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THE STORAGE ABILITY OF BROCCOLI AFTER 1-METHYLCYCLOPROPENE TREATMENT

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ABSTRACT

The study evaluated the effect of 1-methylcyclopropene (1-MCP) treatment on broccoli quality and storage ability. Broccoli 'Parthenon' was treated the day after harvest with 1.0 or 3.0 $cm^3 \cdot m^{-3}$ 1-MCP. The treatment was performed at 5 °C for 20 h, and then the plant material was stored at 0-1 °C for 30 or 60 d. After 30 d of refrigerated storage, broccoli was transferred to conditions simulating retail (15 °C) for 6 d. During 30 d of storage, the broccoli crowns maintained excellent quality. The fleshy stalks were slightly inferior due to the darkening of the leaf scar areas. After 60 d, there was a marked reduction in broccoli quality. Still, the positive effect of 1-MCP treatment on broccoli was observed as inhibiting the senescence of the remaining petiole fragments. During shelf life after 30 days of cold storage, broccoli treated with 1-MCP retained better quality of the crowns and fleshy stems, evident after six days of shelf life evaluation. The study did not find that 1-MCP treatment inhibited the respiration rate of broccoli, or ethylene production.

Key words: postharvest treatment, quality, ethylene, carbon dioxide, senescence

INTRODUCTION

The main commercial attributes of broccoli (*Brassica oleracea* L. var. *italica*) are green color and compactness of the flowering head. Softening and discoloration occur quickly after harvest, during storage at high temperatures such as 20 °C. Senescence symptoms result from chlorophyll breakdown (Gong & Mattheis 2003). At low temperatures (0 °C), the deterioration is delayed, and storage life is extended (Page et al. 2001). A decline in quality at low temperatures is generally limited by rotting and loss of compactness of the heads. Discoloration of stem scars also occurs during storage. These scars are formed where the leaves are cut off from the fleshy stem. During storage, these scars discolor, lowering the appearance of the shoot (DeEll et al. 2001). The storage length of broccoli was determined by Cantwell and Suslow (1997) to be 21–28 d at 0°C, 14 d at 5°C, and 5 d at 10°C. Ethylene, both endogenous and exogenous, affects the loss of chlorophyll and, thus, the yellowing and aging of broccoli (Tian et al. 1994; Cantwell and Suslow 1997; Suzuki et al. 2004). Postharvest broccoli treatment with 1-methylcyclopropene (1-MCP) has been shown to reduce respiration and ethylene production, delaying greening reduction and broccoli senescence (Fan & Mattheis 2000). 1-methylcyclopropene (1-MCP) reduces enzyme activity responsible for ethylene synthesis and the expression of the enzymes' genes (Ma et al. 2009). According to Wills et al. (1999), reducing ethylene concentration from 0.1 to <0.005 $cm^3 \cdot m^{-3}$ at least doubled the shelf life of broccoli at 20 and 5°C. The authors suggested that the threshold level of ethylene action on non-climacteric horticulture produce is below 0.005 $cm^3 \cdot m^{-3}$. The effective concentration of 1-MCP for broccoli is 0.1–10 $cm^3 \cdot m^{-3}$ (Yuan et al. 2010). Broccoli branchlets after treatment with 1-MCP at the dose

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of 1.0 $cm^3 \cdot m^{-3}$ for 14 h at 20°C showed delaying of yellowing during shelf life at 20°C in dark conditions (Gong & Mattheis 2003). Ku and Wills (1999), comparing the effects of different doses of 1-MCP (0.02–50 $cm^3 \cdot m^{-3}$) and treatment times (2–6 h), found that the higher the concentration and longer the time, the greater the storage ability of broccoli heads was. Treatment with 2.5 $cm^3 \cdot m^{-3}$ for six h at 20°C) extended shelf life at 20°C from 2.5 to 5 d. In addition to delaying postharvest deterioration and chlorophyll degradation, the treatment inhibited the degradation of carotenoids, ascorbic acid, and glucosinolates during storage (Yuan et al. 2010). Xu et al. (2016) confirmed that the above treatment improves the shelf life of broccoli florets at 15°C due to the maintenance of higher levels of chlorophyll and sugars. Zsom et al. (2020) recommended a low concentration of 1-MCP (0.625 $cm^3 \cdot m^{-3}$) for 24-h treatment. This treatment protects against the negative effects of ethylene applied at a concentration of 2.0 $cm^3 \cdot m^{-3}$ for 9 days at 5°C. Broccoli florets stored at 10°C after treatment with 1-MCP at 12 $cm^3 \cdot m^{-3}$, for 16 h, at 20°C showed a 20% longer shelf life than untreated florets (Able et al. 2002). Also, in a study by Forney et al. (2003), treatment with 1.0 $cm^3 \cdot m^{-3}$ for 14 h at 10°C delayed yellowing, and during 5 d of storage at 10°C, treated florets maintained their green color, while untreated ones turned yellow. The storage period at 5°C increased by 5–7 d of treated broccoli, and the percentage of commercial heads rose from 0 to 72–100 during simulated retail display (7°C) for up to 2 weeks (Ekman et al. 2019). Wichrowska et al. (2021) confirmed that this treatment affects the maintenance of color and firmness during storage at 4°C. However, the authors hypothesized that the response depends on the cultivar, and not all tend to store better after 1-MCP treatment.

