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Effect of Ethephon Application on Fruit Quality at Harvest and Post-harvest Storage of Japanese Plum (*Prunus salicina*) cv. Fortune

Carine Cocco[1,2]
https://orcid.org/0000-0002-1850-2266

Wendel Paulo Silvestre[1,3*]
https://orcid.org/0000-0002-9376-6405

Gabriela Weber Schildt[2]
https://orcid.org/0000-0001-9325-5472

Felipe Afonso Tessaro[2]
https://orcid.org/0000-0003-4109-9724

[1]University of Caxias do Sul, Course of Agronomy, Rio Grande do Sul, Brazil; [2]University of Caxias do Sul, Postgraduate Program in Biotechnology, Rio Grande do Sul, Brazil; [3]University of Caxias do Sul, Laboratory of Studies of the Soil, Plant and Atmosphere System and Plant Metabolism, Rio Grande do Sul, Brazil.

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*Correspondence: wpsilvestre@ucs.br; Tel.: +55-54-32182965 (W.P.S.)

HIGHLIGHTS

- Several ethephon concentrations were applied in pre-harvest on Japanese plums.
- The quality characteristics of the plums prior and after cold storage were evaluated.
- Ethephon use hastened the ripening of the fruits, with no effect in overall yield.
- Some quality characteristics were influenced by ethephon, both in harvest and after storage.

Abstract: The objective of this work was to evaluate different concentrations of ethephon on Fortune plum ripening, also observing the effect of ethephon concentration on the fruit parameters of yield, soluble solids (SS), titratable acidity (TA), SS/TA ratio, firmness, wooliness, diameter, length, and average fruit mass at harvest and post-harvest. The experimental design was completely randomized with five treatments and four replications, each experimental unit consisting of four plants. The ethephon concentrations of zero, 100, 200, 300, and 400 mg·L^{-1} were applied on the plums 20 days before the estimated harvest time. The results indicated that ethephon application induced a higher fruit yield in earlier harvest time, but with no effect on overall yield. Relative to the quality characteristics, the application of ethephon induced a reduction of fruit firmness, soluble solids content, and titratable acidity. Fruit length was not affected. The parameters of soluble solids, titratable acidity, and firmness presented a negative significant correlation with the ethephon dose. Relative to post-storage evaluation, the ethephon application induced a higher SS/TA ratio, and lower wooliness, titratable acidity, and soluble solids content. The parameters of soluble solids and titratable acidity presented a significant negative correlation, whereas the SS/TA ratio was positively correlated with the ethephon dose.

Keywords: fruit ripening; growth regulator; ethylene; phytohormone.

INTRODUCTION

The Japanese plum (*Prunus salicina* Lindl.) is a diploid plant, native from China [1]. In the main producing regions, it is destined mostly to *in natura* consumption, being highly appreciated by its flavor and also its nutritional properties. Plums are rich in anthocyanins, whose content varies according to the cultivars, which confers the plums their characteristic color [2].

China is the main producer of plums with 17% of world production (6.79 million tons), followed by Romania and the USA. In South America, Chile is the main producer, occupying also the seventh position in the ranking of the largest plum producers [3]. The Brazilian plum production has increased in the last years, however, about 60% of the domestic consumption of this fruit is supplied by Chile and Argentina, especially during the off-season (time of the year with low plum offer) [4]. Regarding Brazilian production, the main producer states are Rio Grande do Sul, Santa Catarina, and Paraná (South Brazil), which supply the national market from October to February [5].

The state of Rio Grande do Sul, the largest Brazilian producer, has approximately 2,000 ha of Japanese plum planted area, producing 21,100 t of the fruit in the 2016/2017 harvest. The Serra Gaúcha region, the main producer region of the state, has produced 15,000 t (about 70% of the entire state production). In this region, plum cultivation is carried out in family properties with small acreage (0.5 to 2.0 ha), playing an important role in income generation for these farmers and their families [6]. The Japanese plum cultivars that highlight themselves in this region are the Letícia, Santa Rosa, Reubennel, and Fortune [7].

In the last years, the Brazilian growers have searched for cultural practices to produce high-quality fruits, induce earlier harvest times, and extend the post-harvest and shelf life of the fruits. The use of plant growth regulators (PGRs) may be an important tool to standardize fruit maturation and reduce the timeframe between fruit maturation and harvest, with the correct dose/concentration adjustment for each specific purpose [8]. In many countries with a large experience in the cultivation of temperate fruits, the use of these PGRs aims to change/manipulate the most important phenological stages of the plants, to reduce the costs with labor manpower and increase profitability [9-11].

