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# EFFECT OF METHYL JASMONATE APPLICATION ON BIOACTIVE CONTENTS AND AGRO-MORPHOLOGICAL PROPERTIES OF STRAWBERRY FRUITS

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**ABSTRACT**

In this study, methyl jasmonate were applied to strawberry cultivars, and the pomological and biochemical characteristics of the fruits were investigated. The highest increase in fruit weight was determined in the Honeoye cultivar and it was detected in the application of 0.50 mM MeJa according to the control group. When the organic acid contents of fruits were examined, it was determined that the dominant acid was citric acid and the maximum range (Control: 1.49 g $kg^{-1}$; 0.50 mM MeJa: 16.49 g $kg^{-1}$) was in the Seascape cultivar. When the ellagic acid content of the fruits was examined, the highest increase (Control: 13.350 mg 100 $g^{-1}$, 0.25 mM MeJa: 22.768 mg 100 $g^{-1}$) was found in the Sweet Ann cultivar. In this study, it was determined that appropriate concentrations of MeJa should be preferred in cultivation of strawberry and these concentrations affected the fruit quality parameters.

**Key words:** strawberry, methyl jasmonate, phenolic compounds, organic acids

## INTRODUCTION

Strawberry is one of the most popular of summer fruits. Strawberry fruits have unique, highly desirable taste and flavor that influence consumer preferences. Consumers primarily purchase fruits for an enjoyable eating. Organic acid composition and content are important factors influencing the organoleptic properties of fruits [Bordonaba and Terry 2010]. In addition, increased awareness of possible beneficial effects of phytochemicals such as organic acids, and phenolic compounds on health has led to increased interest in studies on the composition of fruits because they are rich sources of those nutrients. Strawberries are very rich in bioactive compounds and vitamin C. These fruits are known for their high content and wide diversity of phenolic compounds [Afrin et al. 2016]. Some researchers reported that strawberries reduced development of cardiovascular disease and had protective effect against to different types of cancer [Giampieri

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et al. 2015, Mazzoni et al. 2015]. These effects of strawberries have been ascribed to their high antioxidant, anti-inflammatory, antiatherosclerotic and anticarcinogenic properties due to high and wide range of bioactive compounds in the fruits.

By understanding of the beneficial effects of bioactive compounds on health, there has been increased interest in applications for increasing antioxidative compounds such as polyphenol in fruits. Some cultural practices such as pruning, deficit irrigation and cluster thinning are the most common techniques using for this purpose [Perez-Lamela et al. 2007, Singh et al. 2010]. In addition, the some elicitors first used to increase plant resistance to pathogens were found to increase polyphenol levels. Consequently, elicitors are considered as an alternative way to obtain plants with high phenol contents. It was reported that physical elicitors such as high and low temperatures, and ultraviolet and gamma radiation, and chemical elicitors, such as chitosan, benzothiadiazole, harpin, and 1-methylciclopropane induced polyphenol synthesis [Cantos et al. 2003, Liu et al. 2005]. In particular, jasmonic acid or its methyl ester (MeJa) has been reported to increase total phenol in different fruit species [Belhadj et al. 2008, Yang et al. 2011].

Although the effect of jasmonates on total phenol content was investigated in many studies conducted up to now, there is not enough information on the effect of this growth regulator on individual phenols and organic acid content. The present study was conducted to examine the effect of MeJa treatments on individual phenols and organic acid content of five strawberry cultivars.

## MATERIALS AND METHODS

**Plant material.** Experiments were conducted in Mudurnu town (with micro climate characteristics for agricultural practices) of Bolu province (Turkey). Bolu province, located in the western part of the Black Sea Region, is located between 40°06' and 41°01' north latitudes, between 30°32' and 32°36' east longitudes. The strawberry field was organized as summer-sowing by using frigo seedlings. The fruits were harvested in both 2016 and 2017 at the commercially ripe stage. Experiments were conducted in randomized blocks design with 3 replications with 15 plants in each replication. Seedlings were sown over seedling beds at 30 × 30 cm sowing distance in a triangular sowing pattern. Seedling beds were covered with black plastic mulching and irrigations were performed through drip lines. Five different strawberry cultivars (Albion, Aromas, Sweet Ann, Honeoye and Seascape) were used as the plant material of the experiments. Foliar MeJa spray treatments were applied at 0.25, 0.50 and 1 mM doses. Control group was not subjected to any treatments. Ripened fruit samples were manually harvested and transported to laboratory in cloth bags. Fruit samples were subjected pomological analyses instantly and remaining fruits were kept at -80°C for biochemical analyses.