There are a lot of reports on the postharvest treatment of broccoli with 1-MCP, which is usually applied at relatively high temperatures, and broccoli stored for a short time at high temperatures as well. This study aimed to test the effect of treating cooled broccoli with 1-MCP at 5°C for 20 h and then storing them at 0–1°C. The idea was to cool the broccoli as soon as possible after harvest, treat them with low temperature, and keep them under optimal conditions (0–1 °C and 98–100% relative humidity).

MATERIALS AND METHODS

Plant material

Broccoli 'Parthenon F_1' grown for the autumn harvest, was purchased from a horticultural farm located about 50 km from Skierniewice. Immediately after transporting the plant material to the laboratory, the leaves were cut off, and the stalk was trimmed so that the length of the broccoli was 18–20 cm. Next, the broccoli was chilled overnight (about 16 h) to 5°C. The experiments were conducted in two storage seasons.

1-MCP treatment

The heads were divided into three lots, arranged in U-boxes, and treated with 1-MCP at the concentrations of 1.0 and 3.0 $cm^3 \cdot m^{-3}$. The control heads were not treated with 1-MCP. The treatment was conducted out inside gas-tight containers for 20 hours at 5°C. The agent SmartFresh™ 0.14 (active substance: 1-MCP), obtained from AgroFresh Poland, was used in the research.

Storage investigation

After treatment, the broccoli heads were removed from the containers and placed in U-boxes lined with 0.03 mm thick polyethylene (PE) film. 44 broccoli heads from each treatment were arranged in 4 boxes (11 items in one box). Broccoli was stored at 0–1°C for 30 d (one set of broccoli) and 60 d (second set). Broccoli heads in boxes were covered with PE film to keep the humidity in the immediate area at 98–100%. After refrigerated storage for 30 d, broccoli with no signs of rotting or significant reduction in quality was further stored under conditions simulating retail, i.e., at 15°C, for 6 days.

Ethylene (C_2H_4) and carbon dioxide (CO_2) measurement

After 30 d of storage at 0–1°C, in each season, two good quality broccoli heads without signs of yellowing and rotting from each treatment were placed at 5 and 10°C. After one day of acclimatization, the first

measurements were taken, and the next were taken after 3 and 6 d. On the day of the measures, the broccolis were placed in airtight containers with a capacity of 22 dm^3 for two hours. After this time, 1.0 cm^3 of gas was taken from the containers using an insulin syringe to measure ethylene concentration. The measurement was performed using gas chromatograph Hewlett Packard 5890 II (Hewlett Packard, Palo Alto, CA, USA). The reading was calculated and expressed in mm^3 per kg per h. The CO_2 concentration was measured using O_2 and CO_2 analyzer Check Mate II O2 (Zr) CO_2-100% w/Printer (PBI-Dansensor A/S, Denmark). The results were expressed in cm^3 per kg per h.

