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VIII Encuentro Latinoamericano Prunus sin Fronteras

Treatment with 1-MCP

an alternative to extend storage in plums harvested with advanced maturity

Tratamiento con 1-MCP

una alternativa para extender el almacenamiento en ciruelas cosechadas con madurez avanzada

Tratamento com 1-MCP

uma alternativa para estender o armazenamento em ameixas colhidas com maturação avançada

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Abstract

Maturity at harvest is a determining factor in fruit storage potential, especially in such perishable species as plums (*Prunus salicina L.).* However, harvest´s logistics is very complex, and a large percentage of fruits are harvested at a more advanced stage of maturity than the optimum recommended for long storage. Treatment with 1-MCP has shown to be effective in reducing the post-harvest deterioration rate of Japanese plums, but the effectiveness of this treatment may be reduced in late harvested fruit. The aim of this trial was to determine the efficiency of treatment with 0.4 µL L^{-1} of 1-MCP in Larry Ann plums harvested at 4 different maturity stages. The results showed that the treatment was effective in reducing the ripening rate of the fruit at all harvest timings. The duration of this effect and the number of parameters affected decreased as harvest was delayed. In maturity stage 1 (M1, ~62 N) and maturity stage 2 (M2, ~58 N), 1-MCP delayed ethylene production rate during shelf life after 30, 40, and 50 days of storage at 0 ºC and reduced loss of flesh firmness, and acidity. At the maturity stage 3 (M3, ~50N) 1-MCP delayed ethylene production rate during shelf life after 30 and 40 days of storage at 0 ºC and maintained higher flesh firmness values. In fruit harvested at the maturity 4 (M4, ~35 N), 1-MCP did not affect ethylene production rate, but reduced loss of flesh firmness during shelf life, supporting the hypothesis that the treatment has a direct inhibitory effect on softening enzymes, independent of ethylene.

Keywords: ethylene, flesh color, harvest maturity, *Prunus salicina*, softening

Resumen

La madurez en el momento de cosecha es un factor determinante del potencial de almacenamiento de los frutos, principalmente en especies tan perecederas como las ciruelas (*Prunus salicina L.).* Sin embargo, la logística de cosecha es muy compleja y un gran porcentaje de frutos se cosecha con un estado de madurez más avanzado al óptimo recomendado para larga conservación. El tratamiento con 1-MCP ha mostrado ser efectivo en reducir la tasa de deterioro poscosecha de ciruelas japonesas, pero la efectividad de este tratamiento puede verse reducida en frutos de cosechas tardías. El objetivo de este ensayo fue determinar la eficiencia del tratamiento con 0,4 µL L^{-1} de 1-MCP en ciruelas Larry Ann cosechadas en 4 estados de madurez diferentes. El tratamiento redujo la tasa de maduración de los frutos en todas las cosechas. La duración de este efecto y el número de parámetros afectados disminuyó a medida que se retrasó la cosecha. En el estado de madurez 1 (M1, ~62 N) y el estado de madurez 2 (M2, ~58 N), el 1-MCP retrasó la tasa de producción de etileno durante la vida en estante después de 30, 40 y 50 días de almacenamiento a 0 ºC y redujo la pérdida de firmeza y de acidez. En el estado de madurez 3 (M3, ~50 N) el 1-MCP retrasó la tasa de producción de etileno durante la vida en estante después de 30 y 40 días de almacenamiento a 0 ºC y mantuvo mayores valores de firmeza. En frutos cosechados con madurez 4 (M4, ~35 N) el 1-MCP no afectó la producción de etileno, pero redujo la pérdida de firmeza durante la vida en estante, apoyando la hipótesis de que el tratamiento tiene un efecto inhibitorio directo sobre las enzimas del ablandamiento, independiente del etileno.

Palabras clave: etileno, color de la pulpa, madurez a cosecha, *Prunus salicina*, ablandamiento

Resumo

O estádio de maturação na colheita é um fator determinante no potencial de armazenamento dos frutos, principalmente em espécies tão perecíveis como as ameixas (*Prunus persica* L.). No entanto, a logística da colheita é muito complexa e uma grande porcentagem de frutas é colhida com um estado de maturação mais avançado do que o ideal recomendado para conservação prolongada. O tratamento com 1-MCP vem demonstrando ser eficaz na redução da taxa de deterioração pós-colheita das ameixas japonesas, mas a eficácia desse tratamento pode ser reduzida em frutos de colheitas tardias. O objetivo deste estudo foi determinar a eficiência do

