The Effect of Preharvest Application of Arginine on the Postharvest Quality of Sweet Cherry Fruits during Storage

Zahra Pakkish\textsuperscript{a} and Soheila Mohammadrezaakhani\textsuperscript{b}

\textsuperscript{a}Department of Horticultural Science, Faculty of Agriculture, Shahid Bahonar University of Kerman, Kerman, Iran; \textsuperscript{b}Agricultural Jihad Organization of Southern Kerman Province, Kerman, Iran

ABSTRACT
The quality of sweet cherry fruits decrease rapidly after harvest and in some cases does not reach the consumers properly due to the time require for transferring and market. Therefore, using chemical compounds is essential to increase durability and maintain its quality. This study was conducted to investigate the effects of arginine on postharvest quality of sweet cherry fruits. The sweet cherry fruits (Prunus avium L. cv Tak Danehe Mashhad) were sprayed with arginine (0, 200, and 400 \textmu M) one month before harvest. Fruits were harvested at commercial maturity stage according to acceptable color standards. After harvest, the fruits were transferred to the laboratory and immediately kept in cold storage with temperature of 1°C with 90–95% relative humidity (RH) for 20 days. The results showed that in treated fruits, electrolyte leakage, active oxygen production, and lipid peroxidation were decreased. The activity of antioxidant enzymes including ascorbate peroxidase, catalase, and superoxide dismutase was increased compared to control. The treated fruits with arginine 400 \textmu M showed the highest enzymatic activity during cold storage. The percentage of chilling injury and fresh weight loss in treated fruits has decreased compared control fruits. According to the results lowest amount of pH observed in fruits treated with arginine 400 \textmu M. Arginine increased the amount of titratable acid, soluble solids, and vitamin C, as well the firmness of fruits. As short, arginine preharvest treatment at 400 \textmu M concentration improved the postharvest quality of sweet cherry fruits.

Introduction
Sweet cherries are one of the fruits that are harvested in early summer season and have a high economic value (Dever et al., 1996). Sweet Cherry fruits are highly perishable product during postharvest period and in unsuitable postharvest handling may lose its all nutritional quality. Due to its excellent taste and high nutritional values, Sweet cherry fruits are more popular fruit in most of countries and mainly consumed as a dessert fresh fruit (Martinez et al., 2005). Therefore, short cool storage technology is often applied to extend the fresh fruit supply to the market. However, sweet cherry fruits must be stored for a relatively short time under optimal storage conditions (Dziedzic and Błaszczyk 2019). Several conservation techniques have been used to extend the postharvest life of perishable agricultural commodities. In many cases, growers rely on alternative methods, including application of disinfectants or chemicals with low-residues, physical methods, controlled atmosphere, and biological control (Eshel et al., 2009). The exogenous application of some amino acids has been proven to have a positive effect on plant growth and development under stressful conditions. Arginine (Arg) has shown a lot of physiological roles than other amino acids (Matysiak et al., 2020). Generally,
Arginine is a vital regulator for the developmental and physiological process in plants (Galston and Kaur-Sawhney, 1995). Arg is one of the most functionally diverse amino acids in living cells. In addition to serving as a constituent of proteins, Arg is a precursor for the biosynthesis of polyamines, agmatine, and proline, as well as the cell-signaling molecules glutamate, amino butyric acid, and nitric oxide (Liu et al. 2006). Polyamines and nitric oxide are important messengers involved in almost all physiological and biochemical processes, growth and development, and also adaptation of plants to stress. Arg has shown a lot of physiological roles than other amino acids (Kakkar et al., 2000). Postharvest application of the arginine on strawberry fruits leading to inhibiting fruit decay and maintaining fruit quality (Shu et al., 2020). The simulative effect of arginine as polyamines precursor on growth and yield component may act as protective agent in plants adapted to extreme environment (Miller et al., 2007). Moreover, since polyamines (especially spermidine and spermine) share the same precursor (arginine), their function for improving apricot fruit was demonstrated (Paksasorn et al., 1995); also increasing physical and chemical characteristics in peaches (Bregoli et al., 2002), nectarine (Torrigiani et al., 2004) and pear (Franco-Mora et al., 2005). Bagni et al. (1981) reported that the apple fruits treated with spermine and putrescine reached higher sugar content, while plum fruits treated with putrescine by Serrano et al. (2003) showed lower soluble solutions and titratable acids.

Therefore, the aim of our study was to evaluate the effect of preharvest application of Arg on the postharvest quality of Tak Danehe Mashhad sweet cherry fruit stored at 1°C.

