

Effects of paclobutrazol on ethylene sensitivity of potted pepper cultivars

Efeitos do paclobutrazol na sensibilidade ao etileno de cultivares de pimenta em vaso

Efectos del paclobutrazol sobre la sensibilidad al etileno de cultivares de pimiento en maceta

Received: 12/30/2022 | Reviewed: 01/07/2022 | Accept: 01/15/2022 | Published: 01/17/2022

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Abstract

Exposure to ethylene of ornamental plants is one of the factors that affect the life cycle post-production of these plants. The aim of this work was to evaluate the effects of paclobutrazol (PBZ) on the ethylene related responses of ten pepper cultivars of the genus *Capsicum* and one *Solanum* by simulating transport and commercialization. The cultivars were treated with PBZ at concentrations of 0, 5, 10 and 20 mg L⁻¹ applied on the potted cultivation substrate. When the plants had 30% of ripe fruits, they were transferred to a 90 L sealed container and treated with 10 µL L⁻¹ ethylene for 48 hours and then kept at room temperature. Percentages of leaf (LA) and fruit abscission (FA) the plants were recorded at every two days (48h, 96h and 144h). The design used was completely randomized, in an 11 x 4 factorial scheme. The PBZ did not completely inhibit the deleterious effects of exogenous ethylene on plants. However, the 'Pérola Negra' showed moderate sensitivity for leaf and fruit abscission, and the 'Bode Vermelha' for leaf abscission at a concentration of 10 mg L⁻¹. PBZ prevented partially the abscission of fruits of the 'Pirâmide Ornamental' pepper at rates of 5 and 10 mg L⁻¹, and 'Tabasco' pepper at a concentration of 10 mg L⁻¹. In addition, cultivars showed darker foliage when treated with PBZ.

Keywords: Ethylene inhibitors; Ornamentation; Commercialization; Post-production.

Resumo

A exposição ao etileno de plantas ornamentais é um dos fatores que afetam o ciclo de vida pós-produção destas plantas. O objetivo do estudo foi avaliar os efeitos do paclobutrazol (PBZ) sobre a sensibilidade ao etileno de dez cultivares de pimenta do gênero *Capsicum* e uma *Solanum*, em simulação de transporte ou comercialização. As cultivares foram tratadas com PBZ nas concentrações 0, 5, 10 e 20 mg L⁻¹ sobre o substrato de cultivo em vaso. Quando as plantas apresentaram 30% dos frutos maduros, foram transferidas para um recipiente vedado de 90 L e tratados com etileno à 10 µL L⁻¹ por 48 horas, em seguida, mantidas à temperatura ambiente. As porcentagens de folhas (LA) e abscisão de frutos (AF) das plantas foram registradas a cada dois dias (48, 96 e 144h). O delineamento utilizado foi inteiramente casualizado, em esquema fatorial 11 x 4. O PBZ não inibiu totalmente os efeitos deletérios do etileno exógeno nas plantas. Porém, a 'Pérola Negra' apresentou sensibilidade moderada para abscisão de folhas e frutos, e a 'Bode vermelha' para abscisão foliar na concentração 10 mg L⁻¹. De forma moderada, o PBZ impediu a abscisão de frutos da 'Pirâmide ornamental' nas doses 5 e 10 mg L⁻¹, e da pimenta 'Tabasco' na concentração 10 mg L⁻¹. Além disso, os cultivares apresentaram folhagens mais escuras quando tratadas com PBZ.

Palavras-chave: Inibidor do etileno; Ornamentação; Comercialização; Pós-produção.

