Treatment with 1-Methylcyclopropene Complements Temperature Management in Maintaining Postharvest Quality of Broccoli

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Abstract

Broccoli is a highly perishable floral vegetable whose postharvest quality is influenced by temperature and ethylene. Endogenously produced or exogenously applied ethylene promotes sepal yellowing and shortens storage life, whereas low temperature delays color changes and prolongs storage life. We tested the effectiveness of the ethylene action inhibitor, 1-methylcyclopropene (1-MCP), as a complement to refrigerated storage to maintain postharvest quality of broccoli. 'Marathon' broccoli (*Brassica oleracea* var. *italica*) heads were treated with 2 μl·L^{-1} of 1-MCP and stored at 1, 10, and 20 ºC. Untreated broccoli heads used as controls were stored at the same temperatures. Potential storage life, as judged by overall appearance, was 2, 12, and 76 days for untreated broccoli stored at 20, 10, and 1 ºC, respectively. Treatment with 1-MCP increased storage life by 50% at 20 ºC, 67% at 10 ºC, and 13% at 1 ºC. The color of harvested broccoli evolved in two different stages. During phase I, immediately following harvest, color remained unchanged, whereas during subsequent phase II, the hue angle declined and chroma and lightness increased. Storage temperature affected the duration of phase I and rate of color changes during phase II. In contrast, 1-MCP increased the duration of phase I, but did not affect the rate of color changes during phase II. The results indicate that there is little practical benefit to 1-MCP application at 20 ºC and 0 ºC. However, at 10 ºC, typical of retail temperatures, the use of 1-MCP contributed to the maintenance of postharvest quality of broccoli.

INTRODUCTION

The postharvest life of broccoli is short, limited by yellowing, water loss, decay, and off-odor development. At ambient temperature (20 ºC), unacceptable degreening occurs within 2 or 3 days after harvest. Precooling soon after harvest using hydrocooling or package icing and storage at 0 ºC effectively maintains broccoli quality and extends storage life. With appropriate temperature management, broccoli can be stored for more than 2 weeks (Hardenburg et al., 1986).

Yellowing of the sepals of broccoli florets, a process associated with chlorophyll degradation, is accelerated by exogenously applied and endogenously produced ethylene (Tian et al., 1994; Fan and Mattheis, 2000). Thus, treatments that reduce ethylene synthesis or inhibit its perception by the plant tissues should be effective supplements to low-temperature storage, contributing to preserve postharvest quality.

The ethylene action inhibitor 1-methylcyclopropene (1-MCP), reduces the respiration rate, slows the rate of yellowing, and extends the storage life of broccoli, even if the presence of exogenous ethylene (Ku and Wills, 1999; Fan and Mattheis, 2000). The treatment with 1-MCP is effective at concentrations as low as 0.01 μl·L^{-1} for a 12-h exposure, even in the presence of 1 μl·L^{-1} of ethylene (Fan and Mattheis, 2000).

Since both temperature and ethylene affect the rate of senescence of broccoli, we evaluated the effectiveness of 1-MCP as a supplement to low-temperature storage in preserving the appearance of harvested broccoli.

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MATERIALS AND METHODS

Broccoli (*Brassica oleracea* var. *italica* 'Marathon') heads were harvested, immediately placed in sealed buckets in the field, and treated with 2 $\mu l \cdot L^{-1}$ of 1-MCP for 6 h. 1-MCP was generated from EthylBloc® (Floralife, Burr Ridge, Illinois). After treatment, the heads were transported to the laboratory, cut into 2-cm branchlets, placed in folded, unsealed, plastic bags and stored in the dark at 1, 10, and 20 ºC. Untreated controls were handled and stored in the same way. Three plastic bags containing 250 to 350 g of branchlets were used per treatment.

Overall appearance of broccoli branchlets was subjectively assessed by rating the samples from 1 to 5 according to the hedonic scale adapted from Ku and Wills (1999), where 5 was fresh and green, 4 had about 10% yellowing, 3 had 30% yellowing, 2 had 50% yellowing or moderate rotting, and 1 had more than 50% yellowing or severe rotting.

Color and fresh weight were measured throughout the storage period. The surface color of the florets was measured in the CIELAB space with a Minolta CR-300 chroma meter, equipped with a D_{65} illuminant and an 8-mm measuring head. Color of each of 3 samples was measured in 3 branchlets selected at random from the sample. Results are expressed as hue angle (hº), chroma (C*) and lightness factor (L*). For the heads stored at 1 °C, the branchlets with obvious fungal development were removed from the sample, in order to study color development.