Several substances may interfere in plum ripening; ethylene is one of the most important ones. Plum is a climacteric fruit, presenting a marked increase of respiratory rate at the start of the physiological ripening, caused by an increase of the exogenous synthesis of ethylene, which initiates changes in the fruit characteristics (color, aroma, flavor, and texture) [12].

Ethylene is a plant hormone associated with several physiological processes, such as stimulation and inhibition of cell growth, flowering and sprouting induction, promotion of senescence of tissues and organs, ripening of fruits, and abscission of fruits and leaves [13]. Ethylene synthesis occurs in all plant parts, without any specific place of production. However, its production depends on respiratory rate, temperature, and stress levels. The translocation of ethylene is carried out by diffusion throughout the tissues, as a gas or dissolved in the xylem sap, and primarily induces fruit ripening [9].

This PGR is also capable of accelerating the phenological characteristics during the ripening phase in apples and other climacteric fruits, being ethylene the only PGR produced in gaseous form, synthesized through methionine [14]. Its synthesis may be stimulated by synthetic products, such as ethephon (2-chlorosulfonic acid), found in liquid form in commercial formulations. When applied, it decomposes in ethylene, which is promptly absorbed by the plant tissues, stimulating the plant to produce more ethylene in a positive feedback loop [8-9].

According to Petri and coauthors [9], ethephon promotes ethylene biosynthesis, reducing the number of reapplications. However, this generally induces a quick softening of the fruits, causing their premature fall from the plant. This also causes smaller post-harvest durability and shelf-life time. Thus, the post-harvest storage of ethephon-treated fruits is not advisable. The exogenous application of chemicals that stimulate ethylene synthesis accelerates plum ripening, reducing the shelf-life of the fruits and increasing the incidence of several physiologic disturbances [12].

Flores-Cantillano [15] cited that a large fraction of the production costs of plum is related to manpower, especially in the harvest period, due to the uneven fruit ripening, which requires several harvests and trained harvesters to distinguish between suitable and unsuitable fruits to be harvested. Generally, at least three separate harvests are carried out, avoiding harvesting fruits with incomplete or deficient ripening [16].

In this sense, the main objective of the present work was to evaluate the effect of several ethephon concentrations on the harvest time and yield, and also the quality characteristics at harvest and post-harvest of 'Fortune' Japanese plums, cultivated in Serra Gaúcha region, South Brazil.

MATERIAL AND METHODS

Field experiment and yield evaluation

The experiment was carried out in the 2017/2018 harvest, in a commercial orchard in the municipality of Antônio Prado, in the ecoclimatic region of 'Serra do Nordeste do Rio Grande do Sul' (Northeast Mountain Range of Rio Grande do Sul), with the following geographical coordinates: 28°50' S and 51°24' W, and an altitude of 635 m. The climate of this region is characterized as Cfb according to the Köppen classification, with a cold winter with regular rainfall and mild summers; the annual average temperature is 16.6 °C and the annual precipitation is 1,800 mm.

The orchard was composed of 'Fortune' grafted on 'Okinawa' rootstock. The orchard had an age of six years; the spacing was 4.5 m between lines and 1.8 m between plants, with a plant density of 1,235 plants·ha^{-1}, trained in 'Y' system. 'Reubenel' was used as a pollinizer in a proportion of 15%.

The irrigation was carried out by dripping, with a line of drippers for each plant line, with a spacing of 0.6 m between emitters and a flow rate of 0.6 L·h^{-1}. The irrigation time was 30 min, with periods of one hour between irrigations during the daytime, and every four hours during the night. The nutritional management was carried out by fertigation, according to the crop demand throughout the cycle. The winter pruning was carried out in July, to remove bad-positioned branches and to replace the productive ones. During vegetative growth, two summer prunings were carried out, the first 70 days after full bloom and the second after harvest.

The applied treatments consisted of the following ethephon concentrations: zero, 100, 200, 300, and 400 mg·L^{-1}. It was used the commercial product Ethrel® (Bayer, USA), with 24 wt.% of ethephon as the active ingredient. The treatments were applied when the plums were completely developed and their peel presented a light green color, about 20 days before the estimated harvest date, being applied on November 30, 2017. The applications were carried out using a backpack sprayer, with an estimated spray volume of 1,000 L·ha^{-1}.

The plums were collected when their peel presented a uniform purplish coloration, being necessary to carry out three harvests in successive weeks. Commercially, the parameters of peel color, soluble solids content, and titratable acidity are generally taken into account to perform fruit collection. At each harvest, the fruits collected in each replicate were weighted using an Urano US20/2 digital balance with a capacity of 30 kg and resolution of 1 g. The overall yield was calculated by the sum of the yields in each harvest. The yields were expressed as kilogram per plant (kg·$plant^{-1}$).