Resumen

La exposición al etileno de las plantas ornamentales es uno de los factores que afectan el ciclo de vida posproducción de estas plantas. El objetivo de este estudio fue evaluar los efectos del paclobutrazol (PBZ) sobre la sensibilidad al etileno de diez cultivares de pimiento del género *Capsicum* y un *Solanum*, en simulación de transporte o comercialización. Los cultivares de pimiento con PBZ a concentraciones de 0, 5, 10 y 20 mg L⁻¹ sobre el sustrato de cultivo en maceta. Cuando las plantas tenían 30% de frutos maduros, se transfirieron a un recipiente sellado de 90 L y se trataron con etileno a 10 µL L⁻¹ durante 48 horas, luego se mantuvieron a temperatura ambiente. Los porcentajes de abscisión de hojas (LA) y frutos (AF) de las plantas se registraron cada dos días (48, 96 y 144h) después del tratamiento con etileno. El diseño experimental fue completamente al azar, en un esquema factorial de 11 x 4. El PBZ no inhibió completamente los efectos deletéreos del etileno exógeno en las plantas. Sin embargo, la ‘Pérola Negra’ mostró una sensibilidad moderada para la abscisión de hojas y frutos y la ‘Bode vermelha’ para la abscisión de hojas a una concentración de 10 mg L⁻¹. Moderadamente, PBZ impidió la abscisión de frutos de pimiento ‘Pirâmide ornamental’ a dosis de 5 y 10 mg L⁻¹, y pimiento ‘Tabasco’ a una concentración de 10 mg L⁻¹. Además, los cultivares mostraron un follaje más oscuro cuando se trataron con PBZ.

Palabras clave: Inhibidor de etileno; Ornamentación; Comercialización; Postproducción.

1. Introduction

Peppers (*Capsicum* ssp.) are among the most important vegetables of the Solanaceae family (Mahmoud & El-Eslamboy, 2015; Costa et al., 2021). The genetic diversity of the *Capsicum* genus includes plants with different sizes, types, colors, flavor and heat of the fruits (Pinto, Santos, Araújo & Silva, 2016). Peppers fruits are important part of the spice industry (Rebouças, Valverde & Teixeira, 2013), being consumed in natura, processed in the form of sauce, jams, jellies and paprika. In addition, peppers are an important source of antioxidant substances, including vitamin C, carotenoids and vitamin E (Finger & Pereira, 2016).

Peppers plants have been gaining market as ornamentals. In the international market, as in the United States and some countries in Europe, ornamental peppers have great prominence and good acceptance by the consumer (Bosland, 1999). In Brazil, the sale of ornamental pepper plants is still restricted to open markets and some supermarkets, but this reality is changing, and consumers are already buying peppers in flower shops (Rêgo, Rêgo & Barroso, 2016). The varied foliage, intensity in the color of its fruits contrasting with the foliage, ease of seed propagation, shorter harvest time, tolerance to heat and drought and high post-production quality are striking characteristics of ornamental peppers (Stommel & Bosland, 2006 ; Rêgo & Rêgo, 2016 and 2018).

Ornamental peppers are exposed to stresses during their transport to their final destination that can affect their ornamental quality and shelf life (Lima, Ribeiro, Oliveira, Costa & Finger, 2017; França et al., 2018). Transport conditions in Brazil are precarious, ornamental plants are transported in dark trucks, without ventilation and limited supply of water for more than 48 hours, with accumulation and exposure of the plants to ethylene present in the air inside the trucks (Iqbal et al., 2017). Ethylene is a plant hormone produced in low concentrations by the plants, regulating plant growth and development, flowering, fruit maturation and senescence processes (Chen, Etheridge & Schaller, 2005; Santos et al., 2013). However, exposure to high concentrations of ethylene can cause undesirable effects on the plant, such as abscission of leaves, flowers and fruits in different degrees and chlorophyll degradation (Lima et al., 2017; Nascimento et al., 2018; Ribeiro et al., 2019a). The effects caused by ethylene will depend on the ethylene concentration, exposure time, temperature, development stage and sensitivity of the species or variety (Xin et al., 2019).

Treatments with inhibitors of ethylene synthesis and action are indicated to delay the harmful effects of the hormone. Several authors describe the action of paclobutrazol (PBZ) in inhibiting ethylene synthesis in plants (Min & Bartholomew, 1996; Antunes, Ono & Sampaio, 2008; Ahmad, Dole & Whipker, 2015). PBZ is a regulator that blocks the biosynthesis of gibberellic acid, inhibiting plant growth and increasing chlorophyll in ornamental pepper leaves (França et al., 2017).

Few studies were carried out in ornamental peppers in relation to post-production factors, the levels of sensitivity to ethylene,

and the action of inhibitor on post-production longevity of potted plants. Therefore, the aim of the study was to evaluate the effects of different concentrations of the growth regulator paclobutrazol on the post-production shelf life of ten pepper cultivars of *Capsicum* and one *Solanum*.