**Physico-chemical analyses.** For pomological characteristics, 20 fruits were randomly selected from each cultivar and samples were subjected to average fruit weight (with ±0.1 g balance), fruit length and width (with ±0.01 mm digital caliper), fruit flesh firmness, soluble solid content (SSC) content (with a refractometer) and titretable acidity (TA) (with titration method) analyses [Richard 1991]. Sensory analyses were performed to determine fruit taste, aroma and juiciness. Fruit juice extracts were sued to determine fruit pH values with a pH meter. Shape index was calculated by dividing fruit length with fruit width. Fruit volume was determined through immersing fruits into 50 ml measures partially filled with water [Richard 1991].

**Analysis of phenolic compounds.** Gallic acid, protocatechuic, catechin, chlorogenic acid, caffeic acid, vanillic, rutin, ellagic acid, syringic acid, p-coumaric, ferulic acid, phloridzin and quercetin were detected among phenolic acids in strawberry fruits, with the modified method of Rodriguez-Delgado et al. [2001]. Fruit extracts were mixed with distilled water in a ratio of 1:1. The mixture was centrifuged for 15 min at 15000 rpm. Supernatants were filtrated with coarse filter paper and twice with 0.45 µm membrane filter (Millipore Millex-HV Hydrophilic PVDF, Millipore, USA), and injected into an HPLC (Agilent, USA). Chromatographic separation was performed with a 250 × 4.6 mm, 4µm ODS column (HiChrom, USA). Solvent A methanol : acetic acid : water (10 : 2 : 28) and Solvent B methanol : acetic acid : water (90 : 2 : 8) were used as the mobile phase. Spectral measurements were made at 254 and 280 nm, and flow rate and injection volume were adjusted to 1ml $min^{-1}$ and 20 µl, respectively.

**Analysis of organic acids.** Succinic acid, oxalic acid, citric acid, malic acid, fumaric acid and tartaric acid composition of berries were identified by Bevilacqua and Califano [1989]. 20 g of each sample was mixed with 80 ml of 0.009 N $H_2SO_4$ (Heidolph Silent Crusher M, Germany), then homogenized for 1 hour with a shaker (Heidolph Unimax 1010, Germany). The mixture was centrifuged for 15 min at 15000 rpm, and supernatants were filtrated twice with 0.45 μm membrane filter following filtration with coarse filter (Millipore Millex-HV Hydrophilic PVDF, Millipore, USA) and run through a SEP-PAK C18 cartridge. Organic acid readings were performed with HPLC using Aminex column (HPX -87 H, 300 mm × 7.8 mm, Bio-Rad Laboratories, Richmond, CA, USA) at 214 and 280 nm wavelengths, on Agilent package program (Agilent, USA).

**Analysis of vitamin C.** Vitamin C content was detected with modified HPLC procedure suggested by Cemeroglu [2007]. 20 g of the fruit extracts was supplemented with 2.5% (w $v^{-1}$) metaphosphoric acid (Sigma, M6285, 33.5 %), then centrifuged at 6500 rpm for 10 min at 4°C temperature. 0.5 ml of the mixture was bring to final volume of 10 ml with 2.5% (w $v^{-1}$) metaphosphoric acid. Supernatants were filtered with 0.45 μm PTFE syringe filter (Phenomenex, UK). C18 column (Phenomenex Luna C18, 250 × 4.60 mm, 5 μ) was used for the identification of ascorbic acid at temperature of 25°C. Double distilled water with 1 ml $min^{-1}$ flow rate and pH of 2.2 (acidified with $H_2SO_4$) was used as a mobile phase. Spectral measurements were made at 254 nm wavelength using DAD detector. Different standards of L-ascorbic acid (Sigma A5960) (50, 100, 500, 1000, and 2000 ppm) were used for quantification of ascorbic acid readings.

