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# The use of 1-methylcyclopropene (1-MCP) in nectarine storage

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**Abstract**

In this research, the influence of 1-methylcyclopropene (1-MCP) application on the length of storage of nectarine fruits (‘Morsian’) stored in a cold storage was investigated. The fruits were analyzed before storage (control sample), and after 7, 20 and 30 days of storage plus additional 3 days of shelf life at room temperature (20 °C). The content of K (2043.6 mg·kg$^{-1}$) and Mg (41.0 mg·kg$^{-1}$) was high in relation to the content of Ca (17.0 mg·kg$^{-1}$), which contributed to a very high value of the ratio K + Mg/Ca (122.6). The application of 1-MCP affected the fruit firmness retention in storage for up to 30 days, with a slightly smaller effect on shelf life at room temperature. The effect of treatment on the viability of fruit weight was noticeable, while the content of soluble solids content (SSC) was lower, with some variation due to unequal fruit ripeness. Biochemical analyses showed an increased content of titratable acidity (TA) on the treated fruits, while the pH value, total sugars (TS) and invert sugars (IS) did not show the influence of the application of 1-MCP. The content of macroelements and their ratio, as well as the fruit ripeness before storage, indicated partial effects of 1-MCP application, so it is necessary to ensure greater absorption of Ca into nectarine fruits during vegetation and to continue the testing of firmness and other biochemical parameters before and during ethylene inhibitor application.

***Key words*:** 1-methylcyclopropene, shelf-life quality, nectarine

## INTRODUCTION

Peach and nectarine are economically important crops with an expanding world production estimated at 21.6 million tons in 2013. (FAO, 2013). Nectarines are climacteric fruit, and rapid ripening of fruit during storage results in a short storage life (Cantín et al., 2010). Characteristically they are soft-fleshed and have a very short postharvest life span. The fruit has a water content of approximately 87% and is consisted of carbohydrates, organic acids, pigments, vitamins, volatiles, phenolic and antioxidants. At ambient temperatures, they quickly deteriorate in quality, hence, post-harvest technologies are essential to prolong their shelf life and maintain quality attributes of the fruit (Kumar, 2018).

The storage of fruits poses a challenge and is a drain on resources, especially in developing countries (Subramanian et al., 2014). In order to provide price and scale-suitable solutions, researchers are working towards increasing the post-harvest storage life of many fruits to increase their marketability and reduce loss/wastage (Kumar, 2018). Nectarines often negatively respond to prolonged storage; if held too long at or near 0°C they are subjected to chilling injury. This situation necessitates the use of proper preservation and optimum storage conditions (Abdi et al., 2021). Storage and shelf life extension to avoid post-harvest losses of nectarine fruit has been a long-standing goal for producers and traders (Özkaya et al., 2016). Controlled atmosphere related disorders in fruit can be minimized by delaying the exposure to controlled atmosphere (CA) storage after harvest or by pre-storage conditioning fruit under ambient air at higher temperatures than the final storage temperature (Flaherty et al., 2018). In most cases, physiological disorders are most often present, especially superficial burns and core breakdown. Besides storing fruits at lower temperatures, it is necessary to control fruit ripening using inhibitors at the site of ethylene binding. In recent years, increasing applications of 1-methycyclopropene (1-MCP) in the preservation of freshness of harvested fruits have been reported. As a result, treatment with 1-MCP reduces the production of ethylene and other volatiles, respiration, peel color development from green to yellow and the rate of softening (Watkins, 2006; Chiriboga et al., 2013a, 2013b; Hendges et al., 2018). The role of 1-MCP in fruit postharvest physiology, biochemistry, ripening and senescence etiology is of great importance (Satekge & Magwaza, 2022). Therefore, the aim of our research is to determine the influence of 1-MCP on the storage potential of nectarines in a cold storage.

## MATERIALS AND METHODS

*Plant material*

Nectarine fruits were collected from the orchard of nectarines 'Morsian' established in 2013. in production plantations of an agricultural producer in the village Trnava, Čacak (Serbia), under conditions of temperate continental climate.  The beginning of the harvest in the first plantation was in the period of 01.08.-10.08.2021.