Visual quality evaluation

After 30 and 60 days of cold storage, a visual evaluation of the broccoli was carried out. During storage under retail conditions (15 °C), the broccolis were subjected to the visual evaluation every two days for 6 days. The following features concerning the broccoli crown were evaluated: discoloration/yellowing, rotting, compactness, opening of flower buds, and overall appearance. The quality of the fleshy stalk was evaluated separately. All evaluations were scored on a scale of 1–10:

- discoloration/yellowing: 10 – dark green; 8 – light green; 5 – yellowish-green; 3 – greenish-yellow; 1 – yellow;
- rotting: 10 – no symptoms; 8 – very minor (1 or 2 very small spots); 5 – small spots but clearly visible; 3 – medium rotting; 1 – completely rotten;
- compactness: 10 – very compact; 8 – very light loss of compactness; 5 – clearly noticeable loss of compactness; 3 – loose head; 1 – very loose head;
- flower buds opening: 10 – all buds closed; 8 – to 20% bubs open; 5 – to 50% buds open; 3 – to 70% buds open; 1 – 90–100% buds open;
- overall appearance for a head: 10 – excellent (broccoli as freshly harvested); 8 – good; 5 – fair (threshold of commercial suitability); 3 – faulty; 1 – very bad;
- overall appearance for fleshy stalk: 10 – excellent (broccoli as freshly harvested); 8 – good; 5 – fair (clearly visible senescence of the petiole scars); 3 – severe senescence; 1 – very severe senescence.

Weight loss

Weight loss of cold stored broccoli was calculated as the difference between the initial weight (storage time – 0 d) and the weight after 30 or 60 d storage time. Weight loss measured during retail storage was calculated relative to the weight of broccoli on the day when they were moved to 15 °C. The results were expressed in percentages.

Statistical analysis

The results were statistically analyzed using a one-factor analysis of variance, treating 1-MCP concentration as the only variable in the model. Because results from single seasons were not significant, this factor was annulled, and all means from two seasons (88 for quality parameters after storage at 0–1 °C, 30 for quality parameters during shelf life, and 4 for ethylene and carbon dioxide concentration) were analyzed. The obtained averages were compared using the Tukey test at $p = 0.05$. The calculations were done independently for each storage time in the statistical package STATISTICA 13 (Dell 2016).

RESULTS AND DISCUSSION

According to storage recommendations (Cantwell & Suslow 1997; Pogson & Morris 1997; Toivonen & Forney 2016), the broccoli was placed in a cold chamber and cooled overnight at 5 °C immediately after harvest. The 1-MCP treatment was applied at the earliest possible time, i.e., on the second day after harvest (as suggested by Able et al. 2002). Weight losses after 30 d at 0–1 °C were small and ranged from 0.66–0.73% (0.66% – control, 0.73% – 1.0 $cm^3 \cdot m^{-3}$ 1-MCP, and 0.67–3.0 $cm^3 \cdot m^{-3}$ 1-MCP). During the next 30 d, the losses increased slightly, respectively: 1.08% for control, 1.01% for broccoli treated with 1.0 $cm^3 \cdot m^{-3}$ 1-MCP, and 1.04% – 3.0 $cm^3 \cdot m^{-3}$ 1-MCP. Low weight loss was indicative of the lack of wilting and maintenance of good compactness of the heads. As in the study of Ekman et al. (2019), no significant differences in weight loss were found between 1-MCP treated and untreated broccoli.

After 30 d of storage, broccoli crowns, both treated and untreated, represented excellent visual quality. They retained deep green color and good compactness, and only very small black spots were noted on a few crowns (Table 1). In the study by Pogson and Morris (1997), broccoli also maintained perfect color during 35 d at 1 °C and showed only a slight loss of chlorophyll. In contrast, Sabir (2012) found slight crown yellowing after 28 d at 0 °C. Treatment with 1-MCP did not affect quality parameters. In the presented study, no bud opening was observed at all. The fleshy stem was more deteriorated than the crown due to the darkening of the scarred surface when the leaves were cut off. This darkening negatively affected the appearance of the broccoli and reduced its commercial value (Table 1). However, the suitability for consumption was still high, as the stem, after peeling, presented well. A practical solution to avoid this problem is to leave 2–5 cm stumps of petioles on the stem for cold storage. The stumps would be trimmed at the stem only when preparing the material for trade, making the new cut areas fresh and green.