2. Methodology

2.1 Conducting the experiment

The experiment was conducted in a greenhouse at the Department of Agronomy of the Federal University of Viçosa (20° 45' 47" LS and 42° 49' 13" LW). The treatments consisted of ten commercial pepper cultivars of the genus *Capsicum*: 'Pérola negra' and 'Jalapeño' (*Capsicum annuum*); 'Malagueta', 'Tabasco', 'Stromboli ornamental', 'Pirâmide ornamental' (*Capsicum frutescens*); 'Rocoto vermelha' (*Capsicum pubescens*); 'Dedo de moça' (*Capsicum baccatum*), 'Bode vermelha' and 'Biquinho vermelha' (*Capsicum chinense*), and a *Solanum*: 'Peloteira' (*Solanum pseudocapsicum*).

Seeding was carried out in 200 cell polystyrene trays containing commercial substrate. When the plantlets had four pairs of leaves, one plant was transplanted to 700 ml pots, number 13 (10 cm in height x 9 cm in bottom diameter x 12 cm in top diameter). The growth regulator, paclobutrazol (PBZ) was applied after the plants had a height between 10 and 15 cm. Each pot received 150 mL of the PBZ solution drenched directly in the substrate at concentrations of 0.5, 10 and 20 mg L⁻¹, corresponding to 0.75, 1.5 and 3 mg of the active principle (250 g ai PBZ per liter, Syngenta Crop Protection), similar to that described by França et al., (2018).

2.2 Ethylene treatment

When plants reached the stage of 30% of full ripe mature fruits, plants were evaluated for sensitivity to ethylene according to Segatto, Finger, Barbosa, Rêgo e Pinto (2013). Pots were placed in 90-liter sealed chambers in the dark simulating stress conditions during transport or storage, and then exposed to 10 µL L⁻¹ of ethylene for 48 hours.

After exposure to ethylene, the pots were transferred to a room simulating the interior conditions of stores, supermarkets and homes of the final consumers at 25 ± 1 °C, 8-10 µmol s⁻¹ m⁻² of white fluorescent light, and RH 60-65% and watered when necessary. Percentages of leaf (LA) and fruit abscission (FA) the plants were recorded at every two days (48h, 96h and 144h).

2.3 Statistical analysis

The experimental design used was completely randomized, in a factorial scheme 11 x 4, eleven genotypes and four doses of PBZ, with five replications. Quantitative data were subjected to analysis of variance, with subsequent grouping of means by the Skott-Knott criterion at 1% probability and comparison of means by the Dunnett test at 5%. Statistical analyzes were performed using the Genes computer program (Cruz, 2013).

3. Results and Discussion

The effects of the interaction between dose and genotypes were significant by the F test (p<0.01) for leaf and fruit abscission (data not shown), reflecting the behavior of cultivars for resistance to ethylene when treated with different rates of paclobutrazol (PBZ).

Table 1 shows the average of pepper cultivars, treated with PBZ for leaf abscission and fruit abscission after 48 hours of exposure to ethylene. Plants treated with 5, 10 and 20 mg L⁻¹ of PBZ were divided into two groups according to leaf abscission. The cultivars 'Jalapeño', 'Biquinho Vermelha', 'Tabasco' and 'Rocoto Vermelha' formed a group with greater leaf

abscission, above 50% (Table 1), making them unfeasible for commercialization. For these cultivars, PBZ was not effective in reducing sensitivity to ethylene. It is important for every segment of the production chain (production, distribution and commercialization) to discover methods or hormones that reduce the negative effects caused by ethylene, not only in ornamental peppers, but also in every sector of flowers and ornamental plants that depend on trucks to be delivered to the final destination, large commercial centers, supermarkets and open markets in the cities.

Table 1 – Means of eleven cultivars for leaf abscission (LA) and pepper fruit abscission (FA), 48 hours after exposure to ethylene, with application of 0, 5, 10 and 20 mg L⁻¹ of PBZ. Equal letters in columns do not differ statistically by Scott-Knott criterion at 1% probability. *followed on the same line indicates significance by the Dunnett test at 5% probability.