**Materials and Methods**

**Plant Materials and Arginine Treatment**

In this experiment, 12-year-old sweet cherry trees with the same management conditions were selected. Fruit samples were picked from a commercial sweet cherry (Prunus avium L. cv Tak Danehe Mashhad.) orchard located in Kerman province, Iran. One month before harvest, the trees were sprayed with arginine (0, 200, and 400 μM) in three replications. Three trees are considered in each replications. Fruits were harvested at commercial maturity stage according to acceptable color standards. After harvesting, the fruits were transferred to the laboratory and immediately stored at 1°C and 90–95% relative humidity (RH) for 20 days (Hassanpour et al., 2018). Twenty-five fruits per replication were used randomly from the treated fruits in each replication. After cold storage, the quantitative and qualitative characteristics of the fruits, including hydrogen peroxide, lipid peroxidation, electrolyte leakage, ascorbate peroxidase, catalase, superoxide dismutase, firmness, pH, titratable acidity, total soluble solids and weight loss and chilling injury were examined. The measurement intervals for desired traits have been every five days in four stages.

**Hydrogen Peroxide (H₂O₂)**

Hydrogen peroxide concentration was determined according to Loreto and Velikova (2001) method. 0.2 g of fruit samples was homogenized in 3 ml of 1% (w/v) trichloroacetic acid (TCA). The homogenate was centrifuged at 10,000 g for 10 min. Subsequently, 0.75 ml of the supernatant was added to 0.75 ml of 10 mM potassium-phosphate buffer (pH 7.0) and 1.5 ml of 1 M KI. H₂O₂ concentration of the supernatant was measured by comparing its absorbance at 390 nm to a standard calibration curve.

**Lipid Peroxidation**

Lipid peroxidation was measured as the amount of malondialdehyde (MDA) determined by the TBA reaction as described by Heath and Packer (1968). 0.2 g of fruits was homogenized in 4 ml of 1% (w/v) trichloroacetic acid (TCA), and then centrifuged at 10,000 g for 10 min. 1.5 ml of 20% (w/v) TCA containing 0.5% (w/v) thiobarbituric acid (TBA) was added to 1.5 ml of the supernatant. The mixture
was heated at 95°C for 30 min and then quickly cooled in an ice bath. The mixtures were centrifuged at 10,000 g for 5 min and the absorbance of the supernatant was measured at 532 nm. The value for nonspecific absorption at 600 nm was subtracted from the 532 nm reading. TBA reacted with MDA, resulting in a color compound, which can be determined spectrophotometrically. The MDA content was calculated using its extinction coefficient of 155 mM⁻¹ cm⁻¹ and expressed as mmol/g FW.

**Electrolyte Leakage (EL) Analysis**

EL was measured according to Barranco and Natividad (2005). 0.5 g fresh weight of the fruits excised and washed in deionized water. Afterward, samples were placed in an Erlenmeyer flask containing 15 mL of deionized water. The flasks were then shaken for 24 h using a conductance meter (Consortmodel C831, Turnhout, Belgium) at 120 rpm in light conditions and temperature of 20 to 22°C. The initial electrolytic conductivity of each solution (initial EC, in µS·cm⁻¹) was measured, to obtain an indirect indication of the amount of ion released at each freezing temperature. Sample tubes were then autoclaved (1 h, 120°C, 1 atm) to kill the tissues completely. After 2 h shaking at 200 rpm in light conditions, electrical conductivity was measured again (autoclave EC), to obtain a reference value for total ions. Relative EC at each temperature (T) was calculated as EC_r = (initial EC/autoclave EC) × 100.

**Enzyme Assays**

**Preparing of Enzyme Extracts**

Samples extractions were prepared by homogenizing 1 g of fruit in 4 ml of 50 mM potassium phosphate buffer (pH 7.0) containing 2 mM Na–EDTA and 1% (w/v) polyvinyl–polypirrolidone (PVP). The experiment was performed on ice and then the homogenate was centrifuged at 10,000 g for 10 min. The supernatants were collected and stored at −80°C until using.

The total protein content of samples was determined according to Bradford protein assay using bovine serum albumin (BSA) as a standard. 100 ml from 0.5 M tris buffer with pH equal to 6.8 and 2 g SDS was added and dissolved. 200 µl of extraction buffer was added to fresh fruit samples of *Prunus avium* L. cvTakDanehe Mashhad. The solutions were then centrifuged at 13,000 rpm for 20 minutes. To 5 ml of Bradford solution, 100 µl of the above extract was added and after 30 minutes in laboratory conditions, the absorbance of the above extract was measured at 595 nm using bovine serum albumin (BSA) (Bradford, 1976)

**Determination of Ascorbate Peroxidase (APX) Activity**

The APX activity was measured using spectrophotometer (Cary 50-UV-Visible) as described by Nakano and Asada (1981). The assay mixture consisted of 100 µg of the enzyme extract added to assay solution (50 mM potassium-phosphate buffer (pH 6.6) with 2.5 mM ascorbate) and the reaction was initiated by the addition of 10 mM H₂O₂. The decrease in the absorbance of ascorbate was recorded at 290 nm for 3 min against assay solution (ε = 2.8 mM⁻¹ cm⁻¹).