By extending the storage period by another 30 d, the quality of broccoli deteriorated. The most instant contributor to this was rotting (Table 2). A slight loosening of the crowns and the beginnings of their yellowing also contributed to the decline in quality. Makhlouf et al. (1989) noted severe rotting and unpleasant odours after six weeks of broccoli storage at 1 °C. In contrast, Pogson and Morris (1997), after 70 d at 1 °C, found a significant loss of chlorophyll (25%) and signs of head yellowing. In the presented study, the untreated broccoli significantly softened and yellowed more than those treated with 1-MCP. In the quality of the crowns, there was a trend toward higher rating for broccoli treated with 1-MCP. In the case of the stems, those treated with 1-MCP maintained a significantly better appearance. In addition to the stronger darkening of the surface of the scars, the bases of the petioles remaining on stems showed signs of flesh yellowing and senescence (Table 2). For 60 days at 0–1 °C, broccoli, both treated and untreated with 1-MCP, on average, still maintained the quality above a threshold of commercial suitability. It should be considered that this was possible due to the use of a low storage temperature of 0–1 °C. Treatment with 1-MCP had only a minor effect on the storage ability of broccoli (Table 2). Also, according to Able et al. (2002), storage temperature can extend the shelf life of broccoli to a great extent, and this effect is much more significant than that induced by 1-MCP treatment.

Table 1. The quality of broccoli 'Parthenon' after 30 d of storage at 0–1 °C

Concentration of 1-MCP ($cm^3 \cdot m^{-3}$)	Discoloration/yellowing of crown	Compactness of crown	Rotting	Overall quality of crown	Overall quality of shoot
0.0	10.0±0.1 a	9.6±0.4 a	9.8±0.6 a	8.8±0.6 a	7.0±0.0 a
1.0	10.0±0.0 a	9.6±0.5 a	9.9±0.7 a	8.9±0.7 a	7.0±0.0 a
3.0	10.0±0.0 a	9.7±0.4 a	9.9±0.4 a	8.9±0.4 a	7.0±0.0 a

Values are means of 88 samples ± standard deviation (SD). The differences between means in columns indicated by the same letter do not differ significantly ($p<0.05$, Tukey test);
Scoring scales of broccoli crown: discoloration/yellowing: 10 – dark green, 8 – light green, 5 – yellowish-green, 3 – greenish-yellow, 1 – yellow; compactness: 10 – very compact, 8 – very light loss of compactness, 5 – clearly noticeable loss of compactness, 3 – loose head, 1 – very loose head; rotting: 10 – no symptoms, 8 – very minor (1 or 2 very small spots), 5 – small spots but clearly visible, 3 – medium rotting, 1 – completely rotten; overall appearance: 10 – excellent (as freshly harvested), 8 – good, 5 – fair (threshold of commercial suitability), 3 – faulty; 1 – very bad;
Scored scale of overall appearance for fleshy stalk: 10 – excellent (as freshly harvested), 8 – good, 5 – fair (clearly visible senescence of the petiole scars), 3 – severe senescence, 1 – very severe senescence.

Table 2. The quality of broccoli 'Parthenon' after 60 d of storage at 0–1 °C

Concentration of 1-MCP ($cm^3 \cdot m^{-3}$)	Discoloration/yellowing	Compactness of crown	Rotting	Overall quality of crown	Overall quality of shoot
0.0	9.4±0.9 b	9.0±0.5 b	7.9±2.2 a	6.5±2.5 a	5.0±0.1 b
1.0	9.9±0.4 a	9.3±0.5 a	8.2±2.0 a	7.0±2.2 a	6.0±0.1 a
3.0	9.9±0.3 a	9.4±0.5 a	8.0±2.2 a	6.8±2.3 a	6.0±0.0 a

Values are means of 88 samples ± standard deviation (SD). The differences between means in columns indicated by the same letter do not differ significantly ($p<0.05$, Tukey test)
Scored scales – see under Table 1.

Under retail conditions, which occurred after 30 d of refrigerated storage, weight loss increased quite rapidly, despite the heads being covered with PE film. After two days, losses were 0.25% for all objects, 4 d from 0.60 to 0.64%, and 6 d from 1.04 to 1.09%. No significant differences were found between broccoli treated with 1-MCP and untreated. For two days, the heads continued to look very good, their color remained unchanged, and only a slight decrease in compactness and very little rotting was observed. A slightly worse appearance presented in the stems due to the darkening of the scar areas of the leaves, which was already visible after refrigerated storage. After another two days, the crowns were found to be slightly discolored, compactness decreased somewhat, and rotting increased significantly. The quality of the crowns reached a fairly good level, but the shoots were only satisfactory.