Cultivars	48 hours							
	0 mg L ⁻¹		5 mg L ⁻¹		10 mg L ⁻¹		20 mg L ⁻¹	
	LA	FA	LA	FA	LA	FA	LA	FA
Pirâmide ornamental	41.69b	54.67a	43.58b ^{ns}	21.14a ^{ns}	43.53b ^{ns}	26.44b ^{ns}	45.92b ^{ns}	18.29b*
Pérola negra	68.97	33.01a	16.90b*	5.83a ^{ns}	23.59b*	9.91b ^{ns}	27.76b*	26.32b ^{ns}
Dedo de moça	52.78b	31.27a	34.38b ^{ns}	31.33a ^{ns}	20.97b ^{ns}	7.93b ^{ns}	28.32b ^{ns}	2.85b ^{ns}
Bode vermelha	38.91b	38.11a	37.37b ^{ns}	45.25a ^{ns}	20.21b ^{ns}	57.80a ^{ns}	26.53b ^{ns}	54.17a ^{ns}
Peloteira	5.88c	6.04b	39.58b*	21.74a ^{ns}	29.27b ^{ns}	15.53b ^{ns}	13.04b ^{ns}	9.46b ^{ns}
Jalapeño	64.53a	1.81b	88.06a ^{ns}	42.0a*	72.02a ^{ns}	30.96b ^{ns}	54.98a ^{ns}	28.88b ^{ns}
Biquinho vermelha	97.55a	45.54a	61.06a*	42.34a ^{ns}	90.76a ^{ns}	59.76a ^{ns}	70.85a ^{ns}	67.91a ^{ns}
Tabasco	31.24b	66.87a	54.40a ^{ns}	43.07a ^{ns}	31.93b ^{ns}	18.92b*	42.22b ^{ns}	20.23b*
Stromboli	49.39b	11.24b	43.24b ^{ns}	2.27a ^{ns}	48.26b ^{ns}	0.86b ^{ns}	37.46b ^{ns}	2.10b ^{ns}
Malagueta	17.20c	17.80b	28.96b ^{ns}	26.88a ^{ns}	18.56b ^{ns}	30.75b ^{ns}	42.75b ^{ns}	38.55a ^{ns}
Rocoto vermelha	39.10b	14.71b	61.04a ^{ns}	13.33a ^{ns}	71.45a*	45.59a ^{ns}	83.39a*	50.0a*

Source: Authors.

Compared with the control treatment (0 mg L⁻¹), PBZ at concentrations 5, 10 and 20 mg L⁻¹ reduced the sensitivity to ethylene of the ‘Pérola Negra’ by 75, 65 and 59%, respectively (Table 1). Similar effect was detected in the ‘Biquinho Vermelha’ treated with 5 mg L⁻¹ PBZ, with a 37% reduction in leaf abscission (Table 1 and Figure 1). The other cultivars did not show significant differences in terms of sensitivity to ethylene, when compared to the control, regardless of the treatment with PBZ applied (Table 1).

Plants treated with PBZ had greener leaves than the control untreated plants (visual observation). Probably exogenous ethylene reduced the chlorophyll content of the leaf (Figure 1). Araújo, Freire, Guimarães, Lima and Finger (2019) also observed these negative effects caused by ethylene in ornamental pepper plants *Capsicum annuum*, accession ‘BGH 1039’. Therefore, in this study, PBZ was efficient in reducing chlorophyll degradation in leaves caused by ethylene. Most studies with PBZ are focused on the effects it causes on plant size, flowering and fruiting, as reported by França et al., (2017 and 2018) and Ribeiro et al., (2019b) in *Capsicum* spp. Whatever the positive effects that PBZ can provide to peppers, in terms of sensitivity to ethylene, it is extremely important to improve plant quality and increase shelf life.

Figure 1 – Effect of ethylene action on cultivar ‘Biquinho Vermelha’, 48 hours after exposure to ethylene. A1 – Control plant (0 mg L⁻¹ PBZ); A2 - 5 mg L⁻¹ PBZ.



Source: Authors.