tratamento com 0,4 µL L^{-1} de 1-MCP em ameixas 'Larry Ann' colhidas em 4 estádios de maturação. Os resultados mostraram que o tratamento com 1-MCP foi eficaz na redução da taxa de amadurecimento dos frutos em todos os momentos. A duração desse efeito e o número de parâmetros afetados diminuíram com o atraso da colheita. Nos estádios de maturação 1 (M1,~62 N) e estádios de maturação 2 (M2,~58 N), a aplicação de 1-MCP atrasou a produção de etileno durante a vida de prateleira após prazo de 30, 40 e 50 dias de armazenamento a 0ºC e reduziu a perda de firmeza de polpa e acidez. No estado de maturação 3 (M3, ~50N), o 1-MCP atrasou a produção de etileno durante a vida de prateleira após 30 e 40 dias de armazenamento a 0ºC e manteve valores mais altos de firmeza. Nos frutos colhidos no maturação 4 (M4,~35 N), o tratamento com 1-MCP não afetou a produção de etileno, mas reduziu a perda de firmeza de polpa durante a vida de prateleira, apoiando a hipótese de que o tratamento tem um efeito inibitório direto sobre as enzimas relacionadas ao amolecimento da polpa dos frutos independente do etileno.

Palavras clave: etileno, cor da polpa, maturação na colheita, *Prunus salicina*, amolecimento

1. Introduction

Most of the plums produced in the valleys of Río Negro and Neuquén (Argentina) are stored at low temperatures in order to extend the window of sale in the domestic market or to withstand the transport period to distant counter-market. Harvesting the fruits in their optimal stage of maturity is one of the determining factors of the final quality of the product[1]. However, the logistics of the harvest are complex, and part of the fruit is harvested with an advanced maturity stage (more than the recommended for storage).

1-Methylcyclopropene (1-MCP) has shown to be effective in reducing the ethylene production rate and consequently softening, acidity loss, and epidermis color changes in different plum cultivars[2][3]. The effectiveness of this treatment depends on the stage of maturity of the fruits at which it is applied, and it has been observed in various species that the more mature the fruit is, the lower the response to treatment with 1- MCP[4]. The aim of this trial was to determine the efficiency of treatment with 0.4 µL L^{-1} of 1- MCP in Larry Ann plums harvested in four different stages of maturity.

2. Materials and methods

Larry Ann plums (*Prunus salicina* L) were harvested from a commercial orchard in Río Negro (Argentina), at 4 maturity stages: maturity 1 (M1, ~62 N), maturity 2 (M2, ~58 N), maturity 3 (M3, ~50 N) and maturity 4 (M4, ~35 N).

After each harvest, the fruits were taken to the laboratory and maturity indexes were determined on 3 repetitions of 20 fruit each. Fruits were divided into two homogeneous lots: treated with 0 (Untreated control) or 0.40 µL L^{-1} of 1-MCP (Treated) for 24 hours during fruit-cooling. Subsequently, fruits were stored at 0 ºC and 90% of relative humidity for 30, 40 and 50 days and evaluated immediately after removal from the chamber, and after 3 and 7 days of shelf life at 20 ºC on 3 replicates of 20 fruit each.

Ethylene production rate (µL kg^{-1} h^{-1}) was determined on 3 repetitions of 6 fruits right after harvest and after removal from cold storage, for up to 20 days at 20 ºC or until reaching the climacteric peak. The fruits were weighed and enclosed in 3-L jars for 30 min at 20 ºC, and then 1 mL sample was extracted from the headspace. The sample was analyzed with a gas chromatograph (GC-14A, Shimadzu, Japan) equipped with an alumina column (40 ºC) and a FID detector (210 ºC). Helium was used as gas carrier.

Flesh firmness (FF) was determined with an electronic fruit texture analyzer (FTA-GS14, Güss, South Africa) with an 8 mm-diameter probe and expressed in Newtons. Sections of skin were removed at the widest point of the fruit on opposite sides to determine FF. Two slices of flesh were taken from each fruit and juiced to determine soluble solids content

(SSC) with a digital refractometer (PAL-1, Atago, Japan) expressed as %, and titratable acidity (TA) (%) by titration of 10 mL of juice with 0.1 N NaOH to a pH of 8.2, which is expressed as a percentage of malic acid.

Epidermis color was determined visually as color coverage (%) and with a tristimulus colorimeter (CR-300, Minolta, Japan) on two well-colored areas on each fruit after removing the epicuticular wax. Data are expressed in coordinates L*, Chroma, $(a^2+b^2)^{1/2}$, and Hue $[\tan^{-1}(b/a)]$.

