	0.510±0.014b	0.566±0.011b	0.520±0.021^{ns}	
	Without	Control	0.612±0.016	0.538±0.021b**	0.615±0.012^{ns}	0.647±0.008a**	0.536±0.010^{ns}	
		0.5 mmol L^{-1}	0.612±0.016	0.492±0.020b	0.623±0.031^{ns}	0.503±0.003c	0.542±0.007^{ns}	0.571±0.017^{ns}
		1.0 mmol L^{-1}	0.612±0.016	0.604±0.020a	0.681±0.001^{ns}	0.540±0.003b	0.545±0.004^{ns}	
Laminate	With	Control	0.359±0.019	0.317±0.010b**	0.445±0.007a**	0.365±0.006^{ns}	0.324±0.003b**	
		0.5 mmol L^{-1}	0.359±0.019	0.378±0.003a	0.395±0.006b	0.344±0.012^{ns}	0.387±0.006a	0.363±0.013^{ns}
		1.0 mmol L^{-1}	0.359±0.019	0.334±0.003b	0.428±0.016a	0.358±0.003^{ns}	0.290±0.018c	
	Without	Control	0.359±0.019	0.414±0.007^{ns}	0.416±0.003^{ns}	0.371±0.006a**	0.332±0.006^{ns}	
		0.5 mmol L^{-1}	0.359±0.019	0.319±0.009^{ns}	0.439±0.007^{ns}	0.313±0.006b	0.328±0.003^{ns}	0.361±0.013^{ns}
		1.0 mmol L^{-1}	0.359±0.019	0.335±0.003^{ns}	0.396±0.013^{ns}	0.354±0.006a	0.321±0.002^{ns}	
Galvanized steel	With	Control	0.364±0.025	0.475±0.020a*	0.441±0.013^{ns}	0.447±0.003a**	0.396±0.006b**	
		0.5 mmol L^{-1}	0.364±0.025	0.422±0.003b	0.445±0.010^{ns}	0.330±0.030c	0.344±0.006b	0.420±0.013^{ns}
		1.0 mmol L^{-1}	0.364±0.025	0.455±0.013ab	0.439±0.013^{ns}	0.393±0.003b	0.466±0.007a	
	Without	Control	0.364±0.025	0.379±0.010b**	0.462±0.007a*	0.453±0.003a**	0.338±0.012b**	
		0.5 mmol L^{-1}	0.364±0.025	0.445±0.003a	0.441±0.003ab	0.252±0.012c	0.444±0.003a	0.410±0.018^{ns}
		1.0 mmol L^{-1}	0.364±0.025	0.445±0.013ab	0.414±0.033b	0.399±0.006b	0.462±0.013a	

**: $p < 0.01$, *: $p<0.05$, ns: not significant. The difference between the same letters in the same column is insignificant. Number following ± are standard errors.

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