*1-methylcyclopropene (1-MCP) treatment*

For the purposes of the experiment, nectarine fruits of uniform shape and without visible mechanical damage were selected, with 30 fruits each in three repetitions that were treated, while an equal number of samples were left in the cold storage as a control variant. After selection of samples for analysis, the fruits were placed in cold storage for 4-7 days at temperature of 4 °C. The fruit selected for treatment were arranged in crates and placed in a chamber with a volume of 500 $m^3$ in the cold storage with an occupancy capacity of 50%. Treating the fruits with the agent acting as an ethylene inhibitor was performed by dissolving tablets of 1-MCP (SmartFresh$^{TM}$) with activator tablets (blue activator tablets) in citric acid. After diluting 1-MCP (SmartFresh$^{TM}$ protab), the chamber was sealed airtight for the next 24 h, until the gas concentration of 500 ppb was achieved. Control fruits were stored in wooden crates and placed in an adjacent empty chamber, under the same cooling conditions. The temperature during treatment in the first cold storage was 2 °C.

*Fruit storage and sampling*

All of the replications of the fruits selected for treatment, as well as the ones that were not subjected to the 1-MCP treatment, were placed in wooden crates and kept in vertical tiers. The fruits were kept in a cold atmosphere: 1-2 °C, 90 ± 5% relative humidity (20.9 kPa $0_2$ + < 0.5 kPa $CO_2$), for the period of 30 days. Sampling of fruits for analyses was carried out before fruit treatment (Ø), and then in three phases: 1 day, 20 days and 30 days after treatment, for analysis of fruit weight (FW), fruit firmness (FF), SSC and 7, 20, 30 days after harvest for analysis of pH and titratable acidity (TA). After taking the samples from the cold storage, the fruits were left in conditions of normal atmosphere: 20 ± 1°C and 60 ± 5% RH, for 3 days (shelf life), followed by measurement and chemical analyses (1-control; 2-treatment). FW was determined on a Mettler 0.01 g precision scale (Switzerland). FF measuring was performed using the penetrometer Fruit Pressure Tester FT 327 (Winopal Forschungsbedarf GmbH, Germany) with an 8 mm probe. Two measurements were made in six fruits per each replication on both sides and expressed in Newtons using formula: (N $cm^{-2}$) = fruit firmness value (kg $cm^{-2}$) × 9.81.

*Assessments*

The soluble solid content (SSC) of the fruit was determined on a manual refractometer (3828, Carl Zeiss, Germany). Actual acidity (pH value) was measured by a pH Meter Iskra MA 5707, Slovenia. Titratable acidity (TA) was determined by neutralization of fruit extract with 0.1 N NaOH to pH 8.2, using phenolphthalein as indicator, and the content of total sugars, invert sugars and sucrose were determined by the Luff-Schoorl method (Tanner & Brunner, 1979). Acidity was expressed as mg malic acid·100 $g^{-1}$ fresh weight.

*Content of macro and microelements in the* fruits of nectarines

The content of macro and microelements was determined before the experiment setup, by sampling 1 kg of average samples in three replications, for each cultivar. The content of macro (K, Ca, Mg) and microelements (Cu, Zn, Mn, Fe, Co) was analysed using modified method (Morais et al., 2017). Readings were performed on AAS, Perkin-Elmer, PinAAcle 500 (USA 2018), and values were expressed in mg $kg^{-1}$ of fresh weight of the sample, whereas K+Mg/Ca, K/Ca ratio was determined using calculation.

*Statistical analysis*

The obtained data was subjected to analysis of variance (*ANOVA*) using statistical package MSTAT-C (Michigan State University, USA). The least significance difference (LSD) was used to compare treatment means and treatments declared different at $P \leq 0.05$ level of significance.

## RESULTS AND DISCUSSION

The minerals present in the fruit include Ca, Mg, K, Na, P, Cl and S. Calcium is a crucial mineral which is responsible for activating many catabolic processes, and its deficiency contributes to the occurrence of physiological disorders in fruit crops. Prolonging the period of fruit storage and delaying the ripening of fruits requires a better understanding of the physiological and biochemical role, especially the ratio of Ca, K, Mg, K+Mg/Ca, K/Ca, while the content of microelements is also important. Calcium also has a beneficial effect on marketing and storage by inhibiting senescence and reducing respiration rate, protein disintegration, weight loss and rotting. In this sense, Tsantili et al., (2002) noted that fruits with high calcium content have lower respiration rates and a longer shelf life compared to low fruits. The results of macroelement content in fruits of nectarines are shown in Table 1. The K content had very high values of 2043.6 $mg \cdot kg^{-1}$ compared to the Ca content of 17.0 $mg \cdot kg^{-1}$, which together with Mg 41.0 $mg \cdot kg^{-1}$ influenced the high values of the K+Mg/ Ca 122.6 and K/Ca 120.2. In apple fruits, if the K/Ca ratio is higher than 30, and in certain cultivars higher than 25, even 20, physiological diseases and lower potential of fruit keeping occur, accordingly (Milinković et al. 2021).

