

Influence of 1-methylcyclopropene on the longevity of potted ornamental peppers

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ABSTRACT: Exposure to ethylene is one of the main factors compromising the quality and shelf life in the post-production phase of potted ornamental plants and flowers in general. In preliminary tests to determine the desirable characteristics of a potted ornamental pepper (*Capsicum annuum* L.), the accession BGH 1039, from the Vegetable Germplasm Bank of the Federal University of Viçosa, was highlighted. However, this accession was sensitive to ethylene. Thus, this study aims to evaluate the influence of 1-methylcyclopropene (1-MCP) in extending the longevity of potted ornamental pepper. Potted peppers were placed in separate 60-L sealed chambers for the control, 1-MCP and ethylene treatments. To evaluate the quality and post-production shelf life, plants of all treatments were kept at 25 ± 1 °C under white fluorescent light with an intensity of $8-10 \mu\text{mol s}^{-1} \text{m}^{-2}$ and 60-65% relative humidity and watered whenever necessary. In plants treated with $10 \mu\text{L L}^{-1}$ of ethylene for 48 h, there was a reduction in the content of chlorophyll a and in total chlorophyll. Pre-treatment with $1 \mu\text{L L}^{-1}$ of 1-MCP followed by the application of $10 \mu\text{L L}^{-1}$ of ethylene for 48 h was effective in maintaining the green coloration of the leaves and in reducing leaf and fruit abscission over the 18 days of shelf life, demonstrating the efficiency of this product in blocking the action of ethylene. 1-MCP improved the quality and commercial durability of potted BGH 1039 ornamental pepper.

Key words: *Capsicum annuum* L.; chlorophyll; ethylene; leaf abscission; 1-MCP

Influência do 1-metilciclopropeno na longevidade de pimenta ornamental de vaso

RESUMO: A exposição ao etileno é um dos principais fatores que comprometem a qualidade e tempo de prateleira na fase de pós-produção de plantas e flores ornamentais em geral. Em ensaios preliminares para determinação de características desejáveis para pimentas ornamentais em vaso, o acesso BGH 1039 (*Capsicum annuum* L.) do banco de Germoplasma de Hortaliças da Universidade Federal de Viçosa obteve destaque, no entanto, apresentou-se sensível ao etileno. Desta forma, este trabalho teve como objetivo avaliar a influência da utilização de 1-MCP em estender a longevidade de pimenta ornamental em vaso. Pimentas em vasos foram colocadas em câmaras seladas de 60 L para os tratamentos controle, 1-MCP e etileno. Para avaliação da qualidade e vida de prateleira pós-produção, plantas de todos os tratamentos foram mantidas a 25 ± 1 °C sob luz fluorescente branca com intensidade de $8-10 \mu\text{mol s}^{-1} \text{m}^{-2}$, umidade relativa de 60-65% e regadas quando necessário. Nas plantas tratadas com $10 \mu\text{L L}^{-1}$ de etileno durante 48 h houve redução do conteúdo de clorofila a e clorofila total. O pré-tratamento com $1 \mu\text{L L}^{-1}$ de 1-MCP seguido de $10 \mu\text{L L}^{-1}$ de etileno por 48 h foi eficaz na manutenção da coloração verde das folhas e na redução da abscisão de folhas e frutos ao longo dos 18 dias de vida de prateleira, demonstrando a eficiência deste produto em bloquear a ação do etileno. O 1-MCP melhora a qualidade e a durabilidade comercial da pimenta ornamental BGH 1039 em vaso.

Palavras-chave: *Capsicum annuum* L.; clorofila; etileno; abscisão foliar; 1-MCP

Introduction

The species of the genus *Capsicum* have a wide genetic variability and can be used for different purposes. Within this genus, plants of the species *Capsicum annuum* are the most cultivated and have greater genetic variations (Carvalho & Bianchetti, 2008). The cultivation of potted ornamental peppers has expanded and this has become a new trend for the Brazilian and international consumer markets. The commercial success of the crop depends on characteristics such as quality, vigor, color, shape and size of the leaves and fruit (Costa et al., 2015). When used for pottery ornamentation, the plant must adapt in small containers, have a compact structure and a long post-production or shelf life (Pinto et al., 2010).

Several biotic and abiotic factors affect vase life and post-production quality in potted plants, but, in general, exposure to ethylene is one of the most important (Segatto et al., 2013). According to Finger et al. (2015), to improve post-production life, it is necessary to block the ethylene receptors before exposing the plant to ethylene during shipping, storage and sale retailing or when the plant is subject to any stress that might induce ethylene production.