Fruit abscission in plants treated with 5 mg L⁻¹ PBZ had no formation of groups, all the cultivars showed less than 50% of fruit abscission (Table 1). At doses of 10 and 20 mg L⁻¹ PBZ, the cultivars were divided into two distinct groups. ‘Bode vermelha’, ‘Biquinho vermelha’, ‘Malagueta’ and ‘Rocoto vermelha’ were the cultivars that presented the highest average percentages for fruit abscission (Table 1). In this case, these cultivars treated with 10 and 20 mg L⁻¹ PBZ did not affect the sensitivity to ethylene. Fruits are the main decoration elements of ornamental peppers, which attract the most attention of consumers at the time of purchase (Neitzke, Fischer, Vasconcelos, Barbieri & Treptow, 2016). Therefore, it is necessary that, in addition to presenting an adequate size for ornamentation, the peppers have colored fruits, contrasting between foliage (Finger, Rêgo, Segatto, Nascimento & Rêgo, 2012) the fruits must remain attached to the plant.

In Table 2, after 96 hours of the exposure to ethylene, cultivars treated with 5, 10 and 20 mg L⁻¹ PBZ were divided into two distinct classes for leaf abscission. The cultivars ‘Pérola Negra’, ‘Bode vermelha’ and ‘Peloteira’ had the lowest average leaf abscission. Although they are more resistant to the harmful action of ethylene, the cultivars showed a high average leaf abscission (Table 2). However, when compared to the control treatment, leaf abscission was reduced by more than 50% in the ‘Pérola Negra’ when treated with 5, 10 and 20 mg L⁻¹ PBZ (Table 2). On the other hand, the ‘Peloteira’ and ‘Pirâmide Ornamental’ had increased leaf abscission at concentrations of 5 and 20 mg L⁻¹ PBZ (Table 2).

The other cultivars treated with PBZ did not show significant effects when compared to the control treatment (Table 2). This divergence of results can be explained by the fact that the effects caused by PBZ on plants vary between species, varieties, concentration and form of application (Rademacher, 2000). França et al. (2018) and Ribeiro et al. (2019b) studying the effect of PBZ on *Capsicum*, obtained different responses among the varieties studied, when using different ways of treatment, concentrations and varieties of pepper.

Table 2 – Means of eleven cultivars for leaf abscission (LA) and fruit abscission (FA) of pepper, 96 hours after exposure to ethylene, with application of 0, 5, 10 and 20 mg L⁻¹ of PBZ. Equal letters in columns do not differ statistically by Scott-Knott criterion at 1% probability. * followed on the same line indicates significance by the Dunnett test at 5% probability.

Cultivarss	96 hours							
	0 mg L ⁻¹		5 mg L ⁻¹		10 mg L ⁻¹		20 mg L ⁻¹	
	LA	FA	LA	FA	LA	FA	LA	FA
Pirâmide ornamental	49.42b	59.61a	57.10b ^{ns}	24.28b*	70.63a ^{ns}	24.44b*	80.50a*	24.31b*
Pérola negra	84.03a	35.99b	40.62b*	5.83b ^{ns}	38.04b*	12.99b ^{ns}	42.09b*	35.30b ^{ns}
Dedo de moça	76.82a	42.51a	57.48b ^{ns}	33.0a ^{ns}	47.57b*	19.47b ^{ns}	65.75a ^{ns}	11.19b ^{ns}
Bode vermelha	53.90b	56.40a	58.82b ^{ns}	50.52a ^{ns}	43.19b ^{ns}	62.83a ^{ns}	51.01b ^{ns}	61.14a ^{ns}
Peloteira	11.21c	7.52b	44.95b*	31.58a ^{ns}	38.13b ^{ns}	31.31b ^{ns}	22.67b ^{ns}	15.94b ^{ns}
Jalapeño	79.04a	23.66b	95.71a ^{ns}	47.33a ^{ns}	81.40a ^{ns}	39.69b ^{ns}	77.72a ^{ns}	46.11a ^{ns}
Biquinho vermelha	100a	62.44a	94.31a ^{ns}	49.05a ^{ns}	98.13a ^{ns}	64.89a ^{ns}	96.12a ^{ns}	85.79a ^{ns}
Tabasco	70.86a	72.63a	81.79a ^{ns}	49.90a ^{ns}	73.23a ^{ns}	26.93b*	77.40a ^{ns}	33.09b*
Stromboli	77.93a	19.75b	84.23a ^{ns}	3.92b ^{ns}	80.65a ^{ns}	5.70b ^{ns}	71.86a ^{ns}	5.74b ^{ns}
Malagueta	72.11a	32.58b	92.42a ^{ns}	39.89a ^{ns}	85.59a ^{ns}	37.55b ^{ns}	78.86a ^{ns}	64.74a ^{ns}
Rocoto vermelha	88.47a	14.71b	89.34a ^{ns}	31.66a ^{ns}	95.20a ^{ns}	76.30a*	92.89a ^{ns}	75.0a*

Source: Authors.