Table 1. Content of macroelements and their relation in nectarine fruits

| Samples | K | Ca | Mg | K+Mg/Ca | K/Ca |
|---|---|---|---|---|---|
| | $mg \cdot kg^{-1}$ | | | computational ratio | |
| Fruits | 2043.6 | 17.0 | 41.0 | 122.6 | 120.2 |

The analysis of microelements showed low values for the content of Cu, Zn, Mn and Co with values of 0.11-0.92 $mg \cdot kg^{-1}$, except for Fe with a measured content of 21.68 $mg \cdot kg^{-1}$ (Table 2).

Table 2. Content of microelements in nectarine fruits

| Samples | Cu | Zn | Mn | Fe | Co |
|---|---|---|---|---|---|
| | $mg \cdot kg^{-1}$ | | | | |
| Fruits | 0.18 | 0.90 | 0.92 | 21.68 | 0.11 |

1-Methylcyclopropene (1-MCP) is an inhibitor of ethylene receptors thus retarding ethylene-dependent responses such as ripening, senescence and physiological disorders (Watkins, 2006). Based on the results of this research, no significant difference was found in the weight of the treated nectarine fruits compared to the control, with the fact that the weight of the fruits was significantly reduced after 30 days, compared to the initial measurements after harvesting (Table 3).

The firmness of nectarine fruits treated with 1-MCP was significantly higher, and the significance of 1-MCP application was also confirmed in the interaction effects of the measurement period and treatment.

The firmness decreased by about 11 N within all three measurement intervals (41.59 N (1); 30.12 N (2); 19.82 N (3)), on fruits treated with 1-MCP and the shelf-life of 3 days showed the effect of the application of ethylene blockers up to 20 days of fruit storage in the cold storage. Similar results were found for SSC content, where the application of ethylene blockers affected the sustainability of SSC content compared to untreated fruits, where this parameter significantly increased.

Destructive firmness (FF) is in the range of 35.6–133.3 N for nectarines, (Valero et al., 2007), which is in the range of our values of initial hardness of fruits. In a study conducted by Kumar, (2018), the firmness of nectarine fruits decreased by 5 N, with a longer storage period of fruits. Sanhueza et al., (2015) stated that the fruit firmness of 8.9 N is suitable for eating, and the initial fruit firmness was 57 N, SSC 13.3%, TA 0.8%, which are higher values compared to our research.

