Article

Delay of 1-MCP Treatment on Post-Harvest Quality of 'Bosc Kobak' Pear

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Abstract: Information about 1-MCP application time on pears is crucial to optimize the schedule of treatment in commercial practice. In the present work, the effect of a 3, 5 and 7 d delay of 1-MCP treatment after harvest on 'Bosc Kobak' pears was investigated, with an emphasis on shelf life. Fruit was treated with 1-MCP (625 ppm) on the 3rd, 5th and 7th d after harvest for 24 h and then kept at 20 °C for 14 d or stored at 1 °C in normal atmosphere for 6 months. Ethylene, carbon dioxide production, flesh firmness, soluble solid content and color index was determined after 4 and 6 months of cold storage and an additional 7 d of shelf-life at 20 °C. Pears treated with 1-MCP had lower values in ethylene and carbon dioxide production after storage compared to the control group; in particular, fruit treated on the 3rd d after harvest obtained the lowest values. Moreover, flesh firmness of treated samples had a higher value than that of the others after cold storage and subsequent 7 d of shelf life at 20 °C. In addition, fruit treated on the 3rd d after harvest exhibited the slower change in surface color than that of other groups. However, 1-MCP treatment on the 5th and 7th d after harvest had a minor effect on firmness and surface color change after a long storage period. The effect of 1-MCP treatment depends on the time from harvest to application. The application of 1-MCP on the 3rd d after harvest obtained the highest efficacy. The results of this study provided information on scheduling the commercial 1-MCP application for 'Bosc Kobak' pears.

Keywords: postpone; SmartFreshTM; storage; shelf life

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1. Introduction

The 'Bosc Kobak' pear is one of the most important cultivars grown in Hungary; it is harvested from mid-September to mid-October [1]. Since the market demand for this fruit is continuous, maintaining its quality is a key issue in postharvest. Different cultivars were found to respond to 1-methylcyclopropene (1-MCP) treatment differently [2–5]. However, investigation of the delay of 1-MCP application is missing on this specific cultivar. Even though the application of 1-MCP has a vital role in preserving the fresh produce for long period, its effectiveness depends on various factors including maturity, cultivar, 1-MCP concentration, temperature treatment and time from harvest to application [2–5].

The response of fruit to 1-MCP is related to ethylene production at the time when 1-MCP is applied [6,7]. The effects of delay application of 1-MCP treatment on fruit quality are highly cultivar-dependent, due to differences in metabolic rates and ethylene production [8]. For example, superficial scald incidence of 'Law Rome' apples increased during storage with greater time between harvest and 1-MCP application [9], whereas scald

development was not affected by delay of treatment for ‘Cortland’, ‘Delicious’, ‘Jonagold’ and ‘Empire’ [6].

Other reports also showed that the time between harvest and 1-MCP treatment influenced the quality of the ‘La France’ pear and the ‘Bartlett’ pear during shelf-life [10,11]. The firmness of the ‘La France’ pear reduced markedly, when 1-MCP treatment was applied at the 7th d compared to the 4th d after initial ripening [10]. In contrast, the delay of 12 d at 0 °C between harvest and 1-MCP application did not affect the benefit of 1-MCP in maintaining the quality of the ‘Bartlett’ pear compared to the treatment right after harvest [11]. The effectiveness of 1-MCP depends highly on cultivar.

Application of 1-MCP as soon as possible after harvest on commodity is crucial to control fruit quality [6]. Nevertheless, it is challenging to carry out the 1-MCP treatment at the harvest day in commercial practice due to transport or occasional lack of the airtight storage room [6]. This issue was not investigated in the previous research for the ‘Bosc Kobak’ pear yet. Therefore, the effect of a several-days delay of 1-MCP treatment is unknown for this cultivar. So far, this is an important question in commercial practice, particularly for storage operators, who are facing the need of rapidly filling up the cold storage rooms in a short time after harvest. They usually must wait until the storage room is fully loaded, then 1-MCP treatment can be started. In fact, the delay of 1-MCP application mainly depends on the storage facilities such as the size of storage room; the maximum allowed time between harvest and treatment is up to cultivars [2].