**Statistical analysis.** The study was planned as three repetitions and 20 fruits per repetition. The introductory statistics belonging to analysis and measurement

**Table 1.** Effect of MeJa applications on pomological properties of strawberry fruits (mean of 2016 and 2017)

| Cultivars | MeJa (mM) | Fruit weight (g) | Volume (ml) | Width (mm) | Height (mm) |
|---|---|---|---|---|---|
| Albion | Control | 15.3a* | 17.0a | 32.3a | 37.8ab |
| | 0.25 | 16.8a | 21.7a | 35.5a | 38.8a |
| | 0.50 | 14.6a | 19.0a | 33.4a | 34.1a |
| | 1 | 13.1a | 17.0a | 31.4a | 31.1a |
| Aromas | Control | 13.1b | 15.7a | 29.2b | 31.7b |
| | 0.25 | 13.8b | 20.0a | 41.8a | 37.8a |
| | 0.50 | 17.3a | 19.3a | 33.1ab | 38.1a |
| | 1 | 12.9b | 14.0a | 31.2ab | 34.3ab |
| Honeyone | Control | 10.9b | 12.3a | 29.1a | 26.6a |
| | 0.25 | 14.7a | 17.3a | 29.6a | 27.1a |
| | 0.50 | 15.3a | 16.7a | 32.1a | 31.3a |
| | 1 | 12.9ab | 15.0a | 31.1a | 29.2a |
| Seascape | Control | 40.3ab | 45.0a | 43.5a | 53.1a |
| | 0.25 | 41.8ab | 45.3a | 45.2a | 52.0a |
| | 0.50 | 43.1a | 42.3a | 44.3a | 54.0a |
| | 1 | 37.9b | 41.7a | 41.4a | 51.3a |
| Sweet Ann | Control | 38.3a | 44.0a | 40.3a | 50.7a |
| | 0.25 | 39.9a | 47.7a | 41.2a | 51.7a |
| | 0.50 | 40.3a | 45.0a | 41.5a | 53.0a |
| | 1 | 40.3a | 45.7a | 41.5a | 51.2a |

* There are significant differences ($p < 0.05$) among the cultivars having different letters in same column

results was offered as average ± standard deviation. In the statistical evaluations, Windows SPSS 20 was used and the differences between the means was evaluated by subjecting to ANOVA variance analysis and determined with Duncan multiple comparison test ($p < 0.05$).

## RESULTS AND DISCUSSION

The effect of MJ applications on fruit weight varied depending on the cultivars. Fruit weight was similar in all treatments for Albion, Honeyone and Sweet Ann cultivars. On the other hand, significant changes due to MeJa applications were observed in fruit weights of Aromas and Seascape strawberries. A remarkable increase was observed in fruit weight of Aromas cultivar treated with 0.5 mM MeJa compared to control. No MeJa treatment was significantly different than the untreated control with respect to fruit volume, shape index, pH and TA in all five strawberry cultivars. Except for the some exceptions, the same situation was observed in fruit width, height, firmness and SSC values (Tabs. 1, 2).

MeJa treatments caused very significant changes in organic acid contents of strawberry cultivars. The most pronounced change in oxalic acid content was observed in Seascape and Sweet Ann cultivars (Tab. 3). Oxalic acid contents of 0.5 mM MeJa treatments of Seascape and Sweet Ann were about 15 and 3 times higher, respectively, than their own control treatment. Contrary to other cultivars, MeJa applications caused a decrease in the oxalic acid contents of Albion and Honeoye. Responses elicited by exogenous MeJa in terms of citric acid content varied depending on the cultivars and application concentration. While MeJa applications decreased citric acid content in Al-