Table 3 Effects of 1-MCP application on fruit weight, FF, SSC

| Variants | | | FW (g) | FF (N) | SSC (%) |
|---|---|---|---|---|---|
| Measurements A | Ø | | 220.8±7.1 $^{a}$ | 41.50±0.16 $^{a}$ | 11.39±0.26 $^{a}$ |
| | Ø +3d$^{\#}$ | | 201.3±10.5 $^{b}$ | 5.10±0.02 $^{d}$ | 10.23±0.28 $^{b}$ |
| | 20d | | 169.5±5.5 $^{c}$ | 20.21±0.36 $^{b}$ | 10.84±0.36 $^{ab}$ |
| | 20d+3 | | 161.5±7.5 $^{cd}$ | 7.95±0.084 $^{d}$ | 11.62±0.28 $^{a}$ |
| | 30d | | 147.9±4.7 $^{d}$ | 13.24±0.19 $^{c}$ | 11.33±0.45 $^{a}$ |
| | 30d+3 | | 146.7±4.9 $^{d}$ | 6.77±0.13 $^{d}$ | 11.11±0.51 $^{a}$ |
| Treatments B | Ø | | 175.6±6.14 $^{a}$ | 12.17±0.19 $^{b}$ | 11.53±0.21 $^{a}$ |
| | Treatment | | 173.6±4.68 $^{a}$ | 19.42±0.20 $^{a}$ | 10.64±0.21 $^{b}$ |
| Measurements x Treatments AxB | Ø | Ø | 231.0±13.49 $^{a}$ | 41.30±0.21 $^{a}$ | 10.98±0.38 $^{bcd}$ |
| | | treatment | 210.6±2.18 $^{a}$ | 41.59±0.26 $^{a}$ | 11.80±0.31 $^{ab}$ |
| | Ø +3d | Ø | 218.1±14.53 $^{a}$ | 5.00±0.01 $^{f}$ | 10.48±0.40 $^{cde}$ |
| | | treatment | 184.6±13.54 $^{b}$ | 5.20±0.03 $^{ef}$ | 9.98±0.39 $^{de}$ |
| | 20d+0 | Ø | 173.6±3.98 $^{bc}$ | 10.30±0.17 $^{de}$ | 10.30±0.59 $^{cde}$ |
| | | treatment | 165.3±10.32 $^{bcd}$ | 30.12±0.51 $^{b}$ | 11.38±0.37 $^{bc}$ |
| | 20d+3 | Ø | 153.8±5.58 $^{cde}$ | 4.91±0.00 $^{f}$ | 11.91±0.32 $^{ab}$ |
| | | treatment | 169.1±13.85 $^{bc}$ | 10.99±0.07 $^{d}$ | 11.32±0.46 $^{bc}$ |
| | 30d+0 | Ø | 133.8±3.03 $^{e}$ | 6.68±0.06 $^{def}$ | 12.90±0.25 $^{a}$ |
| | | treatment | 162.0±5.87 $^{bcd}$ | 19.82±0.18 $^{c}$ | 9.77±0.44d $^{e}$ |
| | 30d+3 | Ø | 143.1±5.53 $^{de}$ | 4.91±0.00 $^{f}$ | 12.60±0.46 $^{a}$ |
| | | treatment | 150.2±8.30 $^{cde}$ | 8.63±0.26 $^{def}$ | 9.61±0.57 $^{e}$ |
| ANOVA | | | | | |
| A | | | ** | ** | ** |
| B | | | ns | ** | * |
| AxB | | | * | ** | * |

$^{\#}$d-days; FW-fruit weight; FF-fruit firmness; SSC- soluble solid content. Data is shown as mean values ± standard error. Means in a column followed by the same superscript letters are not significantly different according to the Duncan test ($P \leq 0.05$). ns – not significant.

The application of 1-MCP did not affect the pH of the juice, while the TA content had significant differences in the treated fruits depending on time of the assessment (Table 4). Initial TA values of 1.48 were reduced to 0.79 after 30 days. The main soluble sugars that constitute 75% of the total are sucrose, glucose and fructose. Soluble sugars contribute about 7-18% of total weight and fibre provides about 0.3% of the fresh weight (FW) of the fruit. Organic acids contribute to about 0.4-1.2% FW and the ratio of soluble solids to titratable acidity determines the flavor and consumer perception of the fruit (Crisosto and Valero, 2008). Malic acid and citric acid constitute the main organic acids. Acidity usually decreases for about 30% during ripening. In our research, acidity was reduced by up to 30% in the period of up to 20 days of storage, and after that the TA reduction was up to 50%.
Kumar (2018) found initial TA 1.9 reduced to 0.9 g·100 $mL^{-1}$ malic acid in the control after 45 days of fruit storage, and similar results were obtained in the treatment. TS showed higher values compared to our research.

Table 4 Effects of 1-MCP application on pH and TA

| Variants | | | pH | TA *(%)* |
|---|---|---|---|---|
| A Measurements | Ø | | 3.78±0.04 [a] | 1.48±0.03 [a] |
| | 7 | | 3.70±0.11 [a] | 1.17±0.14 [b] |
| | 20d[#] | | 3.64±0.09 [a] | 1.23±0.04 [b] |
| | 30d | | 3.61±0.07 [a] | 0.79±0.03 [c] |
| B Treatments | Ø | | 3.65±0.03 [a] | 1.09±0.09 [b] |
| | treatment | | 3.71±0.07 [a] | 1.24±0.08 [a] |
| Measurements x Treatments AxB | Ø | Ø | 3.73±0.06 [a] | 1.47±0.06 [a] |
| | | treatment | 3.82±0.04 [a] | 1.49±0.05 [a] |
| | 7 | Ø | 3.66±0.08 [a] | 0.86±0.04 [c] |
| | | treatment | 3.74±0.23 [a] | 1.47±0.08 [a] |
| | 20d | Ø | 3.62±0.05 [a] | 1.28±0.02 [b] |
| | | treatment | 3.65±0.19 [a] | 1.18±0.07 [b] |
| | 30d | Ø | 3.59±0.08 [a] | 0.75±0.06 [c] |
| | | treatment | 3.63±0.13 [a] | 0.83±0.02 [c] |
| ANOVA | | | | |
| A | | | ns | ** |
| B | | | ns | ** |
| AxB | | | ns | * |

[#]d-days; TA- titratable acidity. Data is shown as mean values ± standard error. Means in a column followed by the same superscript letters are not significantly different according to the Duncan test ($p \leq 0.05$). ns – not significant.