The bases of the trimmed leaves on the control broccoli shoots showed deepened signs of yellowing and even abscission from the shoot. The appearance of the control shoots was significantly worse than those treated with 1-MCP. During the next two days, the crowns of the broccoli turned intensely yellow, but this process was particularly fast in the untreated objects (Table 3–6). In treated objects, yellowing also occurred but at a much slower rate, and there was a trend that yellowing was slowest in broccoli treated with 3.0 $cm^3 \cdot m^{-3}$ 1-MCP. This is partially consistent with the findings of Yuan et al. (2010) that significant differences in color and visual quality were noted after 1 day at 20°C following refrigerated storage. In the current study, the crowns loosening and rotting proceeded similarly in both treated and untreated broccoli (Table 4–5). Also, according to Ekman et al. (2019), the effect of treatment on the development of rotting is small, and no differences in weight loss are found between treated and untreated broccoli.

The overall quality of the crowns was excellent after 2 d at 15°C, but in the following days it decreased very fast. After 4 d, they reached quality close to good, but after 6 days, only broccoli treated with 3.0 $cm^3 \cdot m^{-3}$ 1-MCP was rated slightly above commercial suitability (Table 6). Generally, the fast yellowing and quality decreasing during shelf life are in line with the findings of Tian et al. (1994), which also claimed that in high temperatures, broccoli florets senesce rapidly, which is typical for crops harvested before a full mature stage.

After six days, both crowns and shoots looked worst in the untreated broccoli (Table 6). An opposite conclusion was reached by Fernandez-Leon et al. (2013). In their study, 1-MCP

had the effect of maintaining better color in broccoli, but only during refrigerated storage at 1–2°C, up to 27 d. The authors claimed that using 1-MCP reduced the loss of chlorophyll pigments, but only during cold storage; during shelf life at 20°C, yellowing developed faster on treated than on control broccoli. It seems that the response of broccoli to 1-MCP may still depend on many factors such as cultivar, maturity stage, application method, and the length of time between harvest and treatment, as previously reported by Watkins (2006, 2008). In contrast, Ma et al. (2010) confirmed that the yellowing process is suppressed by the treatment with 5.0 $cm^3 \cdot m^{-3}$ 1-MCP at 20°C.

Table 3. Yellowing of broccoli crown during storage at 15°C after 30 d of cold storage at 0–1°C

Concentration of 1-MCP ($cm^3 \cdot m^{-3}$)	Shelf life time (d)		
	2	4	6
0.0	10.0±0.0 a	8.9±1.2 a	5.1±1.0 b
1.0	10.0±0.0 a	8.9±1.2 a	6.8±2.1 a
3.0	10.0±0.0 a	9.4±0.8 a	7.4±1.3 a

Values are means of 30 samples ± standard deviation (SD). The differences between means in columns indicated by the same letter do not differ significantly ($p<0.05$, Tukey test)
Scored scale – see under Table 1

Table 4. Compactness of broccoli crown during storage at 15°C after 30 d of cold storage at 0–1°C

Concentration of 1-MCP ($cm^3 \cdot m^{-3}$)	Shelf life time (d)		
	2	4	6
0.0	9.5±0.3 a	9.2±0.4 a	8.5±0.5 a
1.0	9.4±0.3 a	9.1±0.3 a	8.4±0.5 a
3.0	9.5±0.3 a	9.3±0.4 a	8.7±0.5 a

Values are means of 30 samples ± standard deviation (SD). The differences between means in columns indicated by the same letter do not differ significantly ($p<0.05$, Tukey test)
Scored scales – see under Table 1

Table 5. Rotting of broccoli crown during storage at 15°C after 30 d of cold storage at 0–1°C

Concentration of 1-MCP ($cm^3 \cdot m^{-3}$)	Shelf life time (d)		
	2	4	6
0.0	9.6±1.1 a	8.5±1.9 a	7.9±2.3 a
1.0	9.6±0.9 a	8.6±1.7 a	7.5±2.3 a
3.0	10.0±0.0 a	9.1±1.2 a	8.3±2.0 a

Values are means of 30 samples ± standard deviation (SD). The differences between means in columns indicated by the same letter do not differ significantly ($p<0.05$, Tukey test)
Scored scales – see under Table 1

Table 6. Overall quality of broccoli crown and fleshy stem during storage at 15°C after 30 d of cold storage at 0–1°C

Concentration of 1-MCP ($cm^3 \cdot m^{-3}$)	Crown			Fleshy stem		
	2 d	4 d	6 d	2 d	4 d	6 d
0.0	8.9±0.9 a	7.2±1.6 a	3.2±1.6 b	6.5±0.5 a	5.5±0.5 b	3.3± 0.3 c
1.0	9.0±2.3 a	7.2±0.8 a	4.4±1.9 ab	6.5±2.7 a	6.0 ±0.5 a	3.8± 0.0 b
3.0	9.3±0.3 a	7.7±1.5 a	5.7±2.2 a	6.5±0.5 a	6.0±0.0 a	4.3± 0.3 a