Recently, reports about the influence of time shift from harvest to 1-MCP treatment for apples [12–14] have become available, whereas information on the delay of 1-MCP application for pears is still limited, particularly for the ‘Bosc Kobak’ cultivar. In this context, the aim of this work was to evaluate the effect of 3, 5, and 7 d delay of 1-MCP treatment on the ‘Bosc Kobak’ pear after harvest.

2. Materials and Methods

2.1. Materials and Experimental Design

Pyrus communis cv. ‘Bosc Kobak’ pears were harvested at the end of September from a commercial orchard at Vámosmikola (47°57′51.6″ N 18°48′42.0″ E, Hungary). Harvested fruits were transported to the laboratory (Budapest, Hungary). Samples were selected for experiments based on uniformity of size and shape (fruit weight $\approx$ 165.3 g) and freedom from external damage. Pears were randomly split into 4 groups: 3 treated groups and 1 untreated group (control). Each group contained 200 pieces.

The 1-MCP (0.14% 1-MCP tablet, AgroFresh, Philadelphia, PA, USA) as an application of the SmartFresh™ system was provided by Rohm and Haas Polska Sp.z.o.o. (Warsaw, Poland).

The 1-MCP application procedure followed as it was earlier published by Nguyen et al. [5]. Samples were kept at 1 °C before 1-MCP treatment. Three groups were treated with 1-MCP gas on the 3rd, 5th and 7th d after harvest, respectively, in an air-tight chamber at 1 °C for 24 h (Figure 1).

During the treatment period, control group (untreated) was kept at 1 °C. After 1-MCP application, twenty pieces of each group were moved to room temperature at 20 °C (for post-harvest application shelf life test); the rest of the samples were kept at 1 °C, RH 90–95% for 6 months.

After treatment, twenty pieces of the control group and the 1-MCP_{3rd} group were removed from cold chamber at the same day for post-harvest shelf life application test.

Figure 1. Flowchart of the experiment from harvest (H) with 1-MCP treatments [T] and measurements <M>.

2.2. Measurements

The measurement procedure followed Hitka [1]; Baranyai [15]. Ethylene and CO₂ production, flesh firmness, rate of black seed, starch index, total soluble solid content, surface color and storage disorder were measured at harvest (0 d), 14 d, 4 months, 6 months and subsequent shelf life.

The measurements were conducted at 20 °C. Since ethylene and CO₂ production depend on temperature, samples were kept at 20 °C for 1 d after being withdrawn from cold storage.

2.2.1. Starch Index

Starch index was determined using Lugol's solution (aqueous iodine) on half cut fruit; surface pattern was compared to starch index reference guide and assigned to the scale of 1–6 [16]. Twenty samples were cut and evaluated from each group.

2.2.2. Fruit Firmness

Fruit firmness was recorded with a handheld fruit firmness tester (FT 327, T.R. Turoni srl, Forlì, Italy). The instrument was mounted on a vertical stand to make measurement more stable. Cylindrical probe of 7.9 mm diameter penetrated into the tissue of peeled pear until at a 10 mm depth. The maximum force was measured at two opposite points on the external circumference. The average was recorded for each fruit. The instrument provided values in kg cm^{−2}, which was transformed to the unit of N. Twenty pears were evaluated in each group for each measurement day.

2.2.3. Storage Disorder

Fruit was visually tested following OECD international standard for fruit and vegetables [17] for senescent scald on the skin and internal browning during the storage period. The disorder was determined when a sign of those symptoms occurred. The incidence was calculated as percentage of the total number of fruits in each group.

2.2.4. Soluble Solids Content

The soluble solids content (SSC) was measured with a hand-held refractometer (Atago Co. Ltd., Tokyo, Japan) and expressed as %. Twenty pears were evaluated in each group for each measurement day.

2.2.5. Rate of Black Seeds

The rate of black seeds can give information about the ethylene accumulation of the pears. It was calculated in each group by cutting 20 pears to half at the equatorial region and counting the rate of black and white seeds, following CTIFL (Le Centre Technique Interprofessionnel pour les Fruits et Légumes, Paris, France). Results were expressed as %. Twenty pears were evaluated in each group.