RESULTS AND DISCUSSION

Appearance During Storage and Duration of Storage Life

Temperature had a strong effect on changes in appearance during storage (Fig. 1) and on the potential duration of storage life (Table 1). The appearance of broccoli branchlets stored at 20 ºC suffered little change during the first 48 h after harvest, and declined rapidly afterward. Broccoli treated with 1-MCP and stored at 20 ºC for 3 days was rated 4 (acceptable), whereas untreated samples were rated 3 (unacceptable). Despite dehydration and browning of the cut area of the stem, the subjective appearance of the florets of untreated broccoli stored at 10 and 1 ºC only declined after 10 and 66 days in storage, respectively (Fig. 1). The postharvest life of the branchlets stored at 20 and 10 ºC was terminated by sepal yellowing, whereas at 1 ºC, decay was the limiting factor.

Treatment with 1-MCP resulted in an increase of storage life of 50% at 20 ºC and 67% at 10 ºC (Table 1). The effect of 1-MCP treatment on broccoli stored at 1 ºC was modest, since decay, not senescence, was the limiting factor in storage life at this temperature. In fact, fungal growth was first noticed in both 1-MCP-treated and untreated samples around 29 days after harvest. The actual storage life of broccoli at 1 ºC was about 1 month, but it can be extended to approach the potential storage life indicated in Table 1, if appropriate sanitation practices are followed to reduce pathogen inoculum.

Postharvest Color Development

Postharvest changes in color of 'Marathon' broccoli florets were characterized by a decrease in hue angle, reflecting the transition from green to yellow, in parallel with an increase in chroma, reflecting the loss of the grayish green color of this cultivar, and an increase in lightness. Branchlets first judged unacceptable for consumption had hº ≈110 º.

The average hue angle of broccoli florets at the beginning of the storage period was 125.1 ± 0.7 º (Fig. 2A). The rate of hue angle decline (yellowing) of broccoli branchlets stored at 20 ºC was slow during the first 48 h after harvest, and increased markedly between 48 and 72 h. Similar patterns of hue angle decline have been described for broccoli stored at 20 ºC (Tian et al., 1994; King and Morris, 1994). At 10 ºC the hue angle of untreated broccoli remained constant for 8 days but decreased rapidly thereafter (Fig. 2A), a pattern similar to that observed by Fan and Mattheis (2000). At 1 ºC a slow decline in hue angle started after 40 days in storage. Treatment with 1-MCP delayed the beginning of hue angle decline. Untreated broccoli reached a hue angle of 110 º in 2.6, 15.1, and 75.2 days, at 20, 10, and 1 ºC, respectively. 1-MCP-treated broccoli needed 3.4, 22.9, and 97.3 days to reach the same hue at 20, 10, and 1 ºC, respectively.

Senescing broccoli florets lose their green hue and grayish appearance, as they turn yellow. Initial chroma was 11.2 ± 0.8 and increased during senescence (Fig. 2B). Fan and Mattheis (2000) also reported increases in C* during senescence of broccoli florets and a significant effect of 1-MCP in delaying chroma alterations. L* also increased during senescence, in a way that parallels the increase in C* (Fig. 3).

The rate of color change was not uniform throughout the storage period; instead it followed a biphasic pattern (Fig. 4A). For a period of time following harvest color remained almost unchanged (phase I), after which time it changed rapidly (phase II) as the sepals turned yellow. Temperature affected color development by influencing the duration of phase I, and the rate of color change during phase II (Fig. 4B). On the other hand, 1-MCP prolonged phase I, but had little effect on the rate of color changes during phase II (Fig. 4C). The resumption of normal yellowing after an extended phase I in 1-MCP-treated samples may indicate that the plant tissue became sensitive to ethylene due to de novo synthesis of ethylene receptors or to reversible 1-MCP binding to the existing receptors. Alternatively, these results may indicate that ethylene influenced the duration of phase I of color development, but once degreening has started (phase II), the rate of yellowing was independent of ethylene. In agreement with the latter interpretation, Tian et al. (1994) showed that treating broccoli branchlets with 0.5% propylene accelerates the beginning of decline in hue angle of broccoli stored at 20 ºC when the exposure to propylene occurred within 24 after harvest; in contrast, when broccoli was kept for more than 48 h in air before the exposure to propylene and degreening had already started, propylene does not affect the rate of hue angle decline. Either broccoli sepals are not sensitive to ethylene during phase I, or it takes a time period from the perception of ethylene before yellowing occurs (as suggested by Tian et al., 1994), during which the metabolic processes involved in yellowing progress before color change is detected (Fan and Mattheis, 2000). Alternatively, the tissue where net chlorophyll degradation is occurring has reduced ability to respond to ethylene (Tain et al., 1994).

