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RESEARCH NOTE

Effect of methyl jasmonate treatments on the bioactive compounds and physicochemical quality of 'Fuji' apples

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Abstract

B. Ozturk, E. Altuntas, K. Yildiz, Y. Ozkan, and O. Saracoglu. 2013. Effect of methyl jasmonate treatments on the bioactive compounds and physicochemical quality of 'Fuji' apples. Cien. Inv. Agr. 40(1):201-211. Recently, plant growth regulators have been used for various purposes in apples. Methyl jasmonate (MeJA) has significant effects on the physiology, postharvest biology, processing, and chemical composition of apples. In the present study, the effects of MeJAMeJa treatments on the physicochemical quality and bioactive compounds (total antioxidant activity, total phenolics, and total anthocyanins) of 'Fuji' apples were investigated. The following doses of MeJa were used: 0 (control); 1; 120; 2,240; and 4,480 mg L^{-1}. The highest geometric mean diameter, fruit mass, flesh firmness and skin thickness were obtained from the 2,240 mg L^{-1} MeJA treatment. Fruits harvested from control trees exhibited the highest total soluble solids content (TSSC) and pH, whereas the lowest TSSC and pH values were obtained from the 4,480 mg L^{-1} MeJA treatment. The titratable acidity was lower in the control as compared to the other treatments. The total phenolics of the fruit flesh decreased with increasing MeJa doses. The highest total antioxidant activity for both the FRAP and TEAC of fruit flesh was obtained from the 1,120 mg L^{-1} MeJA dose. The total anthocyanin content was higher in the 4,480 mg L^{-1} MeJA treatment than in the other treatments. Hue angles for both the sun- and shade-exposed sides of the fruit skin and flesh were lower in the 4,480 mg L^{-1} MeJA treatment as compared to the other treatments. Apples without full color formation are sold at lower prices in markets, which results in significant economic losses for producers. MeJA may be used as an efficient treatment to promote color formation in apple species with weak coloring due to genetic and climate conditions.

Key words: Apple, antioxidant, color, firmness, methyl jasmonate, phenolics.

Introduction

Apples are a rich source of various biochemical compounds, such as anthocyanin, antioxidant and phenolic compounds (Rohwer and Erwin, 2008). Some phytochemicals, including phenolics and antioxidants in fruit, consumed as a part of diet may have health benefits toward treating diabetes, obesity, muscle damage, cardiovascular disease, and asthma (Jakopic *et al*., 2009). Because of the health benefits attributed to various fruits, numerous studies have been conducted in recent years to evaluate their properties in terms of quality and biochemistry (Gonzalez-Gomez *et al*., 2009).

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The knowledge of the biochemical compounds, color characteristics and physical properties of apple fruits is of importance to plant breeders, engineers, food scientists, processors, and consumers. In recent years, the use of eco-friendly natural plant growth regulators has targeted the improvement and protection of fruit quality. Pre-harvest and post-harvest applications of some plant growth regulators in fresh fruit and vegetables are new approaches that are effective in maintaining the quality of products.

Methyl jasmonate (MeJa) is widely used both experimentally and commercially for different fruits. MeJA is among the factors that can cause changes in the physical appearance (color and fruit mass), mechanical property (firmness), and bioactive compounds (phenolics and antioxidants) of fruit (Fan *et al.,* 1997; 1998; Kondo *et al.,* 2001; Rudell *et al.,* 2005; Wang and Zheng, 2005; Rohwer and Erwin, 2008). MeJa is an important cellular regulator that is involved in diverse developmental stages, such as fruit ripening, synthesis of ethylene, and accumulation of pigments, phenolics, antioxidants, and flavonoids (Cheong and Choi, 2003; Rohwer and Erwin, 2008; Heridia and Cisneros-Zevallos, 2009).