2.2.6. Ethylene Production

Ethylene production was determined at 20 °C by an ICA-56 hand-held ethylene analyzer (International Controlled Atmosphere Ltd., Paddock Wood, UK). Samples were placed in a hermetically closed plastic container of 4 L for 1 h before measurement was performed. Three pieces were placed in one box at the same time. Measurement was repeated in triplicates. Results were expressed in $\mu\text{L kg}^{-1} \text{ h}^{-1}$ on a fresh weight basis.

2.2.7. Respiration Rate

Carbon dioxide production over an hour in a purpose built, closed respiratory system was measured. The system was built with hermetically closed acrylic sheet containers equipped with FY A600-CO₂H carbon dioxide sensors (Ahlborn Mess-und Regelungstechnik GmbH, Holzkirchen, Germany). An Almemo 3290-8 data logger (Ahlborn Mess-und Regelungstechnik GmbH, Germany) recorded the measurements. Three pieces of pears were placed in one box at the same time. Results were expressed in milliliter of CO₂ produced per kilogram of fruit in 1 h ($\text{mL kg}^{-1} \text{ h}^{-1}$). Measurement was repeated in triplicates.

2.2.8. Surface Color

Russetting of the ‘Bosc Kobak’ pear was removed; the surface color of the pear was then determined based on the commercial color scale No. 24631 of CTIFL (Le Centre Technique Interprofessionnel pour les Fruits et Légumes, Paris, France) from 1 to 8. Twenty pears were evaluated in each group for each measurement day.

2.3. Statistical Analysis

All data were processed by IBM SPSS Statistics (version 25, IBM Corp., New York, NY, USA) using analysis of variance (ANOVA) with the following factors: treatment (control, treated at the 3rd, the 5th and the 7th d after harvest) and storage time. In addition, two-way ANOVA analysis was performed to evaluate possible interaction effects. Data were found to follow normal distribution at the initial time according to Shapiro–Wilk test. Tukey’s post hoc test was applied to compare groups with a significance level of $p < 0.05$. Results are presented on charts with mean value and standard deviation.

3. Results

3.1. Initial Quality of Pear

The initial quality parameters of the ‘Bosc Kobak’ pear are shown in Table 1. The ethylene production and firmness of the ‘Bosc Kobak’ pear at harvest were $1.56 \mu\text{L/kg}\cdot\text{h}$ and 137.4 N , respectively. The ethylene production of samples was very small at the beginning.

Table 1. Quality parameters of pear at harvest.

	Flesh Firmness (N)	Soluble Solid Content (%)	Black Seed (%)	Ethylene Production ($\mu\text{L kg}^{-1} \text{ h}^{-1}$)	Carbon Dioxide Production ($\text{mL kg}^{-1} \text{ h}^{-1}$)	Starch Index	Color Index
Initial fruit	137.4 ± 3.90	12.12 ± 0.66	96.00 ± 5.28	1.56 ± 0.87	2.82 ± 0.67	3.27 ± 0.88	1.47 ± 0.52

3.2. Ethylene Production

The ethylene production of both control and 1-MCP treated fruit increased over the whole storage period, but at different rates. As shown in Figure 2, ethylene production of

treated samples was lower than that of control group during storage at 1 °C and subsequent shelf life at 20 °C.

Figure 2. Effect of delay application of 1-MCP treatment on ethylene production after cold storage (i) and shelf life (ii). Presented values are mean $\pm$ SD. Upper case is for the comparisons of time (Tukey's, $p < 0.05$). Lower case is for the comparisons of treatment (Tukey's, $p < 0.05$).

Interestingly, no distinct increase of ethylene production appeared in treated fruit after 14 d of shelf life at 20 °C (Figure 2ii), but leveled up dramatically over the storage period (Figure 2). The benefit of the 1-MCP treatment was also affected by storage period. The ethylene production leveled up, when the storage time increased, particularly at the end of storage.

These results indicated that 1-MCP treatment at the 3rd d after harvest was effective in suppressing the ethylene production. Application of 1-MCP at 5 d and 7 d after harvest had less effect in reducing ethylene production. However, no significant difference in ethylene production was detected for samples treated at 5 d and 7 d after harvest.