**Determination of Catalase (CAT) Activity**

Catalase activity was determined as described by Chance and Mahly (1995). The assay mixture consisting of 100 µg of the enzyme extract was added to 50 mM potassium-phosphate buffer (pH 7.0) and 200 mM H₂O₂ to initiate the reaction. The decrease in the absorbance H₂O₂ was recorded at 240 nm for 3 min against assay solution (ε = 39.4 mM⁻¹ cm⁻¹).

**Determination of Superoxide Dismutase (SOD)**

Superoxide dismutase (SOD) was assayed in accordance with the method of Beauchamp and Fridovich (1971). The reaction mixture was prepared by mixing 50 µl crude enzyme extract with the SOD assay solution (50 mM potassium phosphate buffer [pH 7.8], 75 mM nitroblue tetrazolium [NBT], 13 mM L-methionine, 0.1 mM EDTA, and 2 µM riboflavin). The test tube was shaken and placed in a light box.
for 15 min. One unit of enzyme activity was determined as the amount of enzyme needed for inhibition of 50% NBT reduction by monitoring absorbance at 560 nm.

**Peroxidase Assay**

5 ml of the assay mixture for the peroxidase activity comprised: 125 mM of phosphate buffer, pH 6.8, 50 mM of pyrogallol, 50 mM of H$_2$O$_2$, and 1 ml of the 20 times-diluted enzyme extract. This was incubated for 5 min at 25°C after which the reaction was stopped by adding 0.5 ml of 5% (v/v) H$_2$SO$_4$. The amount of purpurogallin formed was determined taking the absorbance at 420 nm.

**Measurements of Fruit Firmness**

Flesh firmness (using 10 fruits) was determined on opposite peeled cheeks of the fruit using a Fruit Firmness Tester (FT-327, Italy), equipped with a 8-mm plunger tip.

**pH and Titratable Acidity and Total Soluble Solids (TSS)**

The fruits pH were measured using a pH meter (Hannan). Titratable acidity (TA) was determined by titration to pH 8.1 with 0.1 M NaOH, and was expressed as g malic acid 100 g$^{-1}$ FW. Total soluble solids were measured from five fruits per replication at harvest using a hand-held refractometer (American Optical Co., Keene, N.H.) (Basiouny and Woods, 1992).

**Weight Loss and Chilling Injury**

To determine weight loss, 10 fruit from each treatment were weighed at the beginning of the experiment and during storage. The results were expressed as the proportion (%) of weight loss against the initial value (Zokaee-Khosroshahi and Esna-Ashari, 2007). The chilling injury was calculated as follows:

\[
\text{Chilling injury index} = \frac{\text{Total number of fruits} - \text{Number of damaged fruits}}{\text{Total number of fruits}} \times 100
\]

(Nilprapruck et al., 2008).

**Statistical Analysis**

The experimental design was a completely randomized design with three replications. Data were analyzed using the SAS software version 9.1 (SAS Institute, Cary, NC, USA), and the means were compared (p≤.05) by Duncan’s multiple range test (DMRT).

**Results**

**Electrolyte Leakage, H$_2$O$_2$ and Peroxidation of Lipids**

The results showed that the effect of arginine on electrolyte leakage, hydrogen peroxide, and lipid peroxidation was statistically significant at the level of 1% (Table 1). The lowest amount of the electrolyte leakage, H$_2$O$_2$ and lipid peroxidation were observed in fruits at harvest time. During storage time, level of electrolyte leakage, H$_2$O$_2$ and lipid peroxidation have increased. So that, the highest amount of electrolyte leakage, production of H$_2$O$_2$ and lipid peroxidation in control fruits were observed during storage. But the use of arginine has led to a reduction in electrolyte leakage, H$_2$O$_2$ and lipid peroxidation. The lowest levels of electrolyte leakage, H$_2$O$_2$ and lipid peroxidation were related to fruits treated with arginine 400μM at the start of storage (Table 2).
Table 1. Variance analysis of the effect of arginine on electrolyte leakage (EL), hydrogen peroxide (H$_2$O$_2$) and lipid peroxidation (LP) in TakDanehe Mashhad sweet cherry fruits during cold storage.