Flesh color and chilling injury (CI) development were assessed visually by cutting each fruit on half along the equatorial axis. A four-grade visual scale according to the percentage of flesh colored or injured was used: Uninjured (0%), G1 (up to 25%), G2 (25-50%), G3 (50-75%) and G4 (75-100%). Intensity of coloration and severity of CI were calculated as the total number of fruit in each grade multiplied by the grade and divided by the total of injured fruit. Chilling injury was also expressed as percentage of affected fruits.

Data were subjected to analysis of variance (Anova) using Infostat[5]. The separation of means was performed using Tukey test with a significance level of 0.05 (*p*-values).

3. Results and discussion

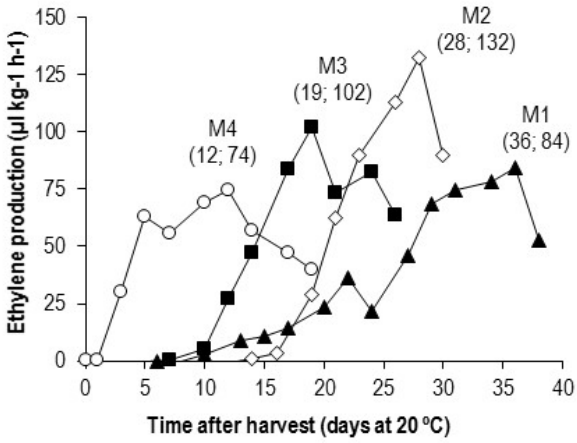
3.1 Harvest evaluations

Ethylene production rate at 20 ºC during ripening after harvest differed significantly between harvest dates (Figure 1). As the harvest was delayed, the time required to start the ethylene production and to reach the climacteric peak was reduced.

Other authors also observed that fruits harvested with more advanced maturity initiated ethylene production before those harvested earlier[6]. In other words, as harvest is delayed, the fruits are closer to reaching their climacteric maximum and consequently their deterioration, which reduces their storage potential.

Flesh firmness values decreased as harvest was delayed, showing significant differences between harvest dates (Table 1). The softening rate also increased with delayed harvest, being lower from the M1 to M2 stage (~ 0.6 N / day) than from the M2 to M3 stage (~ 1 N / day) or from M3 to M4 (2,2 N/day). Titratable acidity decreased significantly from 2.3% to 1.6%, thus increasing the SSC/TA ratio. As the harvest was delayed, an increase in the percentage of color coverage and a darkening of epidermis color (decrease in *L* and Hue*) was observed (Table 1).

Figure 1. Ethylene production rate of Larry Ann plums during shelf life at 20 ºC after harvest on 4 different maturity stages: M1 (▲), M2 (◇), M3 (■) and M4 (○)



*Values between brackets mean days to reach the peak, and maximum ethylene production rate, respectively

3.2 Storage evaluations

In the evaluations immediately after cold storage, ethylene production rate was undetectable in both control and 1-MCP treated fruits for all harvest dates and at all storage times. However, ethylene production increased during the shelf life period showing clear differences between treatments, harvest dates and storage times. 1-MCP delayed ethylene production after 30, 40 and 50 days of storage in fruit harvested with M1 and M2 (Figure 2, M1 and M2). In fruit harvested with M3 it was only effective after 30 and 40 days (Figure 2, M3), while for M4 fruits there were no differences at any storage period (Figure 2, M4). As storage was extended and harvest was delayed, the ethylene production curves flattened, the climacteric peak was weaker and the differences