Fruit quality characteristics

Ten fruits were selected randomly from each replicate (fruits collected to determine the yield) and were used to determine the average mass of the plums using a Marte AD1000 balance, with a capacity of 1 kg and a resolution of 0.01 g. The data were expressed as grams per fruit (g·$fruit^{-1}$). The diameter (longitudinal position) and length (equatorial position) of the fruits were measured using a measuring tape; the results were expressed in millimeters (mm).

Fruit pulp firmness was measured using a digital penetrometer with an 8 mm tip. Two readings were carried out in diametrically opposite sites, in the equatorial portion of the fruit after the removal of the peel by a shallow cut of two discs of 1 cm of diameter. The results were expressed as kilogram-force per square centimeter (kgf·cm^{-2}).

The juice of ten fruits was extracted with an electric juice extractor; the juice was used to determine the soluble solids content (SS) and the titratable acidity (TA). SS content was measured using an Incoterm analogic refractometer, with a measuring range of 0-30 °Brix and a resolution of 0.25 °Brix; the results were expressed as °Brix. The TA was determined according to the procedures described by the method 310/IV of the Instituto Adolfo Lutz [17]; the results were expressed as grams of malic acid per 100 mL of juice (% m/v).

After the harvest, samples of ten fruits for each replicate were placed in plastic boxes and stored in a refrigerated chamber at 0.0±0.5 °C and 85±10% RH for 30 days. After this period, the samples were removed from storage and kept at room temperature for 48 h. Posteriorly, the fruit quality characteristics after post-harvest were carried out following the same procedures used in the fruit quality determinations right after harvest. Wooliness or succulence loss was determined based on fruit appearance, by the presence or not of wooliness, and the results were expressed as a percentage of the analyzed fruits with the characteristic symptoms.

Experimental design and statistical analysis

It was used a randomized block design; each treatment (ethephon concentration) was composed of four blocks and each block was composed of four replicates. Each replicate was composed of four plants, totaling 64 plants per treatment. The obtained data underwent analysis of variance (ANOVA), principal component analysis (PCA), and Spearman correlation analysis. The means were compared by Tukey's multiple range test at 5% probability. The statistical analyses were carried out using Statistica 12.5 software (Statsoft, USA).

RESULTS AND DISCUSSION

Ethephon effect on harvest time and fruit yield

The fruit yields were evaluated in three harvests, separated by two weeks between them. The observed results are presented in Table 1.

Table 1. Yield results (kg·plant^{-1}) of 'Fortune' Japanese plum plants treated with several ethephon concentrations at different harvest dates (CV = 3.61%).

Ethephon concentration (mg·L^{-1})	Harvest 1 (04/12/2017)	Harvest 2 (11/12/2017)	Harvest 3 (20/12/2017)	Overall yield
0	0.50 Cd	2.25 Be	9.40 Aa	12.15 b
100	0.60 Cd	7.00 Ac	5.70 Bb	13.30 a
200	1.05 Cc	8.00 Aa	4.20 Bd	13.25 a
300	1.78 Cb	7.50 Ab	4.70 Bc	13.98 a
400	7.53 Aa	6.25 Bd	0.00 Ce	13.78 a

Means followed by the same letter, uppercase in row (harvest time), and lowercase in column (ethephon concentration) do not present statistical difference among themselves by Tukey's multiple range test at 5% probability (α = 0.05).

It was observed a clear trend of increase in fruit yield with the application of crescent ethephon concentrations in the first harvest. The ethephon concentration of 400 mg·L^{-1} presented the highest fruit yield (7.53 kg·plant^{-1}), whereas the control presented the smallest one (0.50 kg·plant^{-1}), which meant a collection of 54.6% of the plant fruits at the ethephon concentration of 400 mg·L^{-1}, whereas in the control (no ethephon application) it was collected only 4.1% of the fruits. The higher ethephon concentration, associated with higher temperatures in the days that followed the application, caused faster abscission of the fruits. Fioravanço and coauthors [18], using the ethephon concentrations of zero, 120, 240, and 480 mg·L^{-1} in 'Irati' plums cultivated in Brazil, obtained, in the first harvest, a higher proportion of fruits collected in the treatments that used ethephon relative to the control treatment. The authors also reported no differences among the ethephon concentrations, which demonstrated that the three ethephon treatments were enough to induce the 'Irati' plum to hasten its color change, allowing for an earlier harvest. In this sense, the authors advised the preference of employing lower ethephon concentrations (120 mg·L^{-1}), with lower costs to the farmers, and also to prevent fruit loss, which was reported by the authors at higher ethephon concentrations. High ethephon concentrations, associated with periods of high temperatures and intense sunlight, induce the acceleration of plant metabolism and ethylene production, promoting fruit abscission and productivity reduction [9].