| Source       | df  | EL  | H$_2$O$_2$ | LP  | EL  | H$_2$O$_2$ | LP  | EL  | H$_2$O$_2$ | LP  |
|--------------|-----|-----|------------|-----|-----|------------|-----|-----|------------|-----|
| Treatment    | 2   | 0.018 | 0.0007 | 0.0045 | 3.78 | 0.010 | 0.0001 | 0.0005 | 3.29 | 0.0005 |
| Error        | 6   | 0.008 | 0.0001 | 0.0005 | 0.08 | 0.010 | 0.0001 | 0.0005 | 0.08 | 0.0005 |
| CV           |     | 0.82 | 2.86     | 5.13   | 0.23 | 2.49 | 0.79   | 0.34   | 1.24 | 0.72   |

* p < 0.05, ** p < 0.01, ns not significant
Table 2. Effect of arginine on H$_2$O$_2$, lipid peroxidation, and ion leakage in TakDanehe Mashhad sweet cherry fruits during cold storage.

| Storage time (day) | 0       | 5       | 10      | 15      | 20      |
|-------------------|---------|---------|---------|---------|---------|
| H$_2$O$_2$ (µM/g) | C       | A$_1$   | A$_2$   | C       | A$_1$   | A$_2$   | C       | A$_1$   | A$_2$   | C       | A$_1$   | A$_2$   |
|                   | 8.47$^a$ | 7.32$^g$ | 5.62$^h$ | 9.49$^{ef}$ | 8.2$^g$ | 6.14$^h$ | 24.07$^{ab}$ | 11.88$^e$ | 7.34$^g$ | 29.07$^{ab}$ | 17.85$^c$ | 9.28$^{ef}$ | 35.57$^a$ | 20.34$^{ab}$ | 10.5$^d$ |
| Lipid peroxidation(µM/g) | 117.79$^{fg}$ | 116.62$^{g}$ | 111.57$^g$ | 134.95$^f$ | 123.75$^g$ | 120.8$^g$ | 169.59$^{df}$ | 134.65$^f$ | 121.5$^g$ | 233.27$^b$ | 180.25$^c$ | 126$^a$ | 304.09$^a$ | 212.07$^{ab}$ | 150.3$^c$ |
| Ion leakage(%)    | 10.49$^i$ | 6.21$^f$ | 4.4$^k$ | 16.44$^f$ | 9.38$^i$ | 4.43$^k$ | 24.32$^{ab}$ | 12.47$^h$ | 8.31 | 39.31$^b$ | 20.31$^e$ | 12.24$^h$ | 63.49$^a$ | 35.41$^c$ | 15.37$^g$ |

Values in the same row with different superscript letters represent significant differences between different concentrations of arginine at p < .05 by Duncan’s test. C: Control, A$_1$: Arginine 200 µM, A$_2$: Arginine 400 µM.
**Antioxidant Enzymes Activity**

The effect of arginine on the activity of antioxidant enzymes during storage was statistically significant at level 1% (Table 3 and Table 4). The results of the activity of antioxidant enzymes in cherry fruits are shown in Table 2. The results showed that the activity of enzymes in both control and treated fruits increased during storage. The trend of changes at the beginning of storage in control and treated fruits did not show a significant difference. However, the highest levels of CAT, SOD, AXP, and peroxidase were observed in fruits treated with arginine 400 μM within 20 days of storage (Table 5).

**Effect of Arginine on pH, TA, TSS, and Vitamin C**

The pH, TA, TSS, and vitamin C levels were significant as a result of the effect of arginine during cold storage (Table 6 and Table 7). The level of pH was increased in control fruits. According to the results, arginine maintains level of pH and has prevented from increasing pH during storage and the lowest amount of pH was observed in fruits treated with arginine 400 μM. Arginine increases the amount of titratable acids. So that, the lowest titratable acids observed in untreated fruits. The highest titratable acids was observed in fruits treated with arginine 400 μM. The amount of soluble solids and vitamin C during storage has increased, although the fruits treated with arginine 400 μM are higher than the control (Table 8).

