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Ethylene impacts the physiological quality and the longevity of potted ornamental peppers

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Abstract
Ethylene triggers several deleterious responses on ornamental plants. This investigation aimed to evaluate several physiological responses to ethylene on the post-production of potted ornamental pepper cultivars. Plants of the 'Espaguetinho', 'Etna', 'Peppa' and 'Karneval' cultivars were grown in pots. When they reached the appropriate commercial stage, that is, 50% of the plants in a population showed at least 30% fully ripe fruits, they were treated as follows. Plants were subjected to external control, internal control, and exposure to 10 µL L^{-1} ethylene for 48 h. 'Etna' exhibited an intermediate response to the exposure to 10 µL L^{-1} ethylene for 48 h. 'Espaguetinho', 'Peppa' and 'Karneval' were classified as highly sensitive to ethylene, with discard on the first day of shelf life. The leaves from all cultivars showed a strong response to ethylene than the fruits. This study revealed different levels of sensitivity to ethylene depending on the cultivars and species. The exposure to 10 µL L^{-1} ethylene for 48 hours affects the quality and the longevity of the pepper cultivars evaluated, drastically reducing the shelf life. This study thus paves the way for further investigations to reduce ethylene responses, extending the shelf life in the post-production phase of pepper cultivars.

Keywords: Abscission; *Capsicum* spp.; longevity.

O etileno afeta a qualidade fisiológica e a longevidade dos pimentos ornamentais em vaso

Resumo
O etileno desencadeia diversas respostas deletérias em plantas ornamentais. Esta investigação teve como objetivo avaliar as respostas do etileno na pós-produção de cultivares de pimenta ornamental em vasos. As plantas das cultivares 'Espaguetinho', 'Etna', 'Peppa' e 'Karneval' foram cultivadas em vasos e ao atingirem a fase de comercialização, ou seja, 50% das plantas com pelo menos 30% dos frutos totalmente maduros, foram submetidas aos tratamentos: controle externo, controle interno e exposição a 10 µL L^{-1} de etileno durante 48 horas. 'Etna' exibiu resposta intermediária à exposição a 10 µL L^{-1} de etileno por 48 horas. 'Espaguetinho', 'Peppa' e 'Karneval' foram classificados como altamente sensíveis ao etileno, com descarte no primeiro dia de vida útil. As folhas de todas as cultivares mostraram maior resposta ao etileno do que os frutos. A exposição a 10 µL L^{-1} de etileno por 48 horas afetou a qualidade e a longevidade das cultivares de pimenta avaliadas, reduzindo drasticamente a vida de prateleira. Este estudo permite, portanto, novas investigações de forma a reduzir as respostas ao etileno, prolongando a vida útil na fase de pós-produção das cultivares de pimenta.

Palavras-chave: Abscisão; *Capsicum* spp.; longevidade.

Introduction

Plants of the genus Capsicum have wide genetic variability, with considerable potential for commercialization as ornamental potted plants. However, the ornamental quality and longevity of ornamental pepper plants are often interrupted by processes inherent in ethylene action (Lima et al., 2017; Ribeiro et al., 2019).

Given its manifold physiological processes, ethylene controls several aspects of plant physiology by stimulating or inhibiting processes such as growth and senescence (Nazar et al., 2014; Iqbal et al., 2017). However, the process may depend on ethylene concentration, application timing, and plant species (Iqbal et al., 2017). The response to ethylene occurs by binding the hormone to a specific receptor responsible for sending a signal for its activation.

This is accompanied by the activation of several genes responsible for inducing tissue senescence (Blankenship and Dole, 2003; Iqbal et al., 2017). The sensitivity of plant tissues or organs may be related to the synthesis of new binding sites that allow ethylene to act (Blankenship and Dole, 2003).

The Capsicum genus has different levels of sensitivity to ethylene (Lima et al., 2017; Ribeiro et al., 2019). Among *Capsicum* species, different organs of the same plant, that is, leaves, flowers, and fruits, have shown several ethylene responses (Ribeiro et al., 2019). Considerable progress has been made in Brazil towards elucidating the effects of ethylene on ornamental pepper plants. Lima et al. (2017) identified a high level of sensitivity in the cultivar 'Calypso' when it was exposed to 10 μL L^{-1} of ethylene. The 'Calypso' pepper plants had complete abscission of the leaves for 48 h while 'MG 302' showed intermediate sensitivity to ethylene with the same concentration and timing. Ribeiro et al. (2019) reported different organ sensitivity in 'Pimenta colorida,' showing moderate sensitivity to 10 μL L^{-1} of ethylene in the flowers and highly leaf sensitivity to the same concentration after 48 h.