In the second harvest, the ethephon-treated plants, regardless of concentration, presented a higher fruit yield, however, no crescent trend between fruit yield and ethephon concentrations was observed, unlike in the first harvest. In the second collection, the control treatment yielded 18.5% of all harvest, whereas at 200 mg·L^{-1} it was collected 60.4% and at the highest ethephon concentration (400 mg·L^{-1}), 45.4% of the fruits were collected. However, considering both the first and second harvests, the concentration of 400 mg·L^{-1} had a better performance in hastening plum harvest.

In the third harvest, there were no fruits to be harvested in the highest ethephon concentration (400 mg·L^{-1}), once the acceleration of fruit ripeness concentrated the harvesting in the first two collections. On the other hand, most of the fruits of the control treatment were harvested in the third collection (77.4% of the fruits), which demonstrates the potential of ethephon to hasten and standardize the ripeness of climacteric fruits, such as the Japanese plum. Considering that harvest time is concomitant with the period with the most workload of the orchard, several farmers want to hasten the fruit ripening to better distribute the number and periodicity of harvests. The pre-harvest application of ethephon may help to diminish the number of harvests and standardize fruit ripening, thus, optimizing the use of the workforce in the orchard.

Petri and coauthors [9] explained that, generally, ethephon induces a quicker fruit ripening when applied between one and four weeks before harvest, with concentrations varying between 100 and 200 mg·L^{-1}, concentrating the ripening between 7 and 15 days depending on the epoch, ethephon concentration, and temperature during and after application. The authors also highlighted that higher ethephon concentrations or temperatures above 25 °C intensify ethephon action. This was observed in the present work, considering the treatments that used ethephon have had higher fruit collection rates in the first collections.

Relative to the overall yield, it is important to highlight that, despite differing statistically from the control treatment, the ethephon concentrations have not differed among themselves. This may indicate that ethephon may play a role in increasing fruit yield up to a point, however, its main role is in accelerating fruit ripeness, thus, inducing earlier harvest times.

When comparing the different harvests in each ethephon concentration, it can be seen that in the control there was a higher fruit yield in the third harvest. With the increase in ethephon concentration, there were higher yields in the first and second harvests, demonstrating an earlier ripeness of the plums. It is also noteworthy that, for the ethephon-treated plants, the highest yield occurred in the second harvest, with exception of the highest concentration (400 mg·L^{-1}), which presented the highest yield in the first harvest. On the other hand, the control presented an exact opposite trend, with increasing yields with longer pre-harvest times.

Fioravanço and coauthors [18] observed a seven-day hastening of the harvest date of Reubennel plums when ethephon was applied when compared to the control treatment (no-treated plants). According to the same authors, a higher number of fruits in the first harvest may promote a better economic return for the farmers, because, generally, the earlier is the harvest, the higher is the average fruit price, especially in the case of the ‘Fortune’ plum. The same authors also observed that eight days after the application of ethephon, the treated plums were ready to be harvested. Ripening is accompanied by strong activation of respiration and ethylene evolution only in climacteric fruits; correspondingly, fruit treatment with ethylene accelerates their transition from maturity to ripeness [12].

Figure 1 presents the correlation circle of the yields in each harvest relative to the ethephon concentrations.

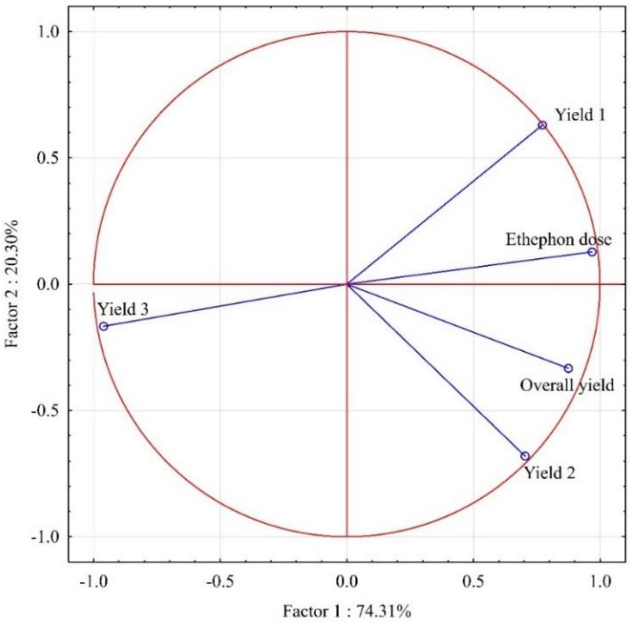

Figure 1. Correlation circle for the fruit yield at the first (1), second (2), and third (3) harvests and the overall yield relative to the ethephon concentration.