**Effect of Arginine on Chilling Injury, Weight Loss, and Firmniss**

Different concentrations of arginine had significant effects on chilling injury, weight loss, and firmness (Table 9). The level of chilling injury and weight loss in the control fruits was higher than treated fruits. The lowest amount of chilling injury and weight loss in fruits treated with Arginine 400 μMat the early days of storage. The firmness of fruit tissue in control plants has decreased compared to the treated

### Table 3. Variance analysis of the effect of arginine on Catalase (CAT), Super oxide dismutase (SOD) in TakDanehe Mashhad sweet cherry fruits during cold storage.

| Source   | df  | 0 Day CAT | 0 Day SOD | 5 Day CAT | 5 Day SOD | 10 Day CAT | 10 Day SOD | 15 Day CAT | 15 Day SOD | 20 Day CAT | 20 Day SOD |
|----------|-----|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| Treatment| 2   | 44.57**   | 0.09ns    | 49.11**   | 6.34**    | 73.13**   | 4.00**    | 87.52**   | 12.27**   | 123.42**  | 15.62**   |
| Error    | 6   | 0.08      | 0.26      | 0.10      | 0.005     | 0.08      | 0.003     | 0.01      | 0.005     | 0.05      | 0.009     |
| CV       | -   | 0.19      | 0.36      | 0.21      | 0.64      | 0.19      | 0.55      | 0.08      | 0.56      | 0.15      | 0.71      |

* p < 0.05, ** p < 0.01, ns not significant

### Table 4. Variance analysis of the effect of arginine on Ascorbate peroxidase (APX) and Peroxidase (POX) in TakDanehe Mashhad sweet cherry fruits during cold storage.

| Source   | df  | 0 Day APX | 0 Day POX | 5 Day APX | 5 Day POX | 10 Day APX | 10 Day POX | 15 Day APX | 15 Day POX | 20 Day APX | 20 Day POX |
|----------|-----|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| Treatment| 2   | 3.96 ns   | 2.43 ns   | 6.34**    | 3.61**    | 8.49**    | 4.00**    | 12.27**   | 6.18**    | 15.62**   | 9.82**    |
| Error    | 6   | 0.002     | 0.008     | 0.005     | 0.004     | 0.002     | 0.003     | 0.005     | 0.005     | 0.009     | 0.011     |
| CV       | -   | 0.46      | 0.92      | 0.64      | 0.65      | 0.37      | 0.55      | 0.56      | 0.61      | 0.71      | 0.86      |

* p < 0.05, ** p < 0.01, ns not significant
Table 5. Effect of arginine on ascorbate peroxidase (APX), superoxide dismutase (SOD), and catalase (CAT) activities in TakDanehe Mashhad sweet cherry fruits during cold storage.

| Storage time (day) | 0  | 5  | 10 | 15 | 20 |
|-------------------|----|----|----|----|----|
| **Treatment**     | C  | A1 | A2 | C  | A1 | A2 | C  | A1 | A2 | C  | A1 | A2 |
| Catalase (U/mg Protein) | 29.54<sup>c</sup> | 30.15<sup>ab</sup> | 31.46<sup>ab</sup> | 29.65<sup>c</sup> | 30.48<sup>ab</sup> | 31.8<sup>ab</sup> | 30.6<sup>bc</sup> | 31.8<sup>ab</sup> | 32.4<sup>ab</sup> | 29.65 <sup>c</sup> | 31.93<sup>ab</sup> | 32.9<sup>b</sup> | 30.08<sup>ab</sup> | 33.02<sup>b</sup> | 37.54<sup>a</sup> |
| Superoxide dismutase (U/mg Protein) | 18.55<sup>c</sup> | 19.38<sup>d</sup> | 23.5<sup>a</sup> | 18.74<sup>c</sup> | 19.66<sup>d</sup> | 23.98<sup>f</sup> | 18.98<sup>f</sup> | 20.07<sup>c</sup> | 25.5<sup>c</sup> | 19.46<sup>d</sup> | 20.65<sup>bc</sup> | 28.6<sup>b</sup> | 19.74<sup>d</sup> | 21.66<sup>bc</sup> | 30.6<sup>a</sup> |
| Ascorbate peroxidase (U/mg Protein) | 23.04<sup>f</sup> | 24.4<sup>f</sup> | 32.6<sup>d</sup> | 23.5<sup>f</sup> | 27.7<sup>f</sup> | 34.8<sup>f</sup> | 29.6<sup>f</sup> | 38.5<sup>ab</sup> | 32.8<sup>de</sup> | 23.7<sup>f</sup> | 32.8<sup>de</sup> | 41.2<sup>b</sup> | 24.14<sup>f</sup> | 24.3<sup>f</sup> | 35<sup>f</sup> | 45.4<sup>a</sup> |
| Peroxidase (U/mg Protein) | 11.06<sup>f</sup> | 14.28<sup>e</sup> | 23.49<sup>d</sup> | 11.51<sup>f</sup> | 16.31<sup>d</sup> | 26.3<sup>cd</sup> | 11.60<sup>f</sup> | 18.15<sup>d</sup> | 29.7<sup>f</sup> | 12.25<sup>f</sup> | 21.10<sup>cd</sup> | 34.6<sup>d</sup> | 12.64<sup>f</sup> | 24.03<sup>d</sup> | 40.46<sup>a</sup> |