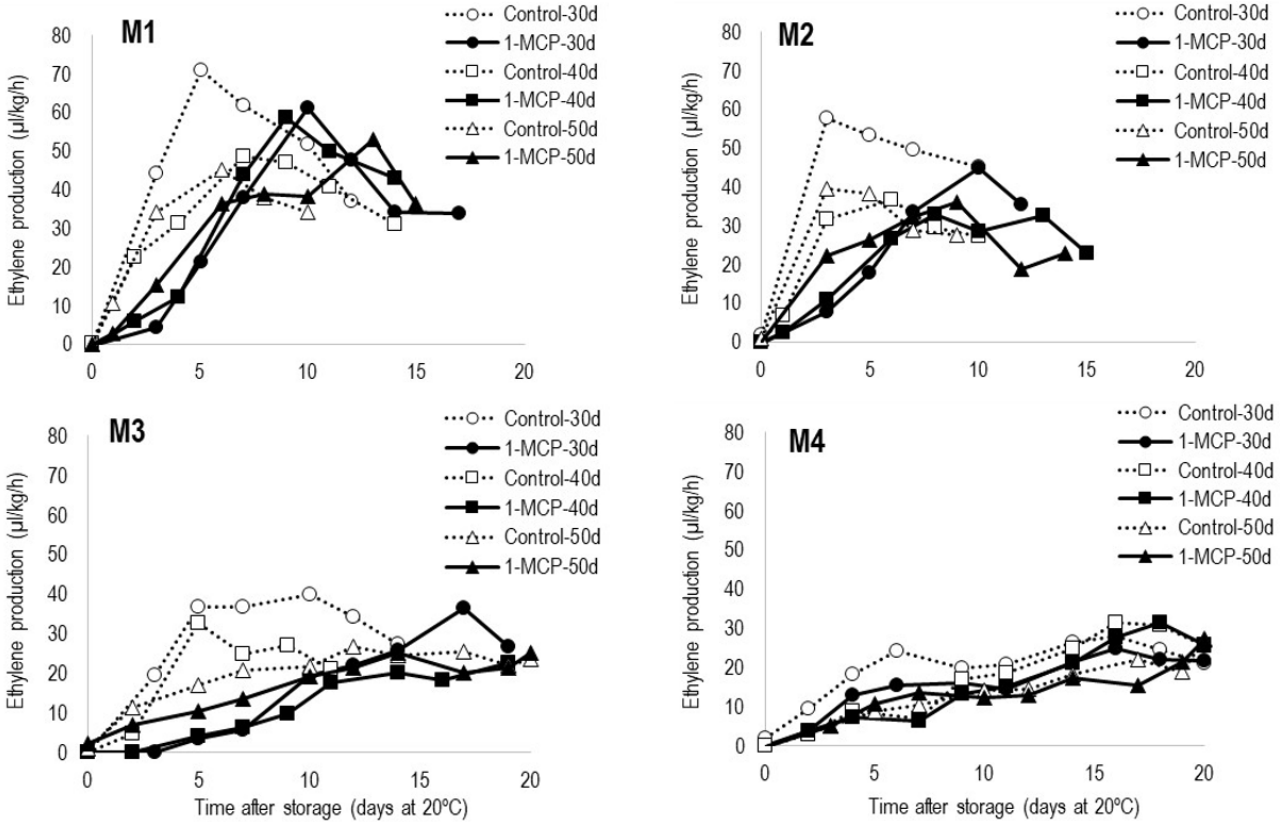
between control and treated fruit were lost (Figure 2). The reduction in ethylene production due to treatment with 1- MCP has been attributed to a decrease in the activity of the enzymes involved in ethylene biosynthesis (ACS and ACO) and to a lower accumulation of ACC[7].

Table 1. Maturity indexes of Larry Ann plums harvested on 4 successive dates

	M1 (31-jan)	M2 (8-feb)	M3 (16-feb)	M4 (3-mar)	*p*-value
Weight (g)	99.84	106.24	99.26	92.34	0.2160
Firmness (N)	62.06 a	57.75 b	50.66 c	35.20 d	<0.0001
Soluble solids (%)	15.73	15.53	15.80	15.33	0.7960
Titratable acidity (%)	2.32 a	2.26 a	2.04 b	1.64 c	<0.0001
Peel coverage (%)	46.67 d	66.67 c	81.67 b	89.42 a	<0.0001
L (peel)*	38.62 a	35.81 b	36.19 b	33.59 c	<0.0001
Hue (peel)	25.67 a	21.28 b	22.37 b	14.41 c	0.0001
Chroma (peel)	23.21 a	21.35 a	21.57 a	15.40 b	<0.0001

*Within each variable, values followed by different letters indicate significant differences according to the Tukey test (0.05)