To date, most of these studies on the responses of ornamental peppers to ethylene have focused on the evaluation of genotypes from pepper germplasm banks (Segatto et al., 2013; Lima et al., 2017; Ribeiro et al., 2019), with most of the materials being examined not yet being marketed. However, few studies have focused on determining the levels of sensitivity to ethylene of potted commercial pepper cultivars already available on the markets, including those previously selected for their ornamental excellence. This has included cultivars such as `Espaguetinho`, `Stromboli` and `Etna` which are offered by some companies, i.e., Isla Sementes, Brazil [7]. Cultivars such as Peppa and Karnival, Prairie Fire or Numex Centennial, that are available in flower and virtual seed shops also remain to be examined (Costa et al., 2019).

The current investigation was thus designed to access the level of sensitivity to ethylene of some ornamental pepper cultivars, providing a better understanding of the ethylene effects aiming to help breeders to develop improved materials that can tolerate ethylene exposure showing longer post-production shelf life, a decisive factor for high-quality production of many ornamental plants.

Hence, this investigation aimed to evaluate several physiological responses to ethylene on the post-production of potted ornamental pepper cultivars.

Materials and Methods

The investigation was carried out in a greenhouse and in the postharvest laboratory located at the Department of Phytotechnics of the Federal University of Viçosa, MG, Brazil. Four commercial ornamental pepper cultivars, namely, 'Espaguetinho' and 'Etna' (*Capsicum frutescens*) and 'Peppa' and 'Karneval' (*Capsicum annum*) were evaluated.

Seeds from the cultivars were sown in seedling trays filled with commercial substrate Bioplant® (composition: *Sphagnum* peat, coconut fiber, rice bark, pine bark and vermiculite). Seedlings with two to three pairs of leaves were transplanted into 760-mL plastic pots filled with commercial substrate Bioplant® and fertilized with 2.5 g of NPK 0-10-10 formulation (Ribeiro et al., 2019). Pots containing one seedling each were grown in a greenhouse, for 120 days until they were ready for commercial sale. Every 20 days plants were fertilized with 10 g of NPK 10-0-10 formulation and monthly with a diluted solution containing 150g L^{-1} of commercial Ouro Verde Fertilizer® 15-15-20 NPK + Ca, S, Mg, Zn, B, Fe, and Mn (Bunge, São Paulo, Brazil) (Lima et al., 2017; Araújo et al., 2019; Ribeiro et al., 2019).

Irrigation on the germination period was carried out once a day until water starts dripping on the bottom of the tray. From the transplanting to the initial establishment period, irrigation was performed daily with 150 mL water pot^{-1}. From the initial establishment period until the trial ends, irrigation was performed daily with 150 mL water pot^{-1} with casually leaf wetness.

Plants were taken to the laboratory at the ideal marketing point (Ribeiro et al., 2019), characterized by 50% of the plants showing at least 30% fully ripe fruits, visually determined (fruits with maximum growth size and typical shape of each species, with the specific color demanded by the plant and without wilting). Afterward, plants were submitted to the following treatments: external control, internal control and exposure to 10 μL L^{-1} of ethylene for 48 hours (Lima et al., 2017; Araújo et al., 2019; Ribeiro et al., 2019). For external and internal controls, 0 application was carried out. For external control, plants remained on a bench, inside a room during all trial. For internal control and exposure to 10 μL L^{-1} of ethylene treatments, the plants were stored in hermetically sealed 90-L chambers, for 48 hours, in the dark by Partial Transport Simulation (SPT). For quality evaluation and post-production life, the plants were transferred to an Interior Simulation Room (SSI) (malls, supermarkets and homes) at 20-25 °C and 7-10 μmol s^{-1} m^{-2} of fluorescent light for 12 hours. Three fully expanded mature leaves were taken at random from each plant (base, center and apex), and demarcated before the SPT. The evaluations were carried out before, immediately after the application of ethylene and every two days throughout the shelf life. The evaluations ended when the plants no longer showed commercial value (50% abscission of leaves and/or fruits or 50% yellowing of leaves).