Ethylene is a developmental regulator that operates in manifold physiological processes in all the tissues throughout the plant life cycle (Van de Poel et al., 2015). It also regulates growth and senescence depending on its concentration, the timing of application and the plant species (Khan et al., 2008; Iqbal et al., 2017). In general, exposure to ethylene during greenhouse production, shipping and retailing can reduce the shelf life of ornamental plants (Jones & Ling, 2012) because ethylene triggers a series of deleterious responses, including leaf yellowing caused by chlorophyll degradation and its impaired biosynthesis, abscission of fruits and leaves and acceleration of the senescence process (Iqbal et al., 2017).

The use of ethylene action inhibitors is generally more effective for increasing the post-harvest longevity of ornamental plants because they block the effect of the exogenous ethylene present in the storage atmosphere during the transportation and marketing of the product (Porat et al., 1995). Among cyclopropenes, 1-methylcyclopropene (1-MCP) is the most useful compound for this purpose, as it is non-toxic, stable at room temperature and active at relatively low concentrations and provides protection over a long period (Finger & Barbosa, 2006). However, the degree of effectiveness of 1-MCP in blocking the ethylene action varies according to the plant species, stage of development, plant maturity, concentration, length of treatment and temperature during treatment (Blankenship & Dole, 2003).

The use of inhibitor treatments affects the ethylene signaling pathway at different levels and collectively reveals an intricate network of interactions, as exemplified by numerous studies of senescence in flowers (e.g. in the review of Ferrante et al. (2015)). Studies are currently being conducted on the post-production of ornamental potted peppers (Segatto et al., 2013; Finger et al., 2015; Lima et al., 2017) and other species such as gentian and inflorescences of *Oncidium*

varicosum (Shimizu-Yumoto & Ichimura, 2012; Mattiuz et al., 2012).

Plant responses to ethylene vary considerably both between and within species and are modulated by differential hormonal sensitivity. Furthermore, the exposure of sensitive plants to ethylene induces symptoms of premature senescence (Iqbal et al., 2017). A preliminary study determined that the accession BGH 1039 presents desirable characteristics as an ornamental plant but is sensitive to ethylene, which reduces its post-production life due to chlorophyll degradation and leaf and flower abscission (Segatto et al., 2013).

In view of the great potential of using 1-MCP as an ethylene action inhibitor and its intraspecific variable sensitivity to ethylene, this study proposes to evaluate the efficiency of 1-MCP in extending the longevity and marketing potential of the accession BGH 1039.

Material and Methods

Seeds from the accession BGH 1039 (*Capsicum annuum* L.) were sown in flats with single cells and transplanted to 760-mL plastic pots when the plantlets had four to five true leaves. Pots containing one plantlet each were filled with the commercial substrate, Tropistrato HT[®], with a composition of pine bark, vermiculite, superphosphate and potassium nitrate (Vida Verde, LOT 14072106) and these were grown in a greenhouse for four months until they were ready for commercial sale. Pots were fertilized every 20 days with 10 g of NPK 10-10-10 and monthly with a diluted solution containing 150 g L⁻¹ of commercial Ouro Verde Fertilizer[®] (15-15-20 NPK + Ca, S, Mg, Zn, B, Fe and Mn) (Bunge, Sao Paulo, Brazil).

Upon reaching the commercial stage for sale, in accordance with Ribeiro et al. (2015), with 50% of the plants in the population showing at least 30% of fully ripe fruit (typical shape for each material, color demanded by the market and no wilting), the plants were taken to the Postharvest Physiology Laboratory of the Federal University of Viçosa, where they were treated with 1-MCP.

Pots were then placed in separate 60-L sealed chambers for the control two, 1-MCP, and ethylene treatments, following the methodology of Segatto et al. (2013). To evaluate the quality and post-production life, the plants of all treatments were kept at 25±1 °C under white fluorescent light with an intensity of 8-10 μmol s⁻¹ m⁻² and 60-65% relative humidity and watered whenever necessary (Finger et al., 2015). Plants were treated with 10 μL L⁻¹ of ethylene for 48 h, fumigated with 1 μL L⁻¹ of 1-MCP for six hours and treated with 1 μL L⁻¹ of 1-MCP for six hours followed by 10 μL L⁻¹ of ethylene for 48 h. Two controls were established. In control one, plants were kept on a laboratory bench, and in control two (control chamber), plants were kept inside 60-L containers for 48 h. In total, there were five treatments.