Note: Values in the same row with different superscript letters represent significant differences between different concentrations of arginine at p < .05 by Duncan’s test. C: Control, A<sub>1</sub>: Arginine 200 µM, A<sub>2</sub>: Arginine 400 µM.
Table 6. Variance analysis of the effect of arginine on pH, TSinTakDanehe Mashhad sweet cherry fruits during cold storage.

| Source | df | pH | TSS | pH | TSS | pH | TSS | pH | TSS | pH | TSS |
|--------|----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Treatment | 2  | 0.0003*** | 0.0002*** | 0.0007** | 0.0007** | 0.001** | 0.001** | 0.002*** | 0.0023*** | 0.004** | 0.0033*** |
| Error   | 6  | 0.0001 | 0.00008 | 0.00004 | 0.00004 | 0.00005 | 0.00005 | 0.001 | 0.00007 | 0.0002 | 0.00003 |
| CV      |    | 2.88 | 2.26 | 1.49 | 1.49 | 1.73 | 1.73 | 2.67 | 1.83 | 3.31 | 1.21 |

*p < 0.05, **p < 0.01, ***not significant

Table 7. Variance analysis of the effect of arginine on Vitamin C (Vit C), TA (B) in TakDanehe Mashhad sweet cherry fruits during cold storage.

| Source | df | Vit C | TA | Vit C | TA | Vit C | TA | Vit C | TA | Vit C | TA |
|--------|----|-------|----|-------|----|-------|----|-------|----|-------|----|
| Treatment | 2  | 0.0002** | 70.35** | 0.0003** | 70.25** | 82.90** | 82.90** | 0.001** | 141.44** | 0.004** | 165.18** |
| E      | 6  | 0.00004 | 0.74 | 0.00005 | 0.19 | 0.03 | 0.03 | 0.00007 | 0.12 | 0.00008 | 0.01 |
| CV     |    | 1.66 | 0.58 | 1.91 | 0.29 | 0.12 | 0.12 | 2.00 | 0.23 | 1.98 | 0.08 |

*p < 0.05, **p < 0.01, ***not significant

during storage. The highest level of firmness found in fruit treated with arginine 400 on the tenth day of storage (Table 10).

Discussion

In recent years, the use of natural compounds has become a new way for controlling postharvest decay of horticultural crops. Among them, L-Arginine (Arg) has drawn wide attention due to its safety and effectiveness (Shu et al., 2020). The results of this study indicate that preharvest treatment with arginine could significantly decreased electrolyte leakage, H₂O₂ and lipid peroxidation in sweet cherry fruits during storage.

So it seems that some positive effects of arginine are related to production of nitric oxide, polyamines, or proline. The application of exogenous arginine reduced the lipid peroxidation and hydrogen peroxide content in tomato seedling under drought stress (Nasibi et al., 2011). Arg. pretreatment decreased the lipid peroxidation, protein oxidation, and hydrogen peroxide content while increased the activity of all antioxidant enzymes in plants which were under cold stress (Barand et al., 2015).

L-arginine is one of the most functionally diverse amino acids in living cells. In addition to serving as a constituent of proteins, arginine is a precursor for biosynthesis of polyamines, agmatine, and proline as well as the cell signaling molecules glutamine and nitric oxide (Liu et al. 2006). Amino acids have a specific role in plant responses to stresses. Among the amino acids, arginine has been implicated as vital modulators in a variety of growth, physiological, and developmental processes in higher plants (Zhang et al., 2013).

Recently, the positive role of arginine in plant stress responses has aroused great attention. Exogenous arginine treatment effectively activated endogenous arginine metabolism and maintained the storage quality and prolonged the shelf-life of button mushrooms (Agaricus bisporus) (Li et al., 2019).

We demonstrated that the activities of the antioxidant enzymes (CAT, APX, and SOD) increased after treatment with arginine. Therefore, the inducing effects of arginine on these defense enzymes may be one of its important mechanisms for maintaining fruit postharvest quality.