It can be seen that the ethephon concentration was positively related to the yields of the first and second harvests, and overall yield, and negatively related to the yield of the third harvest. This indicates both an increase in the crop productivity (overall yield) and a hastening of fruit ripening (higher yields in the first and second harvest, and reduction in the third). These results confirm the ethephon property of inducing an earlier color change in fruit peel, as reported by Powers and coauthors [19], Carvalho and coauthors [20], Delú Filho and coauthors [21], and Steffens and coauthors [22]. Moreover, the harvest of a higher fruit proportion in the first collection, favored by the application of ethephon, allows for an earlier market supply, when the fruit prices are higher.

The Spearman correlation coefficient for the yields of each harvest and the overall yield relative to the ethephon concentrations is presented in Table 2.

Table 2. Spearman correlation coefficients of the fruit quality characteristics at harvest time relative to ethephon concentrations.

Harvest	Spearman correlation coefficient
First (04/12/2017)	**0.9662**
Second (11/12/2017)	0.2991
Third (20/12/2017)	**-0.8869**
Overall yield	**0.8007**

The significant correlations at 5% probability were highlighted in bold.

By verifying the results of correlation analysis, only the fruit yields of the second harvest were not correlated to the ethephon concentration. The yield in the first harvest, and the overall yield, presented a positive correlation coefficient, indicating a direct relationship. On the other hand, the yield in the third harvest and the ethephon concentration were negatively correlated (correlation coefficient of -0.8869), also being significant at 5% probability. Similar results were obtained by Blommaert and coauthors [23], in which ethephon hastened and standardized the ripeness of ‘Santa Rosa’ plums, with no apparent negative effects on fruit quality during storage. In preharvest application, ethephon application increases ripening but also accelerates postharvest detrimental effects [24].

Effect of ethephon concentrations on fruit quality characteristics at harvest

The results of the evaluation of the fruit quality characteristics are presented in Table 3.

Table 3. Statistical analysis of some fruit quality characteristics at harvest of ‘Fortune’ Japanese plums treated with crescent ethephon concentrations.

Ethephon concentration ($mg \cdot L^{-1}$)	Diameter (mm)	Length (mm)	Firmness ($kgf \cdot cm^{-2}$)	Soluble solids (°Brix)	Titratable acidity (% m/v)	Average mass (g)
0	52.5 b	52.5 a	19.8 a	14.3 a	1.77 a	87.2 bc
100	56.2 a	55.2 a	18.4 ab	13.3 ab	1.53 ab	108.7 a
200	54.0 b	53.0 a	19.1 ab	14.4 a	1.28 bc	93.2 b
300	52.8 b	52.6 a	17.7 ab	11.7 c	0.87 d	89.1 bc
400	52.4 b	52.8 a	16.6 b	12.3 bc	0.97 cd	85.9 c
CV* (%)	1.35	2.27	6.81	4.68	11.15	3.28

Means followed by the same letter in column do not present statistical difference among themselves by Tukey’s multiple range test at 5% probability (α = 0.05). * – Coefficient of variation.

Fruit diameter has not differed statistically among treatments, with exception of the treatment 100 $mg \cdot L^{-1}$, which differed statistically (Table 3). On the other hand, no treatment differed statistically relative to plum length, whose overall average was 53.2 mm. According to Bauchrowitz [25], ethephon application in two genotypes of plums has not affected fruit diameter, with plums diameter varying between 45.40 and 47.92 mm. These obtained results are different from the ones obtained in this work. The author also highlighted that average fruit mass was reduced in the treatments that used ethephon.

Relative to fruit firmness, there was a decrease of firmness with increasing concentrations of ethephon; however, only the control treatment and the concentration of 400 $mg \cdot L^{-1}$ differed statistically (19.8 and 16.6 $kgf \cdot cm^{-2}$, respectively). Fioravanço and coauthors [18] observed similar firmness values at harvest for Reubennel plums treated with several ethephon concentrations, indicating that ethephon application intensified the peel color, but has not influenced pulp firmness, even with relatively high concentrations (360 and 480 $mg \cdot L^{-1}$). Crisosto and coauthors [26] reported the range firmness of 17.8-35.6 N as the optimum for Japanese plums.