Changes in Fresh Weight During Storage

The decline in broccoli fresh weight is represented in Fig. 5. Treatment with 1-MCP had no effect on fresh weight loss; therefore mean values of treated and untreated samples are presented for each storage temperature. Fresh weight decreased during storage at an average rate of 1.82, 0.23, and 0.03 $\%\cdot day^{-1}$, for broccoli stored at 20, 10, and 1 ºC, respectively. Under these conditions, broccoli branchlets lost 5% of their initial fresh weight in 3 and 19 days at 20 and 10 ºC, respectively. Branchlets stored at 1 ºC for 3 months lost only 3 % of their initial fresh weight. Under the conditions of our assay, water loss was not limiting of storage life.

CONCLUSION

The practical benefits of 1-MCP are limited at ambient temperature (>20 ºC) and at the temperatures near 0 ºC, optimal for prolonged storage of broccoli. At intermediate temperatures (5 – 15 ºC), the use of 1-MCP is likely to significantly delay the depreciation of appearance during storage, handling, transportation and retail marketing. 1-MCP has the potential to become a useful tool in postharvest handling of broccoli, should it become approved for usage in vegetables.

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Tables

Table 1. Potential storage life of 1-MCP treated and untreated broccoli branchlets stored at different temperatures.

Storage temperature (ºC)	Storage life (days)		Storage life variation (%)
	Untreated	Treated with 1-MCP	
20	2	3	50
10	12	20	67
1	76	86	13

Figures

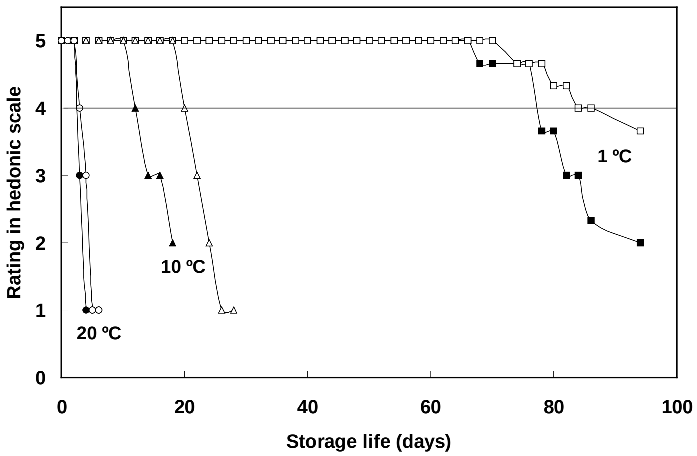

Fig. 1. Evolution of the appearance of broccoli branchlets during storage at 20, 10, and 1 ºC. Values are means of 3 replications.

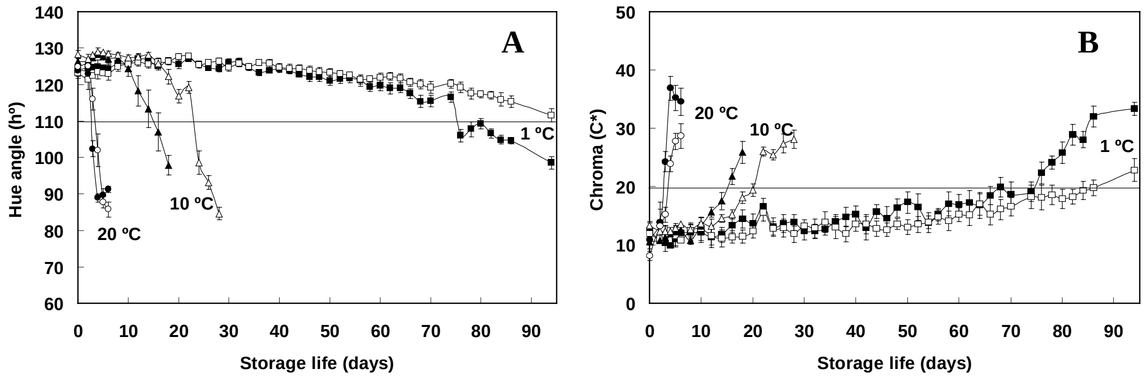

Fig. 2. Hue angle (A) and chroma (B) of 1-MCP-treated (○△□) and untreated (●▲■) broccoli florets stored at 20 (○●), 10 (△▲), and 1 ºC (□■). The lines hº = 110 º and C* = 20 represent the values at which broccoli florets were considered to be unacceptably yellow. Values are means ± SE, n=3.