The chlorophyll and carotenoid contents before and after treatment were evaluated according to the method of Lichtenthaler (1987), with modifications. Subsequently, the values of the chlorophyll and carotenoid contents were

converted to mg.dm² on the leaf surface. The degree of the green color of the leaves was evaluated using the SPAD-502 instrument (Minolta Co. Ltd) on three of the leaves of each plant (from the base, the center and the top of the plant) and the average of the determinations was considered. Leaf and fruit abscissions were determined every three days by counting the total leaves during the entire period of shelf life, expressed as a percentage of the initial leaf count. The end of the longevity period occurred when the plants no longer had a commercial value: when there was 50% leaf and fruit abscission and/or 50% yellowing of leaves (Finger et al., 2015).

Pots were arranged in a randomized complete block design with five replicates of one pot each, totaling 25 pots. Chlorophylls *a*, *b* and total chlorophyll and carotenoid data were analyzed statistically using analysis of variance (ANOVA) and the significance among the treatments was evaluated using Student's t-test at $P \leq 0.05$. The average of the other analyzed parameters was subjected to the standard error of the mean ($n=5$) and SigmaPlot software was used for the data analysis and graph design.

Results and Discussion

In the plants treated with 10 $\mu\text{L L}^{-1}$ of ethylene for 48 h, there was a reduction of chlorophyll *a* and total chlorophyll contents (Table 1). The sensitivity of ornamental plants to ethylene was roughly established at a family level, but there were differences between the species and cultivars (Serek et al., 2006). As previously shown by Segatto et al. (2013) and Lima et al. (2017), in the post-production stage, some cultivars of ornamental peppers have different levels of sensitivity to ethylene. According to the results of Segatto et al. (2013), the accession BGH 1039 is more sensitive to the degradation of chlorophyll in the presence of ethylene. To improve the post-production life, it is necessary to block the receptors before exposing the plants to ethylene during transportation, storage and retail sales (Finger et al., 2015). Ethylene signaling may play an important role in regulating the expression of genes associated with chlorophyll degradation (Xie et al., 2017), promoting increases in chlorophyllase and oxidase enzyme activities that catalyze chlorophyll degradation, converting chlorophylls *a* and *b* to phytol and chlorophyllide (Ferrante & Francini, 2006).

In the controls, 1-MCP and 1-MCP + ethylene treatments, there was no reduction in chlorophyll content (Table 1). Hassan (2016) observed that 1-MCP treatment reduced ethylene production and significantly slowed the degradation of the chlorophyll and carbohydrate contents during the pot life of rose cultivars. 1-MCP has been effective in blocking the negative effects of ethylene on the flowers of roses, geranium, *Phalaenopsis*, clove and gentian varieties (Shimizu-Yumoto & Ichimura, 2012). Its application prior to exposure to ethylene blocks the receptors, preventing its action and the subsequent yellowing and leaf abscission (Finger et al., 2015). In several studies with flowers, 1-MCP had the greatest effect in inhibiting the deleterious action of ethylene when

Table 1. Concentrations of chlorophylls *a* and *b*, total chlorophyll and carotenoids in leaves of ornamental pepper (*Capsicum annuum*) accession 'BGH 1039' before and after treatment with 1-MCP, 1-MCP + 1-ethylene, ethylene and controls (control 1: plants kept for 48 h in closed containers; control 2: plants kept on a bench under white fluorescent light).

Treatment	Control 1	Control 2	1-MCP	1-MCP+ Ethylene	Ethylene
Chlorophyll a (mg dm ⁻²)					
Before	6.25	6.57	6.75	6.54	6.38
After	5.66 ^{ns}	6.14 ^{ns}	6.25 ^{ns}	6.02 ^{ns}	4.76*
Chlorophyll b (mg dm ⁻²)					
Before	1.95	2.20	2.04	1.85	2.28
After	1.69 ^{ns}	1.93 ^{ns}	1.75 ^{ns}	1.96 ^{ns}	1.95 ^{ns}
Total chlorophyll (mg dm ⁻²)					
Before	8.20	8.77	8.79	8.39	8.67
After	7.35 ^{ns}	8.07 ^{ns}	8.00 ^{ns}	7.48 ^{ns}	7.06*
Carotenoids (mg dm ⁻²)					
Before	1.11	0.92	1.13	0.96	1.03
After	0.99 ^{ns}	1.09 ^{ns}	1.28 ^{ns}	0.89 ^{ns}	1.23 ^{ns}

* , ns, significance at 5% and no significance for means before and after treatment of ornamental pepper by Student's t test, respectively.

applied prior to exposure to the hormone. The beneficial effect decreased when 1-MCP is applied either together with or after ethylene treatment (Bankenship & Dole, 2003).