Researchers have conducted studies to investigate the effects of jasmonates on the biochemical and color properties of apple cultivars (Fan *et al*., 1997; Rudell and Mattheis, 2008). However, studies on the effects of different MeJa doses on the total antioxidant activity, total phenolics, total anthocyanins and color characteristics of ‘Fuji’ apples are lacking. Therefore, the objective of this study was to investigate the effects of pre-harvest MeJa treatments on the physicochemical quality (geometric mean diameter, fruit mass, flesh firmness, skin firmness, skin thickness, color characteristics, TSSC, pH, titratable acidity and starch index), total antioxidant activity, total phenolics and total anthocyanins of ‘Fuji’ apples.

Materials and methods

Experimental site

This study was conducted at the Research Station of the Agricultural Faculty Horticulture Department of Gaziosmanpaşa University (40^{o}20’02.19” N and 36^{o}28’30.11” E; 623 masl) in Tokat, Turkey. Twenty-four uniform 4-year-old ‘Fuji’ (*Malus domestica* Borkh.) trees grafted on M9 rootstock, trained by a slender spindle training system, and planted with a spacing of 2 m × 1 m were selected for the experiment.

Treatment design and management

The experimental design was a completely randomized block design with three blocks containing eight trees each. Each MeJA dose was applied to two trees in each block, and two trees in each block were selected for the control treatment (0 mg L^{-1} MeJA). The following treatments were used in the present study: 0 mg L^{-1} (MeJA-0 control); 1,120 mg L^{-1} (MeJA-1); 2,240 mg L^{-1} (MeJA-2); and 4,480 mg L^{-1} (MeJA-3). The MeJA doses were selected based on previous preliminary studies (Rudell *et al.,* 2002; 2005) performed under field conditions. The MeJA doses were applied to the fruit every week using hand-operated pump spray bottles. The MeJA doses (Aldrich, Milwaukee, Wis.) were applied weekly from September 23, 2010, to October 21, 2010. All spray solutions contained 0.077% v/v Triton X–100 (octoxynol; Aldrich). Only Triton X–100 was applied to the control trees. Each fruit was sprayed until the solution started to drip off the fruit. The MeJA treatment was performed in the morning on a day without wind and precipitation. The fruits were harvested on October 22, 2010 (175 days after full blooming), and they were transferred to the laboratory in polythene bags to reduce water loss during transportation.

Plant measurements

Physical properties. A total of 20 fruits were randomly harvested from two trees in each block for each treatment at the estimated harvest date (October 22, 2010). Twenty fruits were used to determine the physical properties (length, width, thickness, fruit mass, fruit firmness, skin thickness, and color characteristics), and the mean values were calculated. Fruit length, width, and thickness were measured with 0.01 mm sensitive digital calipers (Model No. CD-6CSX, Mitutoyo, Japan). The geometric mean diameter (D_g) of the apple fruit was determined by a previously described standard method (Mohsenin, 1970). The measurements of fruit mass were determined with a 0.01 g sensitive digital scale (Radvag PS 4500/C/1, Poland). Fruit stalks were cut off before the measurement. The fruit skin was directly measured at three different points on the equatorial part of the fruit. Moreover, the fruit skin was cut at three different points on the equatorial part of the fruit to measure the flesh and skin firmness using an Effegi penetrometer with an 11.1 mm tip (model FT–327; MoCormick Fruit Tech, Yakima, WA), and the values were expressed as Newton (N). The skin thickness was measured by using a digital micrometer (0-25 mm; Insize, Austria) with an accuracy of 0.001 mm. The color characteristics (L*, a*, b*, chroma and hue angle) of 20 apples from each treatment were measured by using a colorimeter (Minolta, model CR–400, Tokyo, Japan). The measurements of apple skin and flesh colors were performed on the sun- and shade-exposed sides on equidistant points of the equatorial section of the apples. Measurements were obtained using the CIE L*, (light to dark), a* (green to red) and b* (blue to yellow) color spaces, and the a* and b* values were converted to hue angle and chroma. The hue angle ($h°$) expresses the color nuance and was calculated using the following equation: $h° = \tan^{-1} b^*/a^*$. The hue angle values are defined as follows: red-purple, 0°; yellow, 90°; bluish-green, 180°; and blue, 270°. Chroma (C^*) is a measure of chromaticity, which defines the purity or saturation of the color, and it was calculated with the following equation: $C^* = (a^{*2}+b^{*2})^{1/2}$ (McGuire, 1992).