**Table 2.** Effect of MeJa applications on physicochemical properties of strawberry fruits (mean of 2016 and 2017)

| Cultivars | MeJa (mM) | Sape index | Firmness (kg $cm^{2-1}$) | SSC (%) | pH | TA (%) |
|---|---|---|---|---|---|---|
| Albion | Control | 1.17a* | 1.20a* | 9.1b | 4.0a | 1.0a |
| | 0.25 | 1.09a | 1.13a | 9.4ab | 4.1a | 0.8a |
| | 0.50 | 1.02a | 0.43b | 10.3ab | 4.1a | 1.0a |
| | 1 | 0.99a | 0.90ab | 11.7a | 3.9a | 1.3a |
| Aromas | Control | 1.08a | 1.23a | 8.1b | 4.0a | 1.0a |
| | 0.25 | 0.94a | 0.65a | 10.2a | 4.1a | 1.1a |
| | 0.50 | 1.15a | 1.03a | 8.5b | 4.0a | 0.9a |
| | 1 | 1.10a | 0.88a | 8.3b | 3.9a | 0.8a |
| Honeyone | Control | 0.92a | 0.75a | 7.3a | 3.9a | 1.2a |
| | 0.25 | 0.92a | 0.80a | 9.0a | 4.0a | 1.3a |
| | 0.50 | 0.97a | 0.85a | 7.5a | 3.7a | 1.2a |
| | 1 | 0.94a | 0.92a | 8.7a | 3.8a | 1.2a |
| Seascape | Control | 1.22a | 1.33a | 6.7a | 4.1a | 1.1a |
| | 0.25 | 1.15a | 1.42a | 6.9a | 4.1a | 0.9a |
| | 0.50 | 1.22a | 1.33a | 6.2a | 4.0a | 0.9a |
| | 1 | 1.24a | 1.37a | 5.1a | 3.8b | 1.0a |
| Sweet Ann | Control | 1.26a | 1.27a | 8.1a | 3.8a | 1.3a |
| | 0.25 | 1.26a | 1.14a | 8.1a | 3.8a | 1.2a |
| | 0.50 | 1.27a | 1.17a | 6.0a | 3.9a | 1.0a |
| | 1 | 1.24a | 1.34a | 6.3a | 4.0a | 1.1a |

* There are significant differences ($p < 0.05$) among the cultivars having different letters in same column

**Table 3.** Effect of MeJa (mM) applications on Organic acid contents of strawberry fruits (mean of 2016 and 2017) (g $kg^{-1}$)

| Cultivars | MeJa (mM) | Oxalic | Citric | Tartaric | Malic | Succinic | Fumaric | Vitamin C |
|---|---|---|---|---|---|---|---|---|
| Albion | Control | 5.41a* | 14.48a | 2.23a | 7.45a | 9.42a | 0.02c | 0.20a |
| | 0.25 | 5.25b | 11.73b | 1.37b | 5.44b | 9.61a | 0.08a | 0.06b |
| | 0.50 | 4.49c | 10.91c | 1.19c | 4.42d | 6.56b | 0.07b | 0.05b |
| | 1 | 2.89d | 9.25d | 1.08d | 4.52c | 3.28c | 0.06b | 0.04c |
| Aromas | Control | 4.06c | 10.61c | 1.55d | 4.55c | 6.08b | 0.11b | 0.05c |
| | 0.25 | 5.93a | 12.31a | 2.04b | 4.97b | 8.59a | 0.12b | 0.47a |
| | 0.50 | 4.19b | 11.28b | 1.89c | 10.13a | 3.72c | 0.15a | 0.34b |
| | 1 | 4.01d | 10.11d | 2.09a | 3.78d | 3.55d | 0.02c | 0.06c |
| Honeoye | Control | 6.22a | 16.33a | 2.51a | 7.75a | 2.34d | 0.11c | 0.44a |
| | 0.25 | 5.95b | 12.62c | 1.95c | 5.88b | 3.64c | 0.17a | 0.12b |
| | 0.50 | 4.87c | 15.45b | 2.18b | 5.57c | 4.79b | 0.15b | 0.09c |
| | 1 | 3.91d | 8.89d | 1.39d | 3.74d | 5.62a | 0.11c | 0.03d |
| Seascape | Control | 0.59d | 1.49d | 0.038d | 0.44d | 0.24d | 0.01d | 0.01c |
| | 0.25 | 6.65c | 13.01b | 1.73c | 5.52c | 6.22a | 0.08a | 0.16b |
| | 0.50 | 9.15a | 16.49a | 3.26a | 6.47a | 5.23b | 0.05b | 0.19b |
| | 1 | 8.44b | 8.50c | 2.20b | 5.54b | 4.44c | 0.04c | 0.24a |
| Sweet Ann | Control | 3.92c | 12.29c | 1.56b | 4.77d | 2.15c | 0.04c | 0.05d |
| | 0.25 | 5.29b | 14.87b | 2.06b | 5.23b | 4.55b | 0.05b | 0.09c |
| | 0.50 | 10.35a | 21.79a | 3.67a | 7.17a | 13.26a | 0.11a | 0.21a |
| | 1 | 3.52d | 10.86d | 1.54b | 4.77d | 0.95d | 0.04c | 0.13b |