The soluble solids content ranged from 11.7 to 14.4 °Brix, with higher values in the control treatment and differing from the ethephon-treated fruits, with exception of the 200 $mg \cdot L^{-1}$ concentration, which has had a slightly higher content (14.4 and 14.3 °Brix for the 200 $mg \cdot L^{-1}$ ethephon and the control, respectively; Table 2). These differences may be the result of more time (seven days) of the non-treated fruits in the plants, which allowed for a greater accumulation of sugars. The SS values observed in the present work are within the range of 9.4–19.0 °Brix. This range is considered as suitable by Flores-Cantillano and coauthors [15], whereas Díaz-Mula and coauthors [27] indicated the soluble solids range of 10–15 °Brix as adequate, depending on cultivar. Roussos and coauthors [2] highlighted that the ‘Fortune’ plums present a soluble solids range of 12.1-14.4 °Brix and an average titratable acidity of 1.4 wt.% (as malic acid equivalent). Son [28] reported a soluble solids content of 13.7 °Brix for ‘Fortune’ plums, whereas Lozano and coauthors [29] reported a soluble solids content of 12.3 °Brix for ‘Fortune’ plums at earlier harvest.

The titratable acidity reduced with an increase in ethephon concentration, however, the trend is not so clear. Fioravanço and coauthors [18] observed that ethephon has not influenced the firmness, pH, and TA of Reubennel plums; these results diverge from the ones observed in the present study for the Fortune plum. Numerous maturity characteristics, including skin color, fruit firmness, fruit size, soluble solids content (SS), titratable acidity (TA), and the SS/TA ratio are comprehensively used for the determination of the maturity stage of plums at harvest [12]. In Brazil, the most important characteristics considered for stone fruits are fruit size, peel color, and, for plums, the SS/AT ratio.

Regarding the average fruit mass, it can be seen that only the concentration of 100 $mg \cdot L^{-1}$ of ethephon differed statistically from the other treatments, which have not differed from the control. Higher ethephon concentrations may induce a quick ripening of the fruits, thus, hindering the accumulation of water and sugars and limiting the time for the plant to keep the concomitant vegetative growth of the fruits. However, small ethephon concentrations (100 $mg \cdot L^{-1}$) may induce a slight acceleration of the fruit ripening without hindering the plant capacity of storing photoassimilates to the fruits, increasing fruit mass and ripeness relative to the control treatment.

Some studies also verified that small ethephon concentrations may induce an increase in average fruit mass. Khorshidi and Davarynejad [30], studying ‘Cigany’ cherries, reported that harvested fruits treated with ethephon presented higher average mass and were softer (lower firmness) than the control. Smith and Whiting [31] indicated that the ethephon-treated ‘Chelan’ sweet cherry was significantly heavier and darker than non-treated fruits. Ethephon application also influenced Flame Seedless and Bonheur grapes; the average berry mass was influenced by the dosage and tended to reach a maximum value at 200 $mg \cdot L^{-1}$ [32]. El-Zeftawi [33] reported that ethephon application at the concentration of 250 $mg \cdot L^{-1}$ induced higher fruit size and average fruit mass for ‘Imperial’ mandarins. Studying ‘Irati’ plums, Fioravanço and coauthors [18] also verified that smaller ethephon concentrations (240 $mg \cdot L^{-1}$) induced an increase in the average fruit mass, whereas concentrations higher than 400 $mg \cdot L^{-1}$ caused the reverse effect (reduction of the average fruit mass).

The correlation circle presenting the relationships among the fruit quality characteristics at harvest time is presented in Figure 2.

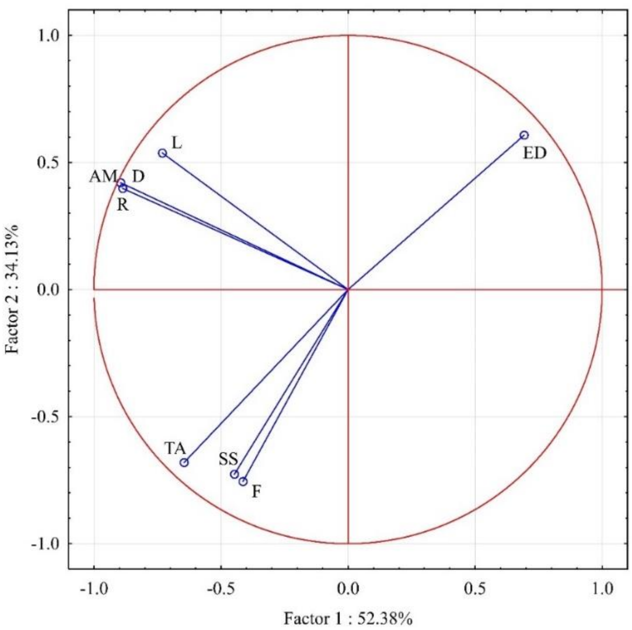

Figure 2. Correlation circle grouping the fruit quality characteristics at harvest time relative to the ethephon concentration (ED: ethephon concentration, F: firmness, SS: soluble solids, TA: titratable acidity, AM: average mass, D: diameter, L: length, R: SS/TA ratio).