The treatments did not affect the carotenoid content (Table 1). Ilić et al. (2017) found that green pepper cultivars treated with 1-MCP maintained the carotenoid contents practically unchanged when compared with the beginning of fruit storage. Carotenoid accumulation that is induced by ripening seems to be regulated by endogenous ethylene that controls the expression of the key genes correlated with the carotenoid content (Wisutiamonkul et al., 2017).

The intensity of the green color of the leaf was maintained throughout the evaluation days in plants treated with 1-MCP and 1-MCP + ethylene and was superior to both controls (Figure 1), thus, demonstrating the effectiveness of this

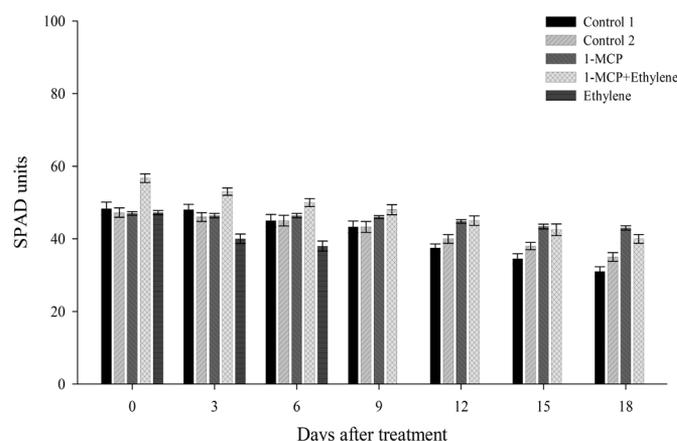


Figure 1. Changes in the leaf chlorophyll content, in SPAD units, of ornamental pepper (*Capsicum annuum* L.) accession 'BGH 1039' after treatment with 1-MCP, 1-MCP + ethylene, ethylene and controls (control 1: plants kept for 48 h in closed containers; control 2: plants kept on a bench under white fluorescent light). Values are mean (\pm standard error) ($n=5$).

substance in blocking the action of ethylene. Treatment with 1-MCP reduced the rates of ethylene production and delayed the yellowing and softening of the fruit of two pear cultivars stored under controlled atmospheric conditions (Lum et al., 2017). Similarly, 1-MCP prevented the degradation of chlorophyll and, consequently, the senescence and yellowing of broccoli florets (Fernández-León et al., 2013; Xu et al., 2016).

Plants treated with 1-MCP and 1-MCP + ethylene had the lowest rate of leaf abscission during the post-production period (Figure 2A) and, after 18 days, only 13% and 16% of the leaves had dropped, respectively. While the control plants presented 33% of the abscission, those treated with ethylene showed more than 50% (Figure 2B). This result shows that even in the absence of exogenous ethylene, 1-MCP was efficient in prolonging the conservation of the ornamental pepper plants. Simulating transportation conditions in Brazil, Cavatte et al. (2013) observed that the fumigation of the

ornamental pepper plants with $1 \mu\text{L L}^{-1}$ of 1-MCP prevented chlorophyll and carotenoid degradation in the absence of light or under low irradiance conditions. In addition, storing the plants in the dark at $35 \text{ }^\circ\text{C}$ for 48 h induced the abscission of 79.7% of the leaves but when 1-MCP was applied, this rate was reduced to 9.4%.

The treatments with 1-MCP and 1-MCP + ethylene were also effective in reducing fruit abscission compared with the plants treated with ethylene alone and the control plants (Figures 2C and 2D). After 18 days of shelf life, the ethylene treatment had about 75% of total fruit abscission, while in the treatments with 1-MCP, both with and without ethylene, there was still no fruit drop. Lima et al. (2017) noted that ethylene treatment at a concentration of $10 \mu\text{L L}^{-1}$ for 48 h induced leaf abscission in the Calypso and MG 302 cultivars. However, when the same dose of 1-MCP was applied, the blocking of all the ethylene receptors did not occur, resulting in leaf abscission. In the same study, fruit abscission remained low throughout