Biochemical properties. Ten fruits were randomly harvested from two trees in each block for each treatment at the estimated harvest date (October 22, 2010). Ten fruits were used to determine the total soluble solids content (TSSC), pH, titratable acidity (TA) and starch index. A sample of juice was also taken from each fruit. TSSC was measured using a digital refractometer (PAL-1; McCormick Fruit Tech., Yakima, Wash) and was expressed as a percentage. The pH values were measured with a pH meter (HI9321; Hanna instruments, Padova, Italy). Titratable acidity was determined by titrating to pH 8.1 with 0.1 N sodium hydroxide (NaOH) and was expressed as percent malic acid. Starch index was determined using the Generic Starch-Iodine Index Chart from Cornell University. Each apple fruit was cut in half transversely, and the flesh starch was then evaluated by spraying half of each apple with a test solution (10 g of potassium iodide and 2.5 g of iodine crystals dissolved in 1 L of water). The degree of staining was rated on a scale of 1 to 8 as follows: 1 = 100% starch and 8 = 0% starch (Blanpied and Silsby, 1992).

Ten fruits from two trees in each block for each treatment were mashed to measure the total phenolics, total antioxidant activity and total anthocyanins. Total phenolics (TPs) were measured according to the Singleton and Rossi (1965) procedure. Briefly, fruit slurries (only cortex) were extracted with a buffer containing acetone, water, and acetic acid (70:29.5:0.5 v/v) for 2 h in darkness. Triplicate samples were used for the measurements. Extracts were combined with Folin-Ciocalteus phenol reagent and water, and the extracts were then incubated for 8 min followed by the addition of 7% sodium carbonate. After 2 h, the absorbance at 750 nm was measured in an automated UV-VIS spectrophotometer (Model T60U, PG Instruments, USA). Gallic acid was used as the standard. The results were expressed as mg gallic acid equivalents (GAE)/kg fresh weight (fw). Total antioxidant activity

(TAA) was estimated using the two standard procedures, FRAP and TEAC assays, as suggested by Ozgen *et al.* (2006). FRAP was determined according to the method of Benzie and Strain (1996). The assay was conducted using three aqueous stock solutions containing 0.1 mol L^{-1} acetate buffer (pH 3.6), 10 mmol L^{-1} 2,4,6-tris(2-pyridyl)-1,3,5-triazine (TPTZ) acidified with concentrated hydrochloric acid, and 20 mmol L^{-1} ferric chloride. These solutions were prepared and stored in the dark under refrigeration. Stock solutions were combined (10:1:1 v/v/v) to form the FRAP reagent just prior to analysis. For each assay, duplicates of each replicate plus 2.90 mL of FRAP reagent and 100 µL of sample extract were mixed. After 30 min, the absorbance of the reaction mixture at 593 nm was determined using a spectrophotometer. The results were expressed in mmol Trolox equivalent (TE) kg^{-1} fw. For the standard TEAC assay, 10 mmol L^{-1} 2,2-azino-bis-3-ethylbenzothiazoline-6-sulfonic acid (ABTS) was dissolved in acetate buffer and prepared with potassium persulfate as described by Ozgen *et al.* (2006). The mixture was diluted using an acidic medium of 20 mM sodium acetate buffer (pH 4.5) to an absorbance of 0.700±0.01 at 734 nm for longer stability (Ozgen *et al.*, 2006). For the spectrophotometric assay, 2.90 mL of the $ABTS^{+}$ solution and 100 µL of fruit extract were mixed and incubated for 10 min. The absorbance at 734 nm was then determined. The results were expressed in mmol trolox equivalents (TE) kg^{-1} fw. The total anthocyanins were estimated by a pH differential method (Giusti and Wrolstad, 2005) using a UV–VIS spectrophotometer (Model T60U, PG Instruments, USA). Absorbance was measured at 533 and 700 nm in buffers at pH 1.0 and 4.5 using pH 4.5 with a molar extinction coefficient of 29.600. Results were expressed as µg cyanidin-3-galactoside g^{-1} fw equivalent in g fresh weight basis.