The percentage of accumulated abscission of leaves and fruits was determined by counting the total number of leaves and fruits before and after the application of ethylene and every two days throughout the shelf life, being ended when plants no longer showed commercial value (Segatto et al., 2013). Only fully expanded leaves and all fruits with maximum growth size and typical shape of each species were considered, with the specific color required by the market and without wilting. The shelf life was determined by the days between the removal of the plants from the chambers until the day when they were commercially unsuitable. The sensitivity of leaves and fruits to ethylene was determined by the abscission percentage (AP). When AP ≤ 10 % = insensitive; 10 % < AP ≤ 50% = moderately sensitive and when AP > 50% = highly sensitive (Ribeiro et al., 2019).

The experiment was carried out in a randomized block design with five independent biological replicates (n = 5) of

one pot each. Data analysis was performed through descriptive analysis for each genotype over time. The average of the analyzed traits were submitted to the standard error of the average and *SigmaPlot* software was used for data analysis and graph design.

Results and Discussion

The findings of this study revealed that different peppers cultivars showed different levels of sensitivity to ethylene. Our categorization for ethylene sensitivity showed moderate to high sensitivity to exposure to 10 µL L^{-1} of ethylene for 48 hours for the four evaluated cultivars, showing greater responsiveness on the leaves compared to the fruits.

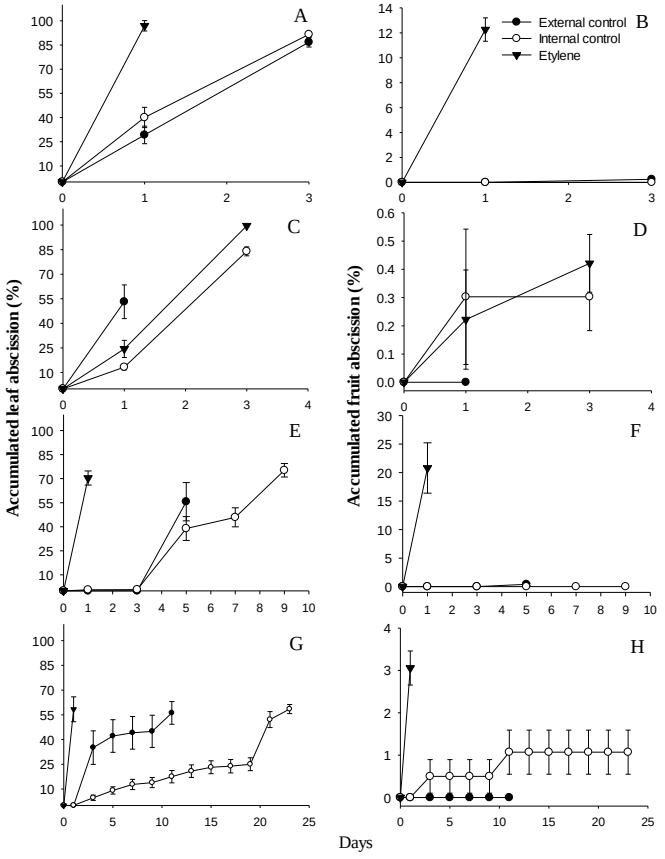

Figure 1. Percentage of accumulated leaf abscission of leaves (A - 'Espaguetinho'; C - 'Etna'; E - 'Peppa' and G - 'Karneval') and percentage of accumulated fruit abscission (B - 'Espaguetinho'; D - 'Etna'; F - 'Peppa' and H - 'Karneval'). Days 0 (zero) and 1 refers to before and immediately after the application of 10 µL L^{-1} of ethylene for 48 h. The vertical bars represent the standard error of the mean (n = 5).