Values are means of 30 samples ± standard deviation (SD). The differences between means in columns indicated by the same letter do not differ significantly ($p<0.05$, Tukey test); Scored scales – see under Table 1

The intensity of broccoli respiration is expressed as the amount of CO_2 released. It was significantly higher in broccoli transferred after refrigerated storage to 10°C than those transferred to 5°C (Fig. 1). The same relationship was found earlier by Cantwell and Suslow (1997). These authors also showed that the respiration intensity at 10°C is more than double that at 5°C. After one day of acclimatization at 5°C, the highest respiration intensity was displayed by untreated broccoli. After three days, the respiration intensity in all combinations decreased and equalized for treated and untreated broccoli. In a study by Forney et al. (2003), respiration rates decreased during five days of storage at 12°C. In the current study, the next three days brought no significant changes in the intensity of broccoli respiration. At 10°C, treated and untreated broccoli respired with similar intensity, and on days 3 and 6 there was a rising trend in this intensity. Thus, in the present study, there was no effect of 1-MCP treatment on the respiration intensity of broccoli (Fig. 1). There was also no increase in respiration intensity for broccoli that turned yellow faster. Likewise, Pogson and Morris (1997) found that respiration intensity is not necessarily related to chlorophyll breakdown, and, thus yellowing and aging of the broccoli. However, most researchers claim that 1-MCP inhibits the increase in respiration rate (Fan & Mattheis 2000; Sabir 2012; Thi Hand Phuong et al. 2022). In the current study, the effect of 1-MCP treatment on respiration intensity can be suppressed by low storage temperature, which is the main factor limiting biochemical reactions in plant tissue.

The broccoli in this study generated very low amounts of ethylene, and despite the lack of statistical differences, slightly less at 5°C than at 10°C. It is noteworthy that at both temperatures, there was a tendency for greater ethylene production by broccoli treated with 1-MCP than untreated. The obtained results contrast with the statement of Wills et al. (1999) and Thi Hand Phuong et al. (2022), and are consistent with Porter et al. (2005), who claimed that treatment of Chinese cabbage with 1.0 $cm^3 \cdot m^{-3}$ 1-MCP stimulated ethylene more than 0.01 $cm^3 \cdot m^{-3}$ 1-MCP. According to Lomaniec et al. (2003), 1-MCP can increase ethylene biosynthesis in parsley. In the current study, broccoli that released more ethylene turned yellow and aged at retail at a slightly slower rate than broccoli that produced less gas. This indicates that alternative factors interfere with the effect of 1-MCP on ethylene production and plant tissue yellowing. It can be hypothesized that other phytohormones may play an important role in the yellowing and aging of broccoli during storage. Tian et al. (1995) have previously demonstrated that cytokinins cause stimulation of ethylene production on the one hand and simultaneous retardation of broccoli yellowing on the other hand. In addition, the response of plant tissue to hormones depends on the number of hormone receptors, and it is possible, as previously stated by Sisler and Serek (1997), that ethylene receptors become active again or new ones are formed during extended storage. This research needs to be continued to clarify the above hypotheses.