Statistical analysis

Experiments were performed using a completely randomized block design. All statistical analyses were performed with SAS version 9.1 software (SAS Institute Inc., Cary, NC, USA). Data were analyzed by analysis of variance. The main effects were analyzed, and means were compared by Duncan's multiple range test at a significance level of 0.05.

Results and discussion

Physical properties

The physical properties (geometric mean diameter, fruit mass, firmness and skin thickness) of 'Fuji' apples are shown in Table 1. The effects of the MeJA treatment on the geometric mean diameter, fruit mass, skin firmness and flesh firmness of apple were not significant, but the skin thickness was affected by MeJA treatment ($P \leq 0.05$). The lowest geometric mean diameter, fruit mass, flesh firmness and skin firmness values were obtained in the MeJA-0 treatment, and the highest geometric mean diameter, fruit mass and flesh firmness values were obtained in the MeJA-2 treatment. Skin firmness values increased with increasing MeJA doses. Flesh firmness values increased in the MeJA-0, MeJA-1, and MeJA-2 treatments but decreased in the MeJA-3 treatment. The highest skin thickness (1.02 mm) was obtained in the MeJA-0 treatment, and the lowest skin thickness value (0.75 mm) was observed in the MeJA-3 treatment. The skin thickness was negatively affected by MeJA applications.

When applied to fruit in the first developmental stages, MeJA can affect cell division and growth. MeJA does not have a positive effect on fruit size when it is applied in the late developmental stages. Cell division continues for 3 or 12 weeks following flowering (Al- Hinai and Roper, 2004). Cell division varies by the length of vegetation period, climatic conditions and fruit varieties. MeJA did not have a positive effect on geometric mean diameter, fruit mass and firmness. In the present study, the basic objective to apply MeJA during the second phase of growth period

Table 1. Physical properties of 'Fuji' apples as affected by methyl jasmonate (MeJa) treatments.

	MeJa treatments			
Physical properties	MeJA-0	MeJA-1	MeJA-2	MeJA-3
Geometric mean diameter, mm	69.5±1.63 a	71.4±0.42 a	73.0±4.45 a	70.0±1.96 a
Fruit mass, g	190.2±14.10 a	196.5±5.89 a	197.3±11.88 a	194.8±13.29 a
Flesh firmness, No.	71.0±7.45 a	74.21.34 a	75.5±2.90 a	72.7±1.80 a
Skin firmness, No.	100.4±2.14 a	101.54.89 a	104.1±1.81 a	112.6±5.29 a
Skin thickness, mm	1.02±0.02 a	0.94±0.01 b	0.87±0.04 c	0.75±0.02 d

The following treatments were used; MeJA-0 (control), 0 mg L^{-1}; MeJA-1, 1,120 mg L^{-1}; MeJA-2, 2,240 mg L^{-1}; and MeJA-3, 4,480 mg L^{-1}.
The difference between mean values shown on the same line with the same lower letter is not significant ($P \leq 0.05$). Means of three replicates ± standard deviations. Each value is the mean of 60 fruits (20 fruits x three replications).