3.3. Respiration

The respiration rate of the 'Bosc Kobak' pear was measured after removal from cold storage and shelf life as well (Figure 3). The CO₂ production increased during cold storage for all samples. At the 6th month, the respiration rate levelled up after removal from storage with a decline during 7 d of shelf life.

Figure 3. Effect of delay application of 1-MCP treatment on carbon dioxide production of pear during cold storage (i) and shelf life (ii). Presented values are mean $\pm$ SD. Upper case is for the comparisons of time (Tukey's, $p < 0.05$). Lower case is for the comparisons of treatment (Tukey's, $p < 0.05$).

The increase in CO₂ production for both control and treated fruit showed similar trend to ethylene production (Figure 3). In addition, treated fruit had lower values in CO₂ production compared to the control during the experiment. However, no distinction between groups treated with 1-MCP at 5 and 7 d after harvest was observed. The 1-MCP treated group on the 3rd d had lower values in CO₂ production compared to others. Based on the results, early treatment could decrease the respiration rate of pears over the whole storage period.

3.4. Firmness

The firmness of the pear decreased over storage and subsequent shelf life (Figure 4). There was a significant difference in firmness between fruit treated at 5 d and 7 d after harvest and the control group after 14 d of shelf life at 20 °C. However, later on, the firmness of the pears treated at 5 d and 7 d after harvest was not strongly affected by 1-MCP application (Figure 4). As a result, the benefit of the 1-MCP treatment was also affected by storage length.

Figure 4. Effect of delay application of 1-MCP treatment on flesh firmness of pear during cold storage (i) and shelf life (ii). Presented values are mean $\pm$ SD. Upper case is for the comparisons of time (Tukey's, $p < 0.05$). Lower case is for the comparisons of treatment (Tukey's, $p < 0.05$).

The flesh firmness of the treated pears was retained over 4 months at 1 °C. At removal from 4 months of cold storage, the flesh firmness of pears treated at 3 d had higher values than that of fruit treated at 5 d and 7 d after harvest (Figure 4i), and those differences were more pronounced after subsequent shelf life (Figure 4ii).

After 6 months, the effect of delayed application of the 1-MCP treatment was even greater. The 1-MCP treatment at 3 d after harvest could maintain the flesh firmness of pears over 6 months of cold storage plus shelf life at 20 °C, whereas the softening of the control group and fruit treated at 5 and 7 d after harvest rose rapidly (Figure 4). Flesh firmness of fruit treated at 3 d after harvest was significantly higher than that of others.

3.5. Color

The surface color development of the 'Bosc Kobak' pears was expressed by the CTIFL color index (Figure 5). The surface color of pears changed throughout the whole storage period due to ripening (Figure 5). The efficacy of 1-MCP in inhibiting the ripening process of pears was also confirmed by slowing the color change.

Figure 5. Effect of delay application of 1-MCP treatment on surface color of pear during cold storage (i) and shelf life (ii). Presented values are mean $\pm$ SD. Upper case is for the comparisons of time (Tukey's, $p < 0.05$). Lower case is for the comparisons of treatment (Tukey's, $p < 0.05$).

The control had a higher value in surface color index than that of others. These results showed that the surface color of control fruit was markedly more yellowish than those of other treatments, after cold storage and shelf life (Figure 5). Significant difference was found in surface color between the control samples and treated fruit until 6 months of cold storage; however, at subsequent shelf life, no distinction was observed among control and treatment at 5 d and 7 d after harvest. Pear treated at 3 d after harvest constantly remained lower values in color index than others. The 1-MCP efficacy was affected by treatment time and storage period.

3.6. Soluble Solid Content

SSC measurement results were shown in Figure 6. Total soluble solid of pear increased slightly during the experiment for all samples (Figure 6).

Figure 6. Effect of delay application of 1-MCP treatment on soluble solid content of pear during cold storage (i) and shelf life (ii). Presented values are mean $\pm$ SD. Upper case is for the comparisons of time (Tukey's, $p < 0.05$). Lower case is for the comparisons of treatment (Tukey's, $p < 0.05$).