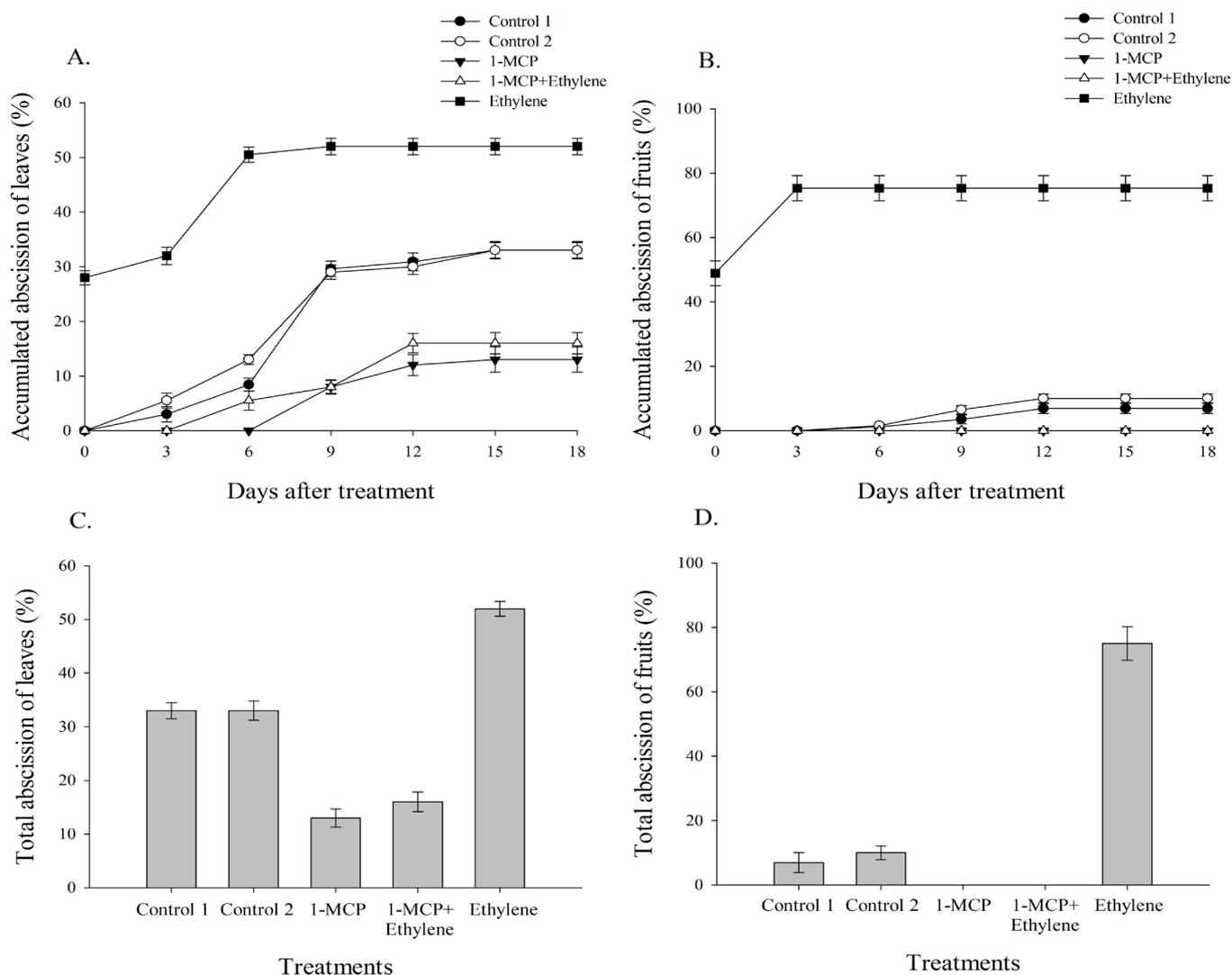


Figure 2. Accumulated abscission of leaves and fruits (A and C) and total abscission of leaves and fruits (B and D) of ornamental pepper (*Capsicum annuum*) accession 'BGH 1039', after treatment with 1-MCP, 1-MCP + ethylene, ethylene and controls (control 1: plants kept for 48 h in closed containers; control 2: plants kept on a bench under white florescent light). Values are mean (\pm standard error) (n=5).

the evaluation in all the treatments tested. The efficacy of 1-MCP in extending shelf life varies with species and varieties, stages of maturity, temperature, concentration and duration of exposure (Phebe & Ong, 2010). Different genotypes may present varying percentages of abscission that are linked to ethylene sensitivity (Santos et al., 2013).