was to determine the effects on variations in physicochemical quality, color and bioactive compounds during this period. Therefore, MeJA was not applied during the first phase of growth. The application time of MeJA (4 weeks before the estimated harvest date) may have contributed to the lack of positive effects caused by MeJA. Indeed, Rudell et *al.* (2005) obtained a similar result when studying 'Fuji' apples. Kheiralipour *et al.* (2008) reported geometric mean diameter, length, width and thickness values of 79.54, 74.78, 83.80 and 80.37 mm, respectively, for 'Redspar' apples and 63.38, 58.31, 67.00 and 65.04 mm, respectively, for 'Delbarestivale' apples. The increase occurring in fruit firmness may have derived from different physiological processes apart from maturity level. A relation between fruit size and firmness can be established. When studying the Fuji' apple variety, Rudell *et al.* (2005) reported that such a relation can exist, and this indicated relationship was also observed in the present study. Janoudi and Flore (2003) reported that MeJA increases fruit firmness in 'Redhaven' peaches. In the present study, the MeJA treatments yielded higher fruit firmness than the control, which may have been due to the effect of MeJA on enzymes that cause softening of the fruit flesh. In relation to fruit firmness, Fan *et al.* (1998) reported that polygalacturonase biosynthesis is inhibited by MeJA treatment. Costa *et al.* (2008) studied 'Fuji' apples and 'Stark Red Gold' nectarines, and they reported that propyl dihydrojasmonate (PDJ) applied pre-harvest maintains fruit firmness in 'Stark Red Gold' nectarines. In addition, Kondo *et al.* (2004) reported that the activity of jasmonates varies by fruit ripening stage and applied concentration. Homutova and Blazek (2006) reported that each apple variety has a different skin thickness. The skin thickness can be influenced by the year, variety, pesticide application and early-late cultivar ripening (Babos *et al.,* 1984). In the present study, the skin thickness may have decreased with increasing MeJA doses.

The skin and flesh color characteristics (L*, chroma, and hue angle) of apples are shown in Table 2. The highest and lowest L* values (53.50 and 48.61, respectively) were in the MeJA-0 and MeJA-2 treatments, respectively, and the highest and lowest chroma vales (37.95 and 35.97, respectively) were in the MeJA-3 and MeJA-0 treatments, respectively, for the sun-exposed side of the apple skin. The chroma and hue angle values of the apple flesh increased with increasing MeJa treatments for both the sun- and shade-exposed sides. The effects of MeJa treatments on color characteristics were statistically significantly ($P \leq 0.05$) for the sun- and shade-exposed sides of the apple skin and flesh.

MeJA promotes the formation of color pigments, which enhance fruit skin color (Lalel *et al*., 2003; Rudell *et al*., 2005). The present study indicated that MeJA treatments particularly promoted red color development. Kondo *et al*. (2001) reported that MeJa treatments promoted not only

Table 2. Effect of methyl jasmonate (MeJa) treatments on the color properties of 'Fuji' apples.

	MeJa treatments			
Color properties	MeJA-0	MeJA-1	MeJA-2	MeJA-3
Sun-exposed side (skin)				
L*	53.5±0.76) a	50.76±1.56 b	48.61±2.86 ab	48.890.76 ab
Chroma	35.97±1.92 a	37.67±2.08 a	36.57±0.40 a	37.95±1.92 a
Hue angle	47.85±3.95 a	41.58±1.54 b	40.95±4.93 b	36.69±3.95 b
Shade-exposed side (skin)				
L*	64.77±1.69 a	64.58±1.18 a	59.12±0.42 b	60.65±1.69 b
Chroma	35.01±1.82 a	36.08±1.51 a	34.91±0.86 a	36.10±1.82 a
Hue angle	77.77±2.53 a	72.80±4.28 ab	67.00±3.20 b	65.122.53 b
Sun-exposed side (flesh)				
L*	83.02±1.30 a	79.20±1.85 a	82.78±0.15 a	83.40±1.30 a
Chroma	37.88±4.00 ab	33.44±1.67 b	36.72±0.64 ab	38.974.00 a
Hue angle	101.75±2.73 a	98.50±0.66 ab	101.44±3.08 a	96.432.34 b
Shade-exposed side (flesh)				
L*	81.58±0.23 b	79.95±1.32 c	82.15±0.57 ab	83.57±0.23 a
Chroma	33.55±3.72 b	31.65±1.38 b	37.26±4.02 ab	41.26±3.72 a
Hue angle	102.03±1.38 a	99.34±0.62 b	101.15±1.63 ab	96.94±1.38 c