There was a small difference among control and treated groups; however, significant difference was not detected between groups during cold storage nor shelf life. The 1-MCP application did not affect total soluble solid over the storage period compared to the control samples. In addition, fruit treated at 3, 5 and 7 d of delay did not differ in total soluble solid. The results also showed that the soluble solid content of pears was not influenced by delayed application of 1-MCP treatment.

3.7. Storage Disorder

The storage disorder occurred after 6 months of cold storage (Table 2). After 4 months of storage and subsequent shelf life, no storage disorder was detected for any groups. However, at the end of the storage period, the effect of delayed 1-MCP treatment, as well as storage time, was observed. The control fruits had a high percentage of storage disorder, followed by samples treated at 5 and 7 d after harvest, whereas 1-MCP treatment at 3 d after harvest could prevent fruit from developing senescent scald and internal browning.

Table 2. Disorder incidence (%) of pear during cold storage and shelf life.

	14 d Shelf-Life	4 Months Cold Storage	4 Months Cold Storage Plus 7 d Shelf Life	6 Months Cold Storage	6 Months Cold Storage Plus 7 d Shelf Life
Senescence scald					
Control	0	0	0	10.00	30.00
1-MCP _{3rd}	0	0	0	0	0
1-MCP _{5th}	0	0	0	6.00	14.00
1-MCP _{7th}	0	0	0	6.00	14.00
Internal browning					
Control	0	0	0	8.00	34.00
1-MCP _{3rd}	0	0	0	0	0
1-MCP _{5th}	0	0	0	4.00	16.00
1-MCP _{7th}	0	0	0	4.00	20.00

Note: 1-MCP_{3rd}, 5th, 7th: 1-MCP application was carried out at 3, 5 and 7 d after harvest, respectively.

4. Discussion

There have been many publications about the role of 1-MCP in delaying the ripening, and maintaining the firmness, taste and appearance, of fruits [2]. Reported experiments typically performed the 1-MCP treatment on pears within one or two days after harvest [3,4,18]. In earlier studies, the information about the treatment time for apples was reported [12–14]; however, discussions on the effect of delayed application for pear cultivars are limited or absent.

The 1-MCP treatment strongly affected ethylene production, when fruits were treated at 3 d after harvest, whereas only a small effect was observed for fruit treated at 5 and 7 d. There was no significant difference in ethylene production between fruit treated at 5 and 7 d after harvest. In addition, earlier research on the ‘Bosc Kobak’ pear had found that 1-MCP application up to 2 d after harvest was successful [1]. The results of the present study showed that shortening the time from harvest to 1-MCP application could decrease the ethylene production. Decreasing the amount of ethylene production is important, because the ethylene can accelerate the ripening of pear rapidly [19]. In this work, pears had high values in ethylene production accompanied by fruit softening. It could be explained by the fact that increasing the time from harvest to treatment enhanced the probability of the combination of ethylene and receptor; thus, ethylene could exert its action [2]. In addition, during 6 months of storage, there was the formation of new receptors; moreover, the ethylene combined with the new receptor rapidly induced ripening [19]. Therefore, 1-MCP applications at 5 and 7 d were less beneficial in maintaining the quality of the ‘Bosc Kobak’ pears compared to treatment at 3 d after harvest.

This research showed that ethylene production of fruit clearly influenced the postharvest respiration, in agreement with the results of an earlier report for ‘Bartlett’ pears [11]. Considering these results, the CO₂ production of 1-MCP-treated ‘Bosc Kobak’ pears remained low over storage time compared to the control. These results coincided with respiratory behavior of ‘Conference’ pear [20]. Low respiration rate provides benefit for maintaining the quality in extended storage time [20].