For the *Capsicum frutescens* species, 'Espaguetinho' showed 96.9% of accumulated leaf abscission, associated with 12.3% of accumulated fruit abscission immediately after exposure to 10 µL L^{-1} of ethylene for 48 hours. Plants treated with ethylene were discarded on the first day of the shelf life, as they were unsuitable for commercialization, in contrast, to control plants that lasted three days on shelf life (Figures 1A e 1B). For control plants, ethylene production by the plants on the bench and the on the chamber were similar, both on leaves and fruits, at the 3rd day of shelf life, which may be related to the low radiation conditions (7-10 µmol s^{-1} m^{-2} fluorescent light) of the SSI. In this case, in addition to the action of the ethylene produced by the plants, effects related to such as malls, supermarkets and homes, may intensify ethylene responses during the shelf life. Cavatte et al. (2013), reported that those responses are dependent on the variety. The authors reported for BGH 1039 that in the presence of an optimum light condition, the plants showed a lower leaf abscission rate than in the dark.

The cultivar 'Etna' showed moderate sensitivity to ethylene with 24.7% of accumulated leaf abscission compared to an external control (53.2%) and only 0.2% accumulated fruit abscission, on the 1st day of the shelf life. The plants of the internal control and ethylene treatment remained until the 3rd shelf day, showing 84 and 100% of leaf abscission, respectively (Figure 1C e D).

Plants undergo ethylene sensitivity to a great extend (Blankenship and Dole, 2003; Iqbal et al., 2017). Our results are in keeping with Lima et al. (2017), that reported that different levels of sensitivity to ethylene are related to the development stage (seedlings or initial flowering). The authors reported that 'Calypso', regardless of the developmental stage showed high sensitivity to 10 µL L^{-1} of ethylene for 48 hours, showing with 100% of leaf abscission while 'MG 302' showed an intermediate response to ethylene with about 88% and 44% of leaf abscission for seedlings and initial flowering stages, respectively. Ribeiro et al. (2019) reported that different sensitivity levels and response intensities are linked to a particular organ or genotype, i.e., 'Pimenta colorida' showed moderate sensitivity to 10 µL L^{-1} of ethylene on the flowers and highly leaf sensitivity to the same concentration after 48 hours.

In general, flowers and ornamental plants show some level of sensitivity after being exposed to concentrations of 0.5 to 1.0 µL L^{-1} of ethylene. Abeles, Morgan and Saltveit (1992) reported that there is a certain similarity in the dose/effect curves, for which it is observed: null response between 0.001 - 0.01 µL L^{-1}; noticeable effects between 0.01 - 0.1 µL L^{-1}; 50% of the maximum response between 0.1 - 1.0 µL L^{-1} and saturation between 1.0 and 10 µL L^{-1}. Ribeiro et al. (2019) reported that after exposure to saturated ethylene concentration, i.e., 10 µL L^{-1} of ethylene, ornamental pepper genotypes or organs can be classified from insensitive to sensitive to ethylene. However, higher concentrations than saturation are not found naturally in indoor environments (Abeles, Morgan and Saltveit, 1992; Khan, 2006; Segatto et al., 2013).

For the *Capsicum annum* species, 'Peppa' and 'Karneval' were considered highly sensitive to ethylene after exposed to 10 µL L^{-1} of ethylene for 48 hours. The leaves and fruits abscission for 'Peppa' was 70.4% and 20.8%, respectively (Figures 1E and 1F) and for 'Karneval', 60% and 3.1%, respectively (Figures 1G and 1H). Plants of both cultivars treated with ethylene were discarded for being improper for commercialization. However, the controls differed in terms of longevity. External control of 'Peppa' was discarded at the

5th day vs internal control, which lasted nine days on shelf life whereas 'Karneval' controls showed the longest shelf life among all cultivars evaluated, with external being discarded at the 11th day compared to internal control, which lasted twenty-three days of shelf life. Thus, ethylene in the surrounding air (external control) might have intensified the leaf abscission for both cultivars, compared to the indoor chamber control.

Changings and/or intensification in the color of the fruits was observed for 'Peppa' after treatment with ethylene, regardless of the stage of maturation of the fruits. No changes in the color of the fruits were observed to 'Karneval'. In fruits are common changes in the color of the fruits by the ethylene exposition, which may be influenced by chlorophyll degradation and activation of genes that codify for carotenogenic enzymes, such as lycopene cyclase, zeaxanthin (Hornero-Méndez et al., 2000).