The following treatments were used: MeJA-0 (control), 0 mg L^{-1}; MeJA-1, 1,120 mg L^{-1}; MeJA-2, 2,240 mg L^{-1}; and MeJA-3, 4,480 mg L^{-1}.
The difference between mean values shown on the same line with same lower letter is not significant ($P \leq 0.05$). Means of three replicates ± standard deviations. Each value is mean of 60 fruits (20 fruits x three replications).

chlorophyll disappearance but also anthocyanin accumulation. Plant growth regulators can improve fruit coloration (Kondo and Hayata, 1995). Hue angle values approaching zero in fruits with red skin color indicate an increase in red coloration (Diaz-Mula *et al*., 2009). MeJA stimulates ethylene release based on growth stages of fruits, speeds up ripening, speeds up chlorophyll breakup and increases carotenoid accumulation (Gonzalez-Aguilar *et al*., 2003; Lalel *et al*., 2003; Yılmaz *et al*., 2007). Kondo *et al.* (2001) reported that MeJA promotes color pigments in apples during the pre-climacteric, climacteric and post-climacteric developmental stages.

Biochemical properties

The chemical properties of 'Fuji' apples are presented in Table 3. The lowest TSSC and pH values were obtained in the MeJA-3 treatment (12.88% and 3.03, respectively), and the highest TSSC and pH values were obtained in the MeJA-0 treatment (14.0% and 3.14, respectively). The pH value was significantly different between the MeJA-3 and MeJA-0 treatments. While the lowest titratable acidity (TA) and starch index values were obtained in the MeJA-0 treatment (0.40 g malic acid 100 g^{-1} and 5, respectively), the highest TA and starch index values were obtained in the MeJA-3 treatment (0.55 g malic acid 100 g^{-1} and 7, respectively).

As fruit maturity increases, TSSC also increases (Turk *et al*., 1995). Fruit sugar content and, consequently, acidity increase with the progress of ripening. Whale *et al.* (2008) reported TSSC and TA values of 13.3 and 0.78% malic acid, respectively, for apples (cv. Cripp's Pink), which were similar to the values obtained in the present study. Fan *et al.* (1997) and Khan and Singh (2007) reported that the chemical content of fruit can change due to MeJA application.

Table 3. Biochemical properties of ‘Fuji’ apples as affected by methyl jasmonate (MeJa) treatments.

	MeJa treatments			
Biochemical properties	MeJA-0	MeJA-1	MeJA-2	MeJA-3
TSSC (%)	14.00±0.61 a	13.05±0.66 a	12.95±0.73 a	12.880.61 a
pH	3.14±0.08 a	3.10±0.05 ab	3.07±0.03 ab	3.03±0.08 b
TA (g malic acid 100 g^{-1})	0.40±0.02 c	0.44±0.01 b	0.48±0.04 b	0.55±0.02 a
Starch index	5±0.76 b	6.00±0.58 a	6.00±0.58 a	7.00±0.76 a
Total phenolic (µg GAE g^{-1} fw)				
Fruit flesh	861.5±103.6 ab	908.7±193.8 a	664.3±129.7 bc	494.9±96.14 c
Skin fruit	7940±990.6 a	7385548.1 a	5599±227.0 b	7724±792.6 a
Total antioxidant activity (µmol TE g^{-1} fw)				
FRAP				
Fruit flesh	0.78±0.06 ab	0.80±0.08 a	0.66±0.03 c	0.71±0.04 bc
Fruit skin	8.16±1.35 a	5.97±0.30 b	4.43±0.37 c	7.34±0.26 a
TEAC				
Fruit flesh	0.69±0.02 a	0.71±0.21 a	0.51±0.02 b	0.63±0.06 ab
Fruit skin	6.90±0.55 a	6.370.47 a	3.71±0.23 b	6.56±0.39 a
Total anthocyanins (µg cyanidin-3-galactoside g^{-1} fw)				
	3.79±1.90 c	6.04±1.60 bc	8.68±0.91 ab	9.26±1.39 a