It can be seen that the application of ethephon induced a reduction of the titratable acidity (TA), soluble solids (SS), and firmness (F) of the fruits. The characteristics of length (L), SS/TA ratio (R), diameter (D), and average mass (AM) were not affected by the ethephon concentration. However, Macedo and coauthors [40] explained that using ethephon, a hastening of the harvest is possible. On the other hand, the average fruit size may be reduced between collections due to a reduction of the fruit growth time. Petri and coauthors [9] also stated that, as promoting early fruit ripening, ethephon use also reduces the flowering-ripening cycle, with a consequent reduction of fruit size.

Table 4 presents the Spearman correlation coefficient for the fruit characteristics at harvest time relative to the ethephon concentration.

Table 4. Spearman correlation coefficient of the fruit quality characteristics at harvest time relative to ethephon concentrations.

Characteristic	Spearman correlation coefficient
Diameter (D)	-0.2698
Length (L)	-0.2150
Average mass (AM)	-0.3222
Soluble solids (SS)	**-0.6703**
Titratable acidity (TA)	**-0.8410**
SS/TA ratio (R)	-0.3223
Firmness (F)	**-0.6806**

The significant correlations at 5% probability were highlighted in bold.

By analyzing Table 4, it was possible to observe that only the soluble solids (SS), titratable acidity (TA), and fruit firmness (F) were significantly related to the ethephon concentrations; all three characteristics presented an inverse trend relative to the concentration of ethephon, i.e., an increase in ethephon concentration induced a reduction of these characteristics.

Effect of ethephon concentrations on fruit quality characteristics in post-harvest after storage

The effect of ethephon on the fruit quality of Japanese plums in port-harvest storage is presented in Table 5.

Table 5. Fruit quality characteristics after post-harvest storage for ‘Fortune’ plums treated with increasing ethephon concentrations.

Ethephon concentration ($mg \cdot L^{-1}$)	Wooliness (%)	Soluble solids (°Brix)	Titratable acidity (% m/v)	Ratio (SS/TA)
0	7.25 a	13.0 a	0.74 a	18.0 b
100	2.75 b	12.2 ab	0.38 b	32.0 a
200	2.75 b	12.2 ab	0.35 b	34.9 a
300	1.25 b	10.8 b	0.28 b	39.4 a
400	3.88 b	11.4 b	0.36 b	31.8 a
CV (%)	36.51	5.47	15.70	10.91

Means followed by the same letter in column do not present statistical difference among themselves by Tukey’s multiple range test at 5% probability ($\alpha = 0.05$).

After the storage period, it could be observed a more pronounced loss of succulence (an increase of wooliness) in the control treatment; the application of ethephon induced a reduction of this physiological disorder, however, there was no statistical difference among the ethephon-treated fruits (Table 3).

Wooliness is a lesion caused by cold, common in stone fruits as peaches, plums, nectarines, and apricots, but affecting mainly peaches, and nectarines. It manifests itself as a lack of succulence and a ‘wooly’ dry texture of fruit pulp [34]. The exogenous application of ethephon accelerates the ripening of plum fruits, reducing their shelf and storage life potentials; it is also reported an increasing development of various physiological disorders of the fruits with the application of ethephon [35]. According to Özkaya and coauthors [36], the increase in ethylene production potentializes the cold-induced damage in the fruits, being related to an increased wooliness occurrence during cold (refrigerated) storage. However, this effect was not observed in the present study, in which the application of ethephon caused a decrease in wooliness occurrence.

Similar results were also reported by Mahajan and coauthors [37] in guava (*Psidium guajava* L.) fruits, who recorded a decrease in acid content during ripening and storage. In ‘Pink Lady’ apples, which underwent ethephon applications in pre-harvest, Anami and coauthors [38] observed that there was no influence in pH and soluble solids content, evaluated three months after harvest and cold storage of the fruits.

The soluble solids (SS) content presented a reduction with an increase of the ethephon concentration; a similar trend was also observed with titratable acidity (TA). As a result, the SS/TA ratio has presented a trend of increase with the use of ethephon relative to the control. The correlation circle of the evaluated fruit quality characteristics in post-harvest is presented in Figure 3.