Regarding the abscission of fruits, the cultivars were divided into two distinct groups, when treated with 5, 10 or 20 mg L⁻¹ PBZ (Table 2). The cultivars ‘Pirâmide ornamental’, ‘Pérola negra’ and ‘Stromboli’ stand out as the most resistant to fruit drop, with an average fruit abscission of less than 25% (Table 2).

Compared to the control treatment, the ‘Pirâmide ornamental’ and ‘Tabasco’ cultivars showed a decrease in fruit abscission when treated with 5, 10 or 20 mg L⁻¹ and 10 or 20 mg L⁻¹ PBZ, respectively (Table 2). These results showed that PBZ is effective in reducing damage caused by exogenous ethylene in ornamental peppers. The damage caused by ethylene on fruit abscission depends on the period of exposure, concentration, temperature, the stage of fruit development and the sensitivity of species and varieties (Finger, Silva, Segatto & Barbosa, 2015). Santos et al. (2013), Lima et al. (2017) and Ribeiro et al. (2019a), evaluating ornamental pepper genotypes for sensitivity to ethylene, reported that ethylene affected, in different degrees, the longevity of plants exposed to the hormone.

Most plants are sensitive to ethylene after being exposed to 0.5 to 1.0 µL L⁻¹ (Abeles, Morgan & Sampaio, 1992; Iqbal et al., 2017). Generally, there is 50% response between 0.1 - 1.0 µL L⁻¹ and saturation between 1.0 and 10 µL L⁻¹ of ethylene. Based on this classification, varieties or organs are classified as sensitive or insensitive to exogenous ethylene. Thus, plants that do not respond to 10 µL L⁻¹ of ethylene can be considered insensitive. According to Iqbal et al. (2017), different species, varieties and organs of *Capsicum* have particular sensitivity levels for each, therefore, different response intensities. This may be related to the amount of ethylene receptors in different organs. Furthermore, the effect of ethylene may be independent or dependent on its interaction with other hormones.

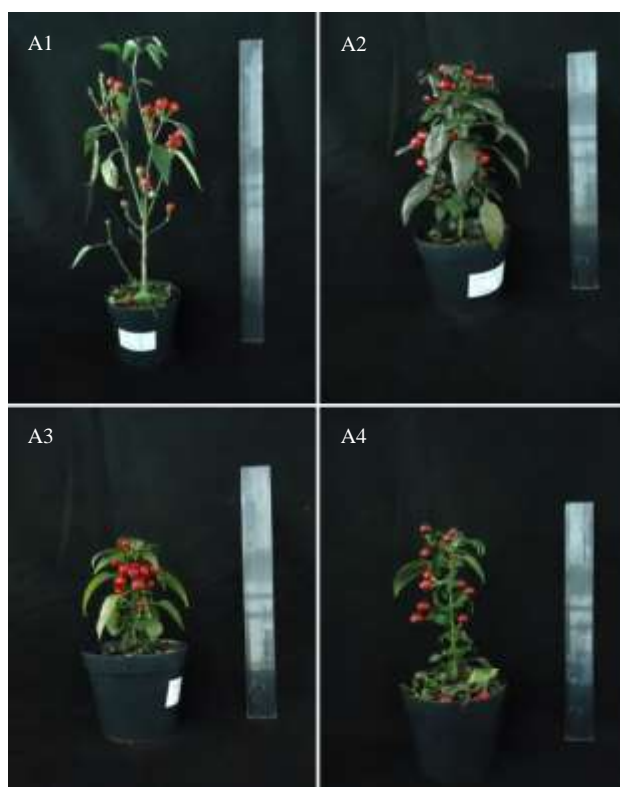
In Table 