The following treatments were used: MeJA-0 (control), 0 mg L^{-1}; MeJA-1, 1,120 mg L^{-1}; MeJA-2, 2,240 mg L^{-1}; and MeJA-3, 4,480 mg L^{-1}.
The difference between mean values shown on the same line with the same lower letter is not significant ($P \leq 0.05$). Means of three replicates ± standard deviations. TSSC, pH, TA, TP, TAA and total anthocyanins (n=12; three replications x four different measurement for each replicate). Starch index (n=30; ten fruits x three replications).

While the MeJA-0 and MeJA-1 treatments were similar in terms of fruit flesh TP values, these treatments differed from the MeJA-3 treatment in terms of these values. While the lowest fruit flesh TP value was obtained in the MeJA-3 treatment (494.9 µg GAE g^{-1} fw), the highest fruit flesh TP value was obtained in the MeJA-1 treatment (908.7 µg GAE g^{-1} fw). The fruit skin TP value significantly decreased with MeJA-2 treatment. According to the FRAP test, the lowest fruit flesh TAA value was obtained in the MeJA-2 treatment (0.66 µmol g^{-1} fw). In contrast, the highest fruit flesh TAA value was obtained in the MeJA-1 treatment (0.80 µmol TE g^{-1} fw). A statistical difference was found among the treatments in terms of fruit skin TAA values. While the MeJA-0 and MeJA-3 treatments were similar in terms of fruit skin TAA values, the MeJA-1 and MeJA-2 treatments were found to be statistically different. According to the TEAC test, the highest fruit flesh TAA value was obtained in the MeJA-1 treatment (0.71 µmol TE g^{-1} fw), and the lowest fruit flesh TAA value was obtained in the MeJA-2 treatment (0.51 µmol TE g^{-1} fw). The MeJA-0, MeJA-1 and MeJA-3 treatments were statistically similar in terms of fruit flesh TAA values, and the MeJA-2 treatment was statistically different from the other treatments with regard to fruit flesh TAA values. The highest fruit skin TAA value (6.90 µmol TE g^{-1} fw) was obtained in the MeJA-0 treatment, and the lowest fruit skin TAA value (3.71 µmol TE g^{-1} fw) was obtained in the MeJA-2 treatment. The total anthocyanins linearly increased with increasing MeJA doses. The lowest and highest total anthocyanin contents were obtained in the MeJA-0 (3.79 µg cyaniding-3-galactoside g^{-1} fw) and MeJA-3 (9.26 µg cyaniding-3-galactoside g^{-1} fw) treatments, respectively.

The composition of phenolics, antioxidants and anthocyanins of fruits are affected by pre-harvest MeJA treatments (Kim *et al.*, 2003).