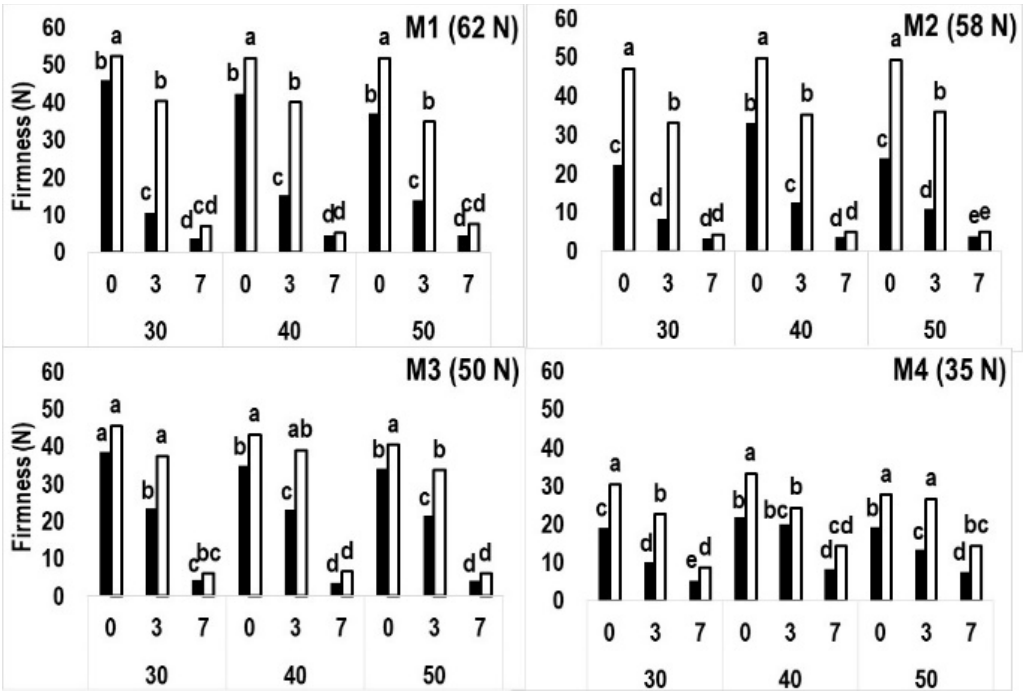
Figure 2. Ethylene production rate of control and 1- MCP treated Larry Ann plums harvested on 31-jan (M1), 8-feb (M2), 16-feb (M3) and 3-mar (M4) during shelf life at 20 ºC after 30, 40 or 50 days of cold storage



The effect on ethylene production rate was manifested in a delay in ripening associated with the maintenance of flesh firmness, acidity and epidermis color, mainly in early harvested fruits and after short storage periods.

Flesh softening was significantly lower in treated fruits than in control fruits of all the harvest dates, both when removed from the cold storage chamber and after 3 days of shelf life (Figure 2). Firmness is related to the sensitivity of the fruit to mechanical damage, which is an important cause of discard in plums and favors the incidence of rot[8]. Some authors recommend that the firmness for handling and marketing plums should not be less than 13 N[9]. Considering this reference value, only fruits treated with 1-MCP maintained recommended values for handling during more than 3 days at 20 ºC (Figure 2). Firmness is also related to the organoleptic quality of plums. The optimum quality of consumption is considered to be reached when the flesh firmness values are between 8 and 15 N for soft pulp plums[10], such as Larry Ann. In this work, control fruits reached firmness values for consumption at 3 days of shelf life at 20 ºC, while fruits treated with 1-MCP maintained values between 23 and 40 N, allowing to extend shelf life of the fruits irrespective of the harvest date (Figure 3).

Figure 3. Flesh firmness (N) in untreated control fruits (■) and treated with 1-MCP (□) of Larry Ann plums harvested in different maturation stages (M1, M2, M3 and M4), kept during 30, 40 or 50 days of cold storage period at 0 ºC, and exposed to different lengths of shelf life (0, 3 and 7 days)



*Different letters indicate significant differences between values, according to Tukey (0.05)

The acids and sugars content are directly related to the flavor of the fruits[11]. The treatment with 1-MCP maintained higher TA values, mainly in the fruits of M1 and M2, although the differences were not as significant as those observed for flesh firmness values (data not shown). SSC varied inconsistently throughout storage and, in general, higher values were observed in the M4 stage (15.3 - 17.2%) than in M3 (14.1 - 16.1%) or M2 (14.4 - 16%), and higher in these than in M1 (13.4 - 15.5%), without showing significant differences between untreated control and treated fruit.

The development of chilling injury symptoms did not limit the storage of the fruits in any of the evaluations

done. Flesh translucency was the most frequently observed symptom and affected between 5% and 30% of the fruits harvested in M1 and M3 (data not shown). The severity of the symptom remained below grade 2, without limiting the commercial quality of the control or 1-MCP treated fruits. Internal browning was only observed after long periods of storage and shelf life, mainly in the untreated control fruits of the first harvest.

4. Conclusions

The treatment with 1-MCP was effective in reducing the ripening rate, where the duration of this effect and the number of parameters affected decreased as harvest was delayed.

In early harvested fruit (~62 N and ~58 N) 1-MCP reduced ethylene production, softening, loss of acidity and darkening of the epidermis, mainly in the shorter storage periods.

In fruits from intermediate maturity (~50 N) 1-MCP delayed ethylene production during shelf life after 30 and 40 days of storage at 0 ºC, and maintained higher flesh firmness values.

In fruit from late harvest (~35 N) treatment with 1-MCP only reduced the loss of flesh firmness, but that was enough to extend both the storage period and fruit shelf life.

Both control and treated fruits reached the flesh firmness for consumption.

Author contribution statement

All authors contributed equally to the content.

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