* There are significant differences ($p < 0.05$) among the cultivars having different letters in same column

bion and Honeoye, they increased citric acid content in Seascape and Sweet Ann cultivars. In the Aromas, the effect of MeJa varied depending on concentrations. When compared to control, all MeJa treatments decreased tartaric acid content of Albion and Honeoye cultivars. On the other hand, in Aromas and Seascape strawberries, tartaric acid contents of control fruits were lower than those of MeJa treatments. As in other organic acid content, there were also very significant increases in malic acid content of Seascape treated with MeJa compared to control. In Albion and Honeoye, all MeJa treatments had lower malic acid content than control treatment. In Aromas, while 0.5 mM MeJa caused a significant increase in malic acid, 1 mM MeJa decreased malic acid content. The effect of MeJa on succinic and fumaric acid contents also varied depending on cultivars and application dose. A similar situation was observed in vitamin C content of strawberry cultivars.

The effects of MeJa treatments on gallic acid content were similar in all strawberries cultivars. In general, low MeJa concentration (0.25 mM) increases gallic acid content while high concentration (1 mM) decreases it (Tab. 4). Similar situation was observed in catchein chlorogenic and vanillic acid contents of cultivars. The effect of MeJa treatments on protocatechuic contents changed depending on the cultivar and application concentrations. Caffeic acid contents of all MeJa treatments were lower than those of control treatments for all cultivars. A similar situation was observed in rutin contents of strawberry cultivars except for Seascape. In Seascape cultivars, while 0.5 mM MeJa increased rutin content, the other MeJa concentrations decreased rutin content compared to control (Tab. 4).

Significantly the highest content of ellagic acids was measured in 0.25 mM MeJa treatments, while the lowest in 1 mM MeJa treatment in all cultivars (Tab. 4). The effect of 0.5 mM MeJa on ellagic acid content varied depending on cultivars. When compared to control, all MeJa treatment caused significant decrease in Syringic and p-Coumaric contents of all cultivars. The effect of 0.25 mM MeJa on pholoridzin and ferulic acid content was similar in all cultivars with significant increases compared to control (Tab. 4). While application of MeJa at 0.5 mM increased ferulic content of Albion, Aromas and Sweet Ann, it decreased ferulic content of Seascape and Honeyone. MeJa at 1 mM significantly decreased ferulic acid and pholoridzin contents of all cultivars content, except for Albion, and Seascape respectively. While the application of MeJa at 0.25 mM decreased quercetin in Aromas, it significantly increased quercetin in the other strawberry cultivars. When compared to control, the fruits from 0.5 MeJa treated plants had higher quercetin contents in Albion, Honeyone, Sweet Ann, while they had lower quercetin contents in Aromas and Seascape strawberries. Similarly the effect of 1 mM MeJa applications on quercetin content varied depending on cultivars.

Gansser et al. (1997) reported that MeJa content is high in immature strawberry fruits and shows a continuous decrease during fruit development and this may be effective in fruit development. Rudell et al. [2005] reported decreasing fruit weight and sizes in Fuji apples with MeJa treatments at early season in which fruits had cell divisions, but reported insignificant effects of treatments when applied at late season in which cell divisions ended. The results obtained

**Table 4.** Effect of MeJa (mM) applications on phenolic compounds of strawberry fruits (mean of 2016 and 2017) (mg 100 $g^{-1}$)