The exogenous application of MeJA treatments affects the ripening parameters, including ethylene production, aroma development, and pigment changes (anthocyanins, chlorophyll and carotenoid), of apple fruit. Moreover, the anthocyanin accumulation, phenolic contents and antioxidant contents of apple fruit are enhanced with MeJA treatments (Wang and Zheng, 2005; Rohwer and Erwin, 2008). Wang and Zheng (2005) reported that the phenolic concentration of fruit increases with pre-harvest MeJA treatment in apples. The anthocyanin content and color development increased during maturation until the commercial harvest date. Pre-harvest MeJA treatment promotes anthocyanin accumulation (Fan *et al*., 1997). Anthocyanin accumulation increases sales appeal, market value and bioactive quality of apples. Consumers will benefit the most by eating apples with peels. Similar increasing anthocyanin trends of apples have been reported by Fan *et al*. (1997). Wojdylo *et al*. (2008) reported total antioxidant activity values of 80.9, 199.1, 88.6, and 181.9 μM g^{-1} according to an ABTS^{+} test and values of 23.4, 29.7, 23.2, and 26.4 μM g^{-1} according to a FRAP test.

Significant effects of MeJA treatments were not observed on the geometric mean diameter, fruit mass, flesh firmness and skin firmness. However, the skin thickness was lower in the MeJA treatments than in the control treatments. The hue angle values were significantly different in the MeJA-2 and MeJA-3 treatments as compared to the other treatments for the sun- and shade-exposed sides of apple skin, and the hue angle value was significantly different in the MeJA-3 treatment as compared to the other treatments for the sun- and shade-exposed sides of apple flesh. The TSSC and pH values decreased linearly with increasing MeJA doses, but the titratable acidity significantly increased with increasing MeJA doses. In general, the antioxidant and phenolic contents of fruit flesh in the present study were negatively affected by increasing MeJA doses. However, the fruit skin total anthocyanins significantly increased with increasing MeJA doses. Therefore, these data suggest that apples should be consumed with their skin because anthocyanins have the greatest contribution to the nutritional value of apples.

Resumen

B. Öztürk, E. Altuntas, K. Yildiz, Y. Ozkan y O. Saracoglu. 2013. Efecto de los tratamientos de metilo jasmonato, en compuestos bioactivos y calidades físico-químicas de la manzana 'Fuji'. Cien. Inv. Agr. 40(1):201-211. Recientemente, los reguladores del crecimiento de plantas se han utilizado para múltiples propósitos en las manzanas. Metil jasmonato (MeJA) afecta de manera importante la fisiología, la biología después de la cosecha, procesamiento y contenido químico de la manzana. En este estudio se investigó el efecto de los tratamientos de metilo jasmonato en calidades fitoquímicas y compuestos bioactivos (actividad antioxidante total, fenoles totales, antocianos totales) de la manzana 'Fuji'. Las dosis de metil jasmonato utilizadas fueron: 1120, 2240 y 4480 mg L^{-1}. El mayor diámetro medio geométrico, masa del fruto, firmeza de la pulpa y el grosor de la piel se obtuvo a partir de tratamiento de MeJA 2240 mg L^{-1}. Las frutas recolectadas de árboles del tratamiento control exhibieron el más alto contenido de sólidos solubles totales (TSSC) y el pH, mientras que la menor TSSC y pH se obtuvo del tratamiento de MeJA 4480 mg L^{-1}. La acidez titulable fue menor en el control, en comparación con los otros tratamientos. Los fenoles totales de la pulpa del fruto disminuyeron con el aumento de dosis metil jasmonato. La mayor actividad antioxidante total, tanto de FRAP y TEAC de pulpa de la fruta se obtuvo de la dosis de MeJA 1120 mg L^{-1}. La antocianina total fue mayor en la dosis de MeJA 4480 mg L^{-1}, respecto a los otros tratamientos. Ángulos de tono para la piel expuesta al sol y sombra y la pulpa de la fruta, fueron menores en la dosis de MeJA 4480 mg L^{-1}, en comparación a los otros tratamientos. Las manzanas sin formación de color se venden a precios más bajos en los mercados, y por consiguiente, importantes pérdidas económicas para los productores. MeJA puede ser utilizado como una herramienta eficaz para promover la formación de color de las especies de manzanas que por condiciones genéticas y clima, poseen un color débil.

Palabras clave: Antioxidante, color, compuestos fenólicos, firmeza, manzana, metil jasmonato.

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