Table 1. Shelf life of potted ornamental pepper plants exposed to 10 µL L^{-1} of ethylene for 48 hours and the external and internal controls. Insensitive (I); Moderately sensitive (M) and Highly sensitive (H) to exposure to 10 µL L^{-1} of ethylene for 48 hours.

Cultivar/ Specie	Shelf life (days)			Sensitivity	
	External control	Internal control	Ethylene	Leaves	Fruit
'Espaguetinho *C. frutescens*	3.0	3.0	1.0	H	M
'Etna' *C. frutescens*	1.0	3.0	3.0	M	I
'Peppa' *C. annuum*	5.0	9.0	1.0	H	M
'Karneval' *C. annuum*	11.0	23.0	1.0	H	I

The results of this investigation were similar findings were reported in several other species. Ethylene increases senescence in climacteric flowers such as carnations and orchids in response to autocatalytic production (Verlinden, Boatright and Woodson, 2002; Mapeli et al., 2009); *Epidendrum ibaguense* are sensitive to ethylene, showing intense wilt and abscission after being exposed to relatively low concentrations (Moraes et al., 2007) and *Dicentra eximia*, *Dicentra formosa* and *Dicentra spectabilis* withered and showed accelerated abscission of the petals in the presence of ethylene (Roberts, Serek and Andersen, 1995). In 'Victory Parade' mini roses, spraying with ethephon has dramatically reduced the longevity post-harvest life of the flowers (Serek and Reid, 1993).

Regarding the shelf life, except for 'Etna', all the cultivars have their shelf lives reduced to only one day (Table 1; Figure 2). Generally, for ornamental pepper, the leaves are more sensitive to ethylene than fruits to the action of ethylene (Segatto et al., 2013; Ribeiro et al., 2019). Our investigation is in keeping with these results, for which in all cultivars, leaves were more sensitive to ethylene than the fruits. If in the real conditions in which the transport of ornamental plants occurs in Brazil, usually in trunk trucks, in the dark, without ventilation and irrigation, for more than 48 hours (Junqueira and Peetz, 2002), all the cultivars, except 'Etna' would be discarded, for showing more than 50% of abscission of leaves.

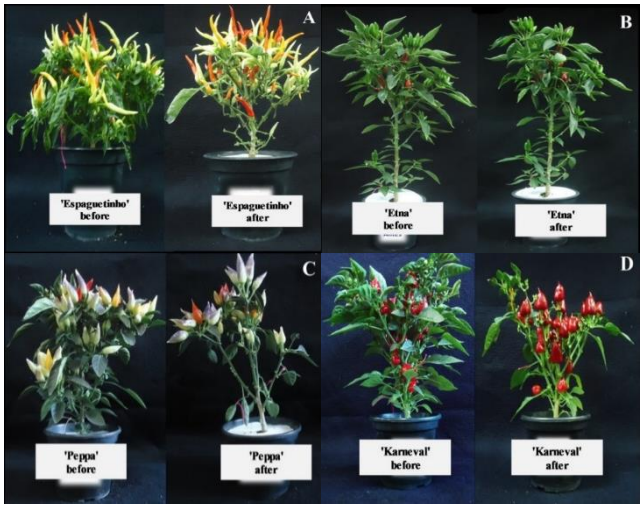

Figure 2. General aspect of pepper plant of 'Espaguetinho' (A) and 'Etna' (B) (*Capsicum frutescens*), before (left side – day 0) and after (right side – last day of shelf life) application of 10 µL L^{-1} ethylene for 48 h and during the post production phase; 'Peppa' and 'Karneval' (*Capsicum annuum*), before (left side – day 0) and after (right side – last day of shelf life) the application of 10 µL L^{-1} of ethylene for 48 hours.

This study thus points out avenues for the selection and introduction of better materials with reduced ethylene responses and long post-production shelf life and also paves the way for further investigations on the use of inhibitors of ethylene action as a valuable technique to reduce ethylene responses, extending the shelf life in the post-production phase of commercial pepper cultivars.

Conclusion

The current study revealed that the cultivars showed different levels of sensitivity to ethylene. 'Etna' exhibited moderate sensitivity to exposure to 10 µL L^{-1} of ethylene for 48 h, while 'Espaguetinho', 'Peppa' and 'Karneval' were classified as highly sensitive to ethylene. The leaves of the four genotypes showed greater responsiveness to ethylene than the fruits.

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