Pre-treatment with 1-MCP was effective in blocking the action of ethylene, preserving the green coloration of the leaves (Figure 3) and decreasing leaf abscission. Similar results were obtained in the plants treated exclusively with 1-MCP (Figure 2). Therefore, the application of 1-MCP prior to exposure to ethylene was effective in inhibiting the action of ethylene. The application of $10 \mu\text{L L}^{-1}$ of ethylene for 48 h was not sufficient for the synthesis of new binding sites or removal of 1-MCP after 18 days of shelf life, demonstrating the high affinity of this compound to the ethylene receptor. 1-MCP binds to the ethylene receptors with a half-life of diffusion that is between seven and 12 days, compared with two to 10 minutes for ethylene (Sisler & Serek, 1997, 1999). This diffusion time suggests that the binding of 1-MCP to the ethylene receptor is practically irreversible (Serek et al., 1994; Sisler & Serek, 1997). However, once the 1-MCP receptor complex is metabolized, the process is reversed with the synthesis of new receptors.

Using 1-MCP, both alone and prior to the application of ethylene, reduced the leaf and fruit abscission of the BGH 1039 accession, in addition to maintaining the green coloration for longer, which led to better results than those produced

in the controls. These results demonstrate that 1-MCP was actually effective in blocking the undesirable effects caused by ethylene, and even in the absence of exogenous ethylene 1-MCP was efficient in the prolonged conservation of ornamental pepper plants.

The buildup of ethylene in the atmosphere occurs mainly during transportation and retail sales, and these effects are increased by the stresses (Sá et al., 2008) caused by the responses to ethylene, which are themselves influenced by environmental factors, including light (Zhong et al., 2012). Plants treated with only 1-MCP showed superior longevity to the BGH 1039 control plants (Figures 2 and 3). This suggests that the low irradiance ($8\text{-}10 \mu\text{mol s}^{-1} \text{m}^{-2}$) provided to the plants were kept inside the chamber induced the production of ethylene and the pre-treatment with 1-MCP was effective in inhibiting the action that the hormone produced as a result of the light stress.

In conclusion, 1-MCP has great potential for the control of ethylene activity in the post-production of many plants and ornamental flowers, maintaining the quality of these products during temporary storage, transportation and lengthy periods of exposure in stores and supermarkets before reaching the final consumers.

Conclusion

Pre-treatment with $1 \mu\text{L L}^{-1}$ of 1-MCP followed by the application $10 \mu\text{L L}^{-1}$ of ethylene for 48 h was effective in maintaining the green coloration of leaves and in reducing leaf and fruit abscission over the 18 days of post-production life, demonstrating the efficiency of this product in blocking the action of ethylene. 1-MCP improved the quality and commercial durability of potted ornamental pepper.

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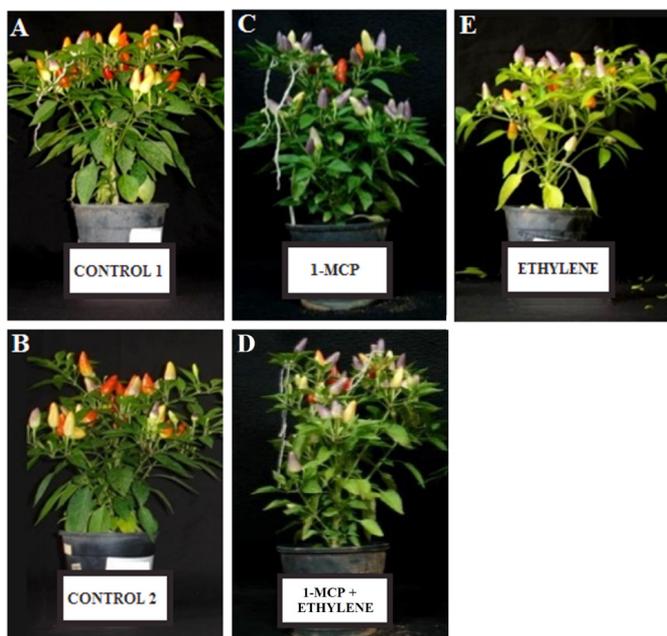


Figure 3. Appearance of ornamental pepper (*Capsicum annuum*) accession 'BGH 1039' after remaining nine days on a bench. A and B- controls (control 1: plants kept for 48 h in closed containers; control 2: plants kept on a bench under white florescent light), C- after treatment with 1-MCP, D- after treatment with 1-MCP + ethylene for 48 h and E- after treatment with ethylene for 48 h.

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