It has been reported that the NO maintained significantly higher levels of SOD, CAT, and APX activities and inhibited the increases of superoxide radical production, MDA contents, and fruit decay.
Table 8. Effect of arginine on pH, TA, TSS, and vitamin C in TakDanehe Mashhad sweet cherry fruits during cold storage.

| Storage time (day) | 0  | 5  | 10 | 15 | 20 |
|-------------------|----|----|----|----|----|
| **Treatment**     | C  | A₁ | A₂ | C  | A₁ | A₂ | C  | A₁ | A₂ | C  | A₁ | A₂ |
| **Characteristics** |    |    |    |    |    |    |    |    |    |    |    |    |
| pH                | 3.94<sup>a</sup> | 3.55<sup>b</sup> | 3.29<sup>b</sup> | 3.82<sup>b</sup> | 3.60<sup>b</sup> | 3.34<sup>b</sup> | 4.06<sup>a</sup> | 3.62<sup>b</sup> | 3.4<sup>a</sup> | 4.10<sup>a</sup> | 3.69<sup>b</sup> | 3.48<sup>b</sup> | 4.09<sup>a</sup> | 3.74<sup>b</sup> | 3.5<sup>b</sup> |
| TA (g/100 ml)     | 1.44<sup>b</sup> | 1.62<sup>a</sup> | 1.96<sup>a</sup> | 1.30<sup>b</sup> | 1.53<sup>b</sup> | 1.91<sup>a</sup> | 1.20<sup>c</sup> | 1.43<sup>b</sup> | 1.86<sup>a</sup> | 1.12<sup>a</sup> | 1.35<sup>b</sup> | 1.77<sup>a</sup> | 1.02<sup>c</sup> | 1.28<sup>c</sup> | 1.71<sup>a</sup> |
| TSS (%)           | 6.42<sup>b</sup> | 6.99<sup>b</sup> | 8.02<sup>a</sup> | 6.64<sup>b</sup> | 7.07<sup>b</sup> | 8.07<sup>a</sup> | 6.84<sup>b</sup> | 7.21<sup>b</sup> | 8.19<sup>a</sup> | 6.91<sup>b</sup> | 7.27<sup>b</sup> | 8.3<sup>a</sup> | 7.01<sup>b</sup> | 7.50<sup>a</sup> | 8.5<sup>a</sup> |
| Vitamin C (mg/100 ml) | 19.92<sup>e</sup> | 21.33<sup>c</sup> | 23.51<sup>b</sup> | 19.49<sup>f</sup> | 20.75<sup>c</sup> | 24.17<sup>a</sup> | 19.53<sup>d</sup> | 21.82<sup>c</sup> | 24.4<sup>a</sup> | 19.6<sup>d</sup> | 21.2<sup>c</sup> | 24.5<sup>a</sup> | 19.96<sup>bc</sup> | 21.52<sup>bc</sup> | 24.69<sup>a</sup> |

Note: Values in the same row with different superscript letters represent significant differences between different concentrations of arginine at p < .05 by Duncan’s test. C: Control, A₁: Arginine 200 µM, A₂: Arginine 400 µM.
Table 9. Variance analysis of the effect of arginine on Weight loss (wL), Firmmiss(F) and Chiling injury (CI) in TakDanehe Mashhad sweet cherry fruits during cold storage.

| Source     | df | 0      |   |      |      | 5Day   |   |      |      | 10Day  |   |      |      | 15Day  |   |      |      | 20Day  |   |      |      |
|------------|----|--------|---|------|------|--------|---|------|------|--------|---|------|------|--------|---|------|------|--------|---|------|------|
| Treatment  | 2  | 2.53   |   | 0.014| 0.01 | 0.01   |   | 21.54 | 0.015| 0.001 |   | 12.46 | 0.01 | 1.01  |   | 0.01 | 0.12 | 1.01   |   | 0.01 | 0.12 |
| Error      | 6  | 0.005  |   | 0.00004| 0.12 | 0.04   |   | 0.02 | 0.00005| 0.01 | 0.04  |   | 0.02 | 0.00004| 0.01 | 0.04 | 0.00004| 0.02 | 0.04 | 0.00004| 0.02 |
| CV         | -  | 0.78   |   | 1.14 | 2.14 | 2.04   |   | 1.23 | 2.14 | 2.04  |   | 1.23 | 2.14 | 2.04  |   | 1.23 | 2.14 | 2.04  |   | 1.23 | 2.14 |

* p < 0.05, ** p < 0.01, ns not significant
Table 10. Effect of arginine on chilling injury, weight loss, and firmness in TakDanehe Mashhad sweet cherry fruits during cold storage.