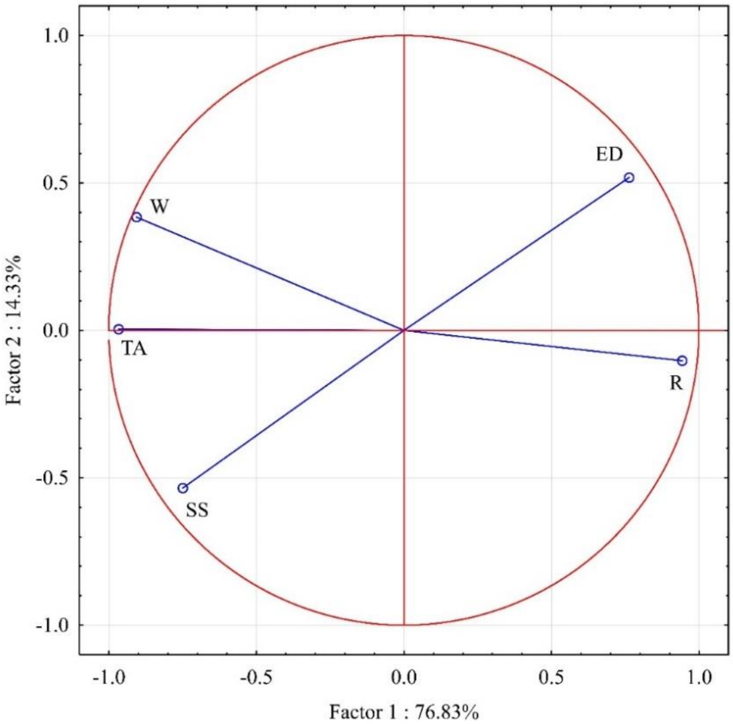

Figure 3. Correlation circle grouping the fruit quality characteristics in post-harvest relative to the ethephon concentration (ED: ethephon concentration, W: wooliness, SS: soluble solids, TA: titratable acidity, R: SS/TA ratio).

By verifying the correlation circle, the SS/TA ratio (R) presented a slight positive relationship with ethephon concentration. The characteristics of wooliness (W), soluble solids (SS), and titratable acidity (TA) presented an inverse relationship with ethephon concentration since the angles between the vectors and ED are higher than 90°. Table 6 presents the Spearman correlation coefficient for the fruit characteristics after the storage period relative to the ethephon concentration.

Table 6. Spearman correlation coefficient of the fruit quality characteristics after 30 days of storage.

Characteristic	Spearman correlation coefficient
Wooliness (W)	-0.4240
Soluble solids (SS)	**-0.7346**
Titratable acidity (TA)	**-0.6523**
SS/TA ratio (R)	**0.5306**

The significant correlations at 5% probability were highlighted in bold.

It can be seen that only the SS/TA ratio presented a direct (positive coefficient) correlation with the ethephon concentration, whereas the soluble solids and titratable acidity presented an inverse (negative coefficient) trend. The correlation coefficient between the ethephon concentration and wooliness (W) was non-significant, indicating that no correlation can be established at all. Likely, fruit wooliness was not influenced by ethephon concentration, unlike the other evaluated characteristics. However, in apples, ethephon has been reported to stimulate and advance ripening and reduce the storage potential of the fruit, due to the appearance of physiological disturbances during storage [39]. There are few studies evaluating fruit characteristics and the appearance of physiological disturbances in Japanese plums treated with ethephon in a pre-harvest application. The present study suggests that the cold storage of Fortune plums for 30 days may be adequate to maintain fruit quality, even the ones treated with growth regulators and phytohormones aiming to hasten the ripening process.

CONCLUSION

The application of ethephon in pre-harvest induced an earlier ripening of ‘Fortune’ Japanese plums, the higher the ethephon concentration, the greater was the number of fruits harvested in the first collections. Relative to the quality characteristics, the use of ethephon induced a reduction of fruit firmness, soluble solids content, and titratable acidity. The characteristics of average mass, length, diameter, and SS/TA ratio were not influenced by ethephon application. After cold storage, the ethephon-treated fruits presented lower wooliness incidence and lower titratable acidity, whereas the SS/TA ratio values were higher. However, the ethephon dose was unrelated to wooliness, indicating that higher concentrations of this growth regulator would not present a further enhancement of the anti-wooliness effect of the ethephon. Therefore, ethephon-treated fruits cold-stored for 30 days retain the quality of the harvested fruits.

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