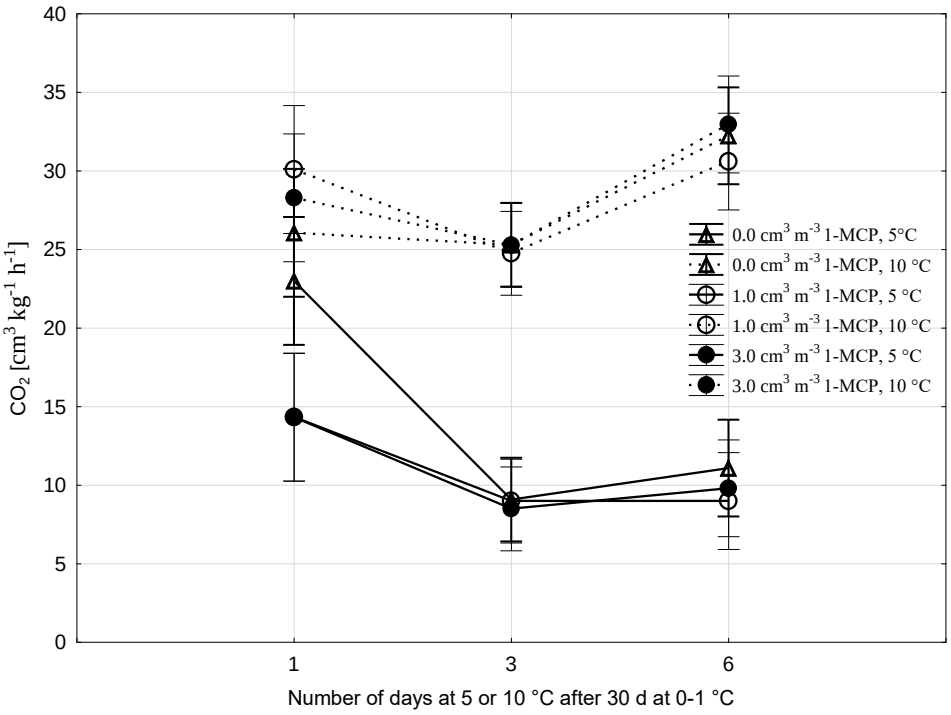

Figure 1. CO_2 generation by broccoli 'Parthenon' treated by 1-MCP. Individual markers indicate the average of 4 repetitions (n=4). Vertical lines are standard deviations

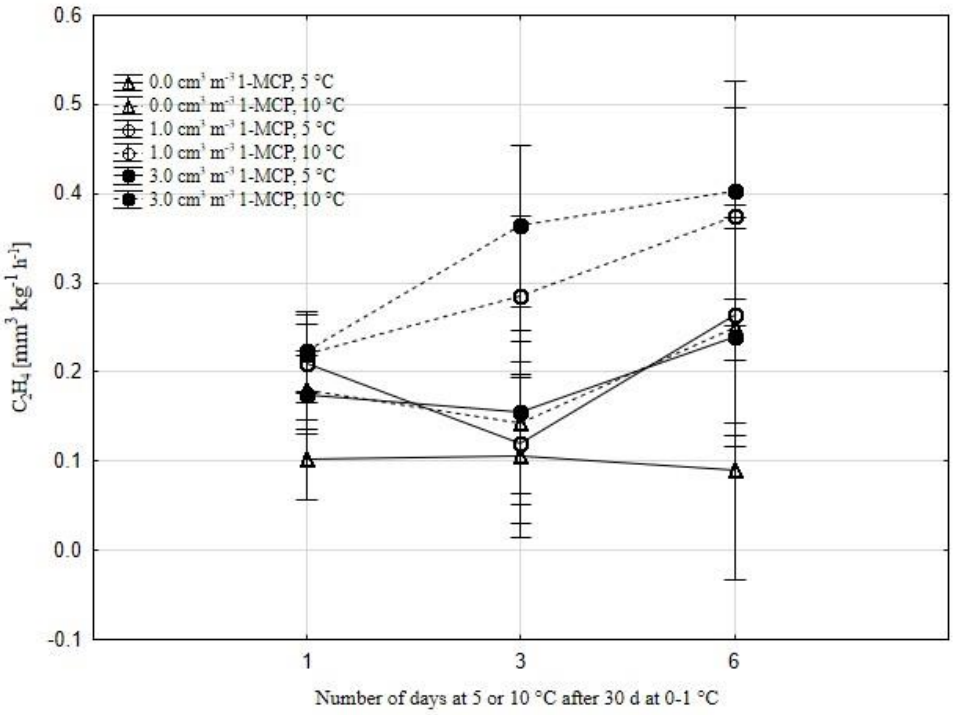

Figure 2. C_2H_4 generation by broccoli 'Parthenon' treated by 1-MCP. Individual markers indicate the average of 4 repetitions (n=4). Vertical lines are standard deviations

CONCLUSIONS

The results obtained in this research led to the conclusion that the use of 1-MCP to improve the storability of broccoli had only marginal benefits. There was a significant delay in yellowing when the heads were moved from refrigerated conditions (30 d at 0–1°C) to a higher temperature of 15°C. 1-MCP treatment delay fleshy stem scar discoloration and senescence during long refrigerated storage and subsequent shelf life. There was no reduction in respiration and ethylene production in broccoli treated with 1-MCP, during shelf life at 5 and 10°C after 30 d of refrigerated storage.

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