In this work, after 14 d of shelf life at 20 °C, there was no significant difference in firmness among treated groups; however, after 4 months of storage plus shelf life, the effect

of the treatment time was observed. The 1-MCP treatment could maintain the quality of pears during storage and shelf life; however, the benefits of 1-MCP decreased strongly with later application at the end of storage. Fruit treated at 3 d after harvest had higher values in firmness than that of others. No significant difference in firmness was observed between the control group and samples treated at 5 and 7 d after harvest. These results indicated that the delay of 1-MCP application after harvest could be up to 3 d for 'Bosc Kobak' pears. This study also found that treatment time is one of the important factors influencing the efficiency of 1-MCP application on 'Bosc Kobak' pears. Nowadays, time between harvest and treatment is still a crucial question in commercial practice; it also highly depends on the cultivar. This report showed that the application time contributed to the success of the 1-MCP treatment, in agreement with experiments on 'McIntosh' apples [14], 'Cortland', 'Delicious', 'Jonagold', 'Empire' apples [6], and 'La France' pears [10]. The effectiveness of 1-MCP would be greater when application is performed close to harvest. Moreover, when minimizing the delay of treatment, the storage period can increase. In this experiment, 1-MCP application could be delayed until 3 d after harvest, whereas treatments at 5 and 7 d after harvest were too late to control the postharvest ripening of pears.

The surface color of pears lost its greenness; additionally, its yellowness increased during ripening [4,21]. In this work, the color of treated fruit changed slower than that of the control, in agreement with other findings for 'Comice' pears [4] and 'Bartlett' pears [3]. However, at the end of shelf life following 6 months of cold storage, no significant difference in color index between the control and fruit treated at 5 and 7 d after harvest was observed. The present results also confirmed that delayed application of 1-MCP treatment greatly influenced the change of surface color. The storage time affected the benefit of 1-MCP, which was due to the formation of new receptors, after long-term storage. Thus, the ethylene bound with new receptors and then accelerated ripening [3].

The total soluble solid content increased gradually after cold storage; however, there was no significant difference between the control and 1-MCP treated groups, in agreement with other findings for 'Comice' pears [4], and for 'Anjou' pears [22]. No effect of delayed treatment was detected, either. However, fruit treated with 1-MCP can obtain higher, lower, or similar values of soluble solid content in comparison with untreated samples, depending on the harvest date [23]. Fruits from early and mid-harvest were observed to behave differently compared to late harvest fruit by means of SSC [23].

The 1-MCP-treated pears had less storage disorder than the control group over the storage period. This was in agreement with previous reports for 'Bartlett' pears [3] and d'Anjou pears [24]. In the present work, the disorder increased with the delay of 1-MCP application. The disorder incidence only occurred at the end of cold storage and subsequent shelf life. Fruit were probably at the advanced ripening stage and, thus, more susceptible to disorder.

This experiment showed that the effect of 1-MCP treatment on the overall quality of 'Bosc Kobak' pears decreased, when the delay in the application of 1-MCP treatment was longer. There was a significant difference in quality between fruits treated at 3 d and that of others during storage at 1 °C and shelf life at 20 °C, whereas only minor difference was detected among control samples and fruit treated at 5 and 7 d after harvest. In this work, 1-MCP treatment on 'Bosc Kobak' pears at 3 d after harvest could maintain the quality during 6 months of storage plus shelf life.

The lessened efficacy of 1-MCP at late treatment was perhaps due to incomplete blocking of the ethylene receptors; thus, ethylene could exert its action in ripening [2,25]. The physiological stage of fruit at the time of 1-MCP treatment decides the efficacy of 1-MCP in prolonging the fruit quality [11]. Regarding delayed 1-MCP treatment, previous reports also indicated that the earlier-applied treatments increased the possible storage period [6,10,26].

5. Conclusions

This work points out the necessary information concerning 1-MCP treatment at different days after harvest on ‘Bosc Kobak’ cultivars that could be useful in commercial practice. Based on the empirical findings, it can be concluded that 1-MCP treatment could be delayed till the 3rd d after harvest. Response of ‘Bosc Kobak’ cultivars after 6 months of storage and shelf life indicated that the effectiveness of 1-MCP decreased significantly with late treatment (5 and 7 d after harvest). The firmness and color of fruit treated at 3 d after harvest was maintained during cold storage and subsequent shelf life. After long-term cold storage at normal atmosphere, 1-MCP-treated pears could resume ripening during shelf life at 20 °C.

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