| Cultivars | MeJa (mM) | Gallic | Protocatechuic | Catchein | Chlorogenic | Caffeic | Vanillic | Rutin |
|---|---|---|---|---|---|---|---|---|
| Albion | Control | 7.607c* | 0.134c | 6.095c | 3.232c | 1.318a | 0.937c | 2.290a |
| | 0.25 | 16.783a | 0.275b | 9.393a | 3.631b | 0.847b | 1.414a | 1.609b |
| | 0.50 | 10.591b | 0.319a | 6.888b | 3.905a | 0.741c | 1.184b | 1.328c |
| | 1 | 5.023c | 0.135c | 3.005d | 1.045d | 0.145d | 0.345d | 0.841d |
| Aromas | Control | 4.032c | 0.129c | 10.006b | 2.856b | 0.703a | 0.207b | 0.503a |
| | 0.25 | 6.023a | 0.226b | 11.493a | 2.949a | 0.506b | 0.305a | 0.405b |
| | 0.50 | 5.022b | 0.278a | 7.653c | 1.577c | 0.403c | 0.205b | 0.304c |
| | 1 | 3.020d | 0.115d | 5.520d | 1.013d | 0.403c | 0.102c | 0.302c |
| Honeyone | Control | 8.438b | 0.209b | 6.983b | 6.626b | 0.517a | 0.455b | 0.539a |
| | 0.25 | 12.837a | 0.207b | 7.076a | 8.311a | 0.470b | 0.505a | 0.262b |
| | 0.50 | 7.046c | 0.312a | 3.072c | 6.035c | 0.314c | 0.412c | 0.214c |
| | 1 | 6.032d | 0.305a | 3.056c | 4.005d | 0.307c | 0.307d | 0.106d |
| Seascape | Control | 9.312b | 0.883d | 7.152b | 1.092d | 0.734a | 1.931b | 0.263b |
| | 0.25 | 10.037a | 1.008c | 7.502a | 2.101a | 0.636b | 2.582a | 0.219c |
| | 0.50 | 7.625c | 2.144a | 5.503c | 1.936b | 0.470c | 1.216c | 0.444a |
| | 1 | 5.800d | 1.145b | 1.366d | 1.493c | 0.370d | 0.991d | 0.110d |
| Sweet Ann | Control | 18.784b | 0.962b | 4.771b | 2.982b | 2.130a | 3.515b | 0.323a |
| | 0.25 | 24.911a | 1.552a | 5.639a | 3.813a | 1.963b | 3.895a | 0.286b |
| | 0.50 | 8.191c | 0.790c | 3.957c | 2.893b | 1.677c | 2.094c | 0.112c |
| | 1 | 7.274d | 0.345d | 2.474d | 1.666c | 1.038d | 2.085c | 0.050d |

* There are significant differences ($p < 0.05$) among the cultivars having different letters in same column

**Table 4 cont.**

| Cultivars | MeJa (mM) | Ellagic | Syringic | p-Coumaric | Ferulic | Pholoridzin | Quercetin |
|---|---|---|---|---|---|---|---|
| Albion | Control | 9.894b* | 0.350a | 2.597a | 0.191d | 0.132c | 0.138c |
| | 0.25 | 15.864a | 0.291b | 2.086b | 0.984a | 0.285a | 0.836a |
| | 0.50 | 7.280c | 0.286b | 1.835c | 0.838b | 0.191b | 0.624b |
| | 1 | 4.025d | 0.117c | 1.014d | 0.321c | 0.108d | 0.124c |
| Aromas | Control | 6.009d | 0.108a | 1.745a | 0.104c | 0.111b | 0.204a |
| | 0.25 | 9.005a | 0.073b | 0.680b | 0.211a | 0.208a | 0.156b |
| | 0.50 | 8.003b | 0.065c | 0.435c | 0.173b | 0.105b | 0.094c |
| | 1 | 7.032c | 0.044d | 0.174d | 0.093d | 0.094c | 0.074d |
| Honeyone | Control | 7.565c | 0.301a | 3.295a | 1.090b | 0.980b | 0.306d |
| | 0.25 | 9.967a | 0.225b | 2.328b | 1.133a | 1.406a | 1.027a |
| | 0.50 | 9.009b | 0.107c | 1.014c | 0.923c | 0.815c | 0.919b |
| | 1 | 7.006d | 0.093d | 0.905d | 0.415d | 0.710d | 0.418c |
| Seascape | Control | 18.713b | 0.191a | 2.566a | 0.790b | 0.170d | 0.290b |
| | 0.25 | 25.299a | 0.109b | 1.595b | 0.973a | 0.430a | 0.393a |
| | 0.50 | 13.313c | 0.096b | 1.230c | 0.369c | 0.407b | 0.183c |
| | 1 | 11.267d | 0.015c | 0.975d | 0.168d | 0.336c | 0.161d |
| Sweet Ann | Control | 13.350c | 0.132a | 1.677a | 1.534c | 1.695c | 0.136d |
| | 0.25 | 22.768a | 0.095b | 0.586b | 2.302a | 2.055a | 0.690a |
| | 0.50 | 15.241b | 0.071c | 0.478c | 2.029b | 1.695c | 0.591b |
| | 1 | 12.023d | 0.047d | 0.346d | 1.258d | 1.093d | 0.200c |

* There are significant differences ($p < 0.05$) among the cultivars having different letters in same column

from present study showed that the effect of MeJa applied early season varied depending on cultivars. This may be related to different inherent jasmonates contents of cultivars.