| Storage time (day) | 0   | 5   | 10  | 15  | 20  |
|--------------------|-----|-----|-----|-----|-----|
|                    | C   | A1  | A2  | C   | A1  | A2  | C   | A1  | A2  | C   | A1  | A2  |
| Chilling injury (%)| 0   | 0   | 0   | 10.25<sup>d</sup> | 5<sup>f</sup> | 1<sup>g</sup> | 38.25<sup>b</sup> | 13.25<sup>d</sup> | 2.25<sup>f</sup> | 65<sup>a</sup> | 27<sup>e</sup> | 6.25<sup>e</sup> | 65<sup>a</sup> | 27<sup>e</sup> | 6.25<sup>e</sup> |
| Weight loss (%)     | 0   | 0   | 0   | 0.8<sup>g</sup> | 0.42<sup>h</sup> | 0.06<sup>gh</sup> | 6.9<sup>a</sup> | 3.12<sup>ab</sup> | 0.7<sup>g</sup> | 12.05<sup>b</sup> | 5.54<sup>d</sup> | 1.73<sup>f</sup> | 24.44<sup>b</sup> | 13.81<sup>b</sup> | 5.67<sup>ac</sup> |
| Firmness (Kg/cm<sup>2</sup>) | 10.24<sup>ab</sup> | 10.7<sup>ab</sup> | 11.8<sup>a</sup> | 10.19<sup>ab</sup> | 10.66<sup>ab</sup> | 11.7<sup>a</sup> | 10.05<sup>b</sup> | 10.22<sup>ab</sup> | 11.42<sup>a</sup> | 9.74<sup>d</sup> | 10.11<sup>ab</sup> | 11.11<sup>a</sup> | 9.02<sup>b</sup> | 9.95<sup>b</sup> | 11.11<sup>a</sup> |

Note: Values in the same row with different superscript letters represent significant differences between different concentrations of arginine at p < .05 by Duncan's test. C: Control, A1: Arginine 200 µM, A2: Arginine 400 µM
(Fan et al., 2008). Liu et al. (2011) reported that the function of NO on alleviation of oxidative stress in cucumber plants under chilling stress was attributed to induction of various ROS scavenging enzyme activities. NO treatment could also induce SOD and CAT activities and maintain membrane integrity on tall fescue leaves under highlight stress (Xu et al., 2010). In another study, it has been shown that Arg pre-treatment decreased the activity of CAT and GPX in tomato plants under drought stress (Nasibi et al., 2011).

The amino acid arginine is involved in the activity of several enzymes in the plant. This amino acid binds to the membrane nucleic acid and phospholipids of the membrane and improves the activity of enzymes (Abdul-Qados, 2009). The results of present study demonstrate that the Arg preharvest application increased fruit firmness, pH, titratable acidity, total soluble solids, and decreased weight loss and chilling injury, where the best effects were found for the 400 µM Arg-treated fruits. This corresponds with the result of a previous study, in which it was found that 0.1 mMArg treatment effectively reduced the weight loss in Asparagus officinalis L (Gong et al., 2017). Our findings, therefore, demonstrated the positive role of Arg in maintaining fruit quality. Zhang et al. (2013) also reported that treatment with exogenous arginine could alleviate chilling injury of tomato fruit during cold storage.

Pomegranate fruit displayed significantly lower chilling injury after treatment with 1 mM Arg (Babalar et al., 2018). Pretreatment of sunflower with Arg improved drought resistance via increase in the polyamine content (Hassan and Mohamed, 2019).

The use of arginine has increased the amount of sugar in pear fruit, which is consistent with the results of this study (Abdul-Qados, 2009). Arginine is involved in the synthesis of polyamines, whose anti-oxidative effect has been confirmed in numerous scientific studies. The role of arginine as an important amino acid for nitrogen storage in plants is complemented by arginine catabolism mobilizing stored nitrogen and fine-tuning the production of NO, polyamines, and potentially proline.

Treatment of strawberry fruits with 1 mM arginine has increased the firmness, titratable acid, soluble solid content (Shu et al., 2020).

Arginine is the main amino acid in plants and two main pathways of its metabolism have been reported which are catalyzed by either arginase or nitric oxide synthase so that the end product will be ornithine or nitric oxide respectively (Liu et al. 2006). Earlier, pre-storage infiltrations by polyamines have been reported to reduce fruit softness and color development in lemons (Valero et al. 1998) and in apricot (Martinez- Romero et al. 2002). The effect of polyamines on maintaining fruit firmness can be attributed to their cross linkages to the -COO- group of pectic substances in the cell wall, blocking the access of degrading enzymes thus reducing the rate of softening during storage (Valero et al. 2002). Jawandha et al. (2012) revealed that the fruits of mango cv. Langra treated with putrescine at 2.0 mmol/L retained the best quality in terms of high palatability rating, good blend of total soluble solids (TSS) and acidity and low physiological loss in weight and spoilage percentage.

**Conclusion**

Arginine treatment is one of the potent stimulators in natural resistance of the plant and increases the postharvest quality of sweet cherry fruits. Comparison of arginine concentrations showed that 400 µM arginine improved postharvest quality in sweet cherry (Prunus avium L. cv TakDanehe Mashhad) fruits.

**Disclosure Statement**

No potential conflict of interest was reported by the author(s).
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