Application of 1-MCP had no significant effect on total sugars (TS), invert sugars (IS) and sucrose (SAH) (Table 5). Similar results for TSS were found by (Powell et al., 1999). The total soluble solids (TSS) of peach/nectarine either declines (Fan et al., 2002; Bregoli et al., 2005) or there is a delay in the development of sugars during ripening (Liu et al., 2005) following 1-MCP application. The titratable acidity (TA) also declines in high acid cultivars (Bregoli et al., 2005; Liu et al., 2005; Fan et al., 2002). Though 1-MCP can increase the shelf life of peach and nectarine at room temperature (Hayama et al., 2005), its application effect was lower compared to application in apple and pear.

Table 5 Effects of 1-MCP application on total sugars (TS), invert sugars (IS) and SAH

| Variants | Total sugars (TS) | Invert sugars (IS) | sucrose (SAH) |
|---|---|---|---|
| | | % | |
| Ø | 7.44±0.14 [a] | 5.85±0.30 [a] | 1.51±0.07 [a] |
| treatment | 7.25±0.04 [a] | 5.71±0.05 [a] | 1.50±0.05 [a] |
| ANOVA | | | |
| | ns | ns | ns |

Data is shown as mean values ± standard error. Means in a column followed by the same superscript letters are not significantly different according to the Duncan test ($p \leq 0.05$). ns – not significant.

A limited number of research studies have documented the effectiveness of 1-Methylcyclopropene (1-MCP) in delaying ripening and postharvest senescence in peaches and nectarines. The firmness and color of the fruit is characteristic of the cultivar, and the emission of ethylene is an indicator of the ripeness of the fruit.

The effective concentration of 1-MCP for peach/nectarine ranges from 0.4 to 5 $\mu L \cdot L^{-1}$ as described in previous experiments (Liquori et al., 2004; Liu et al., 2005). However, only ephemeral changes were observed in the delay of softening in many studies conducted on many peach and nectarine varieties all over the world (Bregoli et al., 2005; Dal Cin et al., 2006; Dong et al., 2001; Fan et al., 2002; Liu et al., 2005). The maintenance of firmness and ground color is short-lived and requires multiple applications to provide a prolonged effect (Liu et al., 2005). However, this method was found to be uneconomical in a cost benefit analysis (Hayama et al., 2005; Liu et al., 2005).

Compared with control fruits, 1-MCP treated nectarines showed significantly reduced total soluble solid (TSS) contents and respiration rates. These results showed that method maintained the post-harvest quality of nectarine fruit and provided longer storage and shelf life. Özkaya et al., (2016) indicated that 1-MCP treatment significantly decrease the rate of softening, a firmness remained at the 'ready to buy' stage for 40 days, while the control fruits were at the 'ready to buy' stage for 30 days. Peach and nectarine ripening upon removal from cold storage involves extensive fruit softening, addition to increasing the TSS content. Our research showed similar results for a 30-day storage period. Shelf life at room temperature for a period of 3 days reduces the use value. Additional calcium nutrition and reduction of the K/Ca ratio can contribute to longer storage of fruits and reduction of physiological diseases, which has been established in numerous studies in the framework of apple and pear tests.

## CONCLUSION

Based on the results of this study, the application of 1-MCP positively influenced the storage of nectarine fruits. The application of 1-MCP significantly affected the preservation of fruit firmness, lower SSC values and higher TA values compared to control nectarine samples. Fruit weight, pH value of juice, content of total sugars, invert sugars and sucrose did not show significant differences in different treatments. Certain differences in initial parameters during fruit harvest contributed to differences between measurements and treatments, but both treated and untreated fruit required marketing after 20 days of storage. Shelf life at room temperature of 3 days had a significant effect on the reduction of fruit firmness, and other parameters were not significantly different.

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