It was reported that MeJa treatments slowed down flesh softening by inhibiting ethylene synthesis in peach fruits [Ziosi et al. 2008]. On the other hand, there are several reports in which exogenous application of MeJa reduced or did not affect flesh firmness in different fruit species [Shafiq et al. 2011, Zapata et al. 2014]. Saracoglu et al. [2017], working on different sweet cherry cultivars, showed that the effect of MeJa on firmness was cultivar-dependent. Except for the significant reduction in 0.5 mM treatment of Albino, in this study, MeJa treatments were found ineffective on fresh firmness of strawberry fruits. Similarly, except for a few exceptions in the SSC, MeJa treatments did not cause any significant changes in SSC, pH and TA values of fruit. It was stated that effects of MeJa may vary based on species, cultivar, application dose and timing, environmental conditions and cultural practices [Rohwer and Erwin 2008].

As consistent with the results of previous studies [Koyuncu and Dilmaçünal 2010], it was also determined in this study that citric and malic acid were the most abundant organic acid in strawberries. In addition to these, strawberry fruits were found to contain succinic and oxalic acid at a remarkable level. Sturm et al. [2003] reported that strawberry fruit contained fumaric and tartaric acids in very small amounts. Similar results have been obtained in this study. Cordenunsi et al. [2002] report that organic acids are important contributors to taste of strawberry fruits. In the present study, although varying depending on the variety, it was determined that MeJa application can make significant changes in compostions of strawberry fruits. This situation indicated that taste and quality of fruits may be changed by MeJa application. Ascorbic acid content is one of the important quality factors for strawberry fruits. It was reported that large variability is observed in ascorbic acid content among cultivars and ascorbic acid content could also vary with growing conditions, cultural practices [Van De Velde et al. 2013]. In this study, while MeJa treatments increased ascorbic acid content of cultivars having low ascorbic acid in control treatment, they decreased ascorbic acid content of cultivars with high ascorbic acid. There are not many studies in the literature about the effect of MeJa application on ascorbic acid content. In a rare work made in this regard, Wolucka et al. [2005] reported that MeJa treatment stimulated ascorbic acid biosynthesis in plant cell suspension. MeJa applications caused significant changes in the specific phenol contents, but direction and amount of the change were cultivars and concentration-dependent. These results are in agreement with the findings of Cocetta et al. [2015], who found that the effect of 0.1 mM MeJa on some specific phenol content of two blueberry cultivars changed depending on cultivars and application time.

MeJa at 0.25 mM significantly increased gallic and ellagic acid contents of all tested cultivars. A similar result from MeJa application was reported by Flores et al. [2017] for gallic acid content of olive fruits. In another study on the effect of MeJa application on individual phenols, it was found that MeJa increased caffeic acid content in Black Amber and Black Beauty plums, chlorogenic acid content in Fortune plum and decreased rutin content in Black Amber [Öztürk et al. 2012]. Some studies indicate that plant flavonols such as rutin and quercetin are powerful antioxidants. In the study, with some exceptions, MeJa treatments decreased rutin contents of strawberry fruits. The treatments caused significant changes in quercetin content of fruits depending on cultivars and application concentrations. The results derived from this work as well as observed by other indicated that specific phenol contents can be changed by exogenous MeJa applications.

## CONCLUSION

In the study, it was found that 0.50 mM MeJa application generally increased fruit weights. Citric acid content, which is the dominant organic acid in strawberry fruits, was the highest found to be 21.79 g kg$^{-1}$ (0.50 mM MeJa) in Sweet Ann cultivar. When the contents of phenolic compounds were examined, it was found that ellagic acid and chlorogenic acid were generally higher than other phenolic compounds. It was determined that ellagic and gallic acid content of fruits of 5 different strawberry cultivars increased in 0.25 mM MeJa application compared to control. Therefore, it was determined that physicochemical properties of strawberry fruits varied depending on the cultivars and dose of MeJa application. The results of this study showed that the use of plant growth regulators such as MeJa can change significantly specific organic acid and phenolic composition of strawberry plant.

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