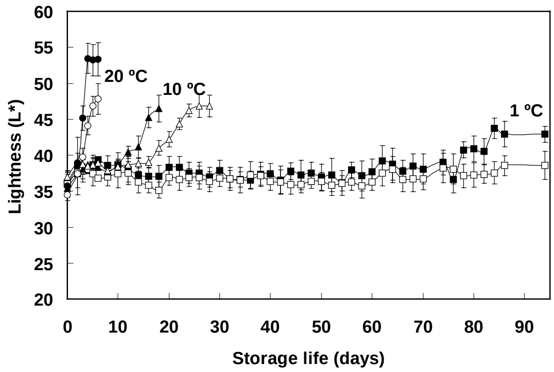

Fig. 3. Lightness of 1-MCP-treated (○△□) and untreated (●▲■) broccoli florets stored at 20 (○●), 10 (△▲), and 1 ºC (□■). Values are means ± SE, n=3.

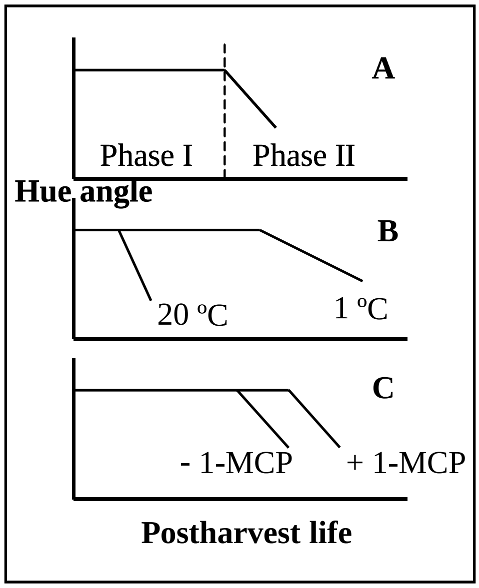

Fig. 4. Schematic representation of the effect of temperature and 1-MCP on color development in broccoli. (A) biphasic pattern of color development, (B) effect of temperature, and (C) effect of 1-MCP.

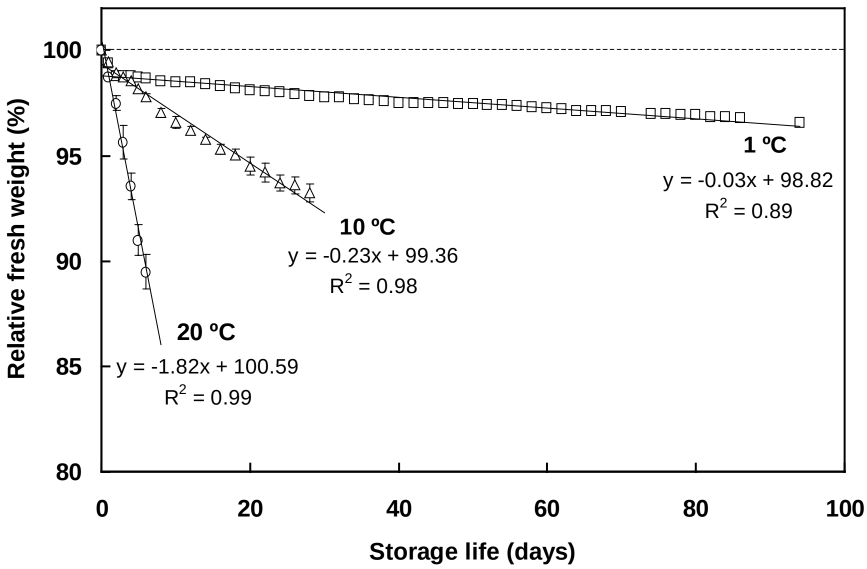

Fig. 5. Relative fresh weight of broccoli stored at 20, 10, and 1 ºC, inside folded plastic bags. Values are means of 1-MCP-treated and untreated samples ± SE, n=6. When not shown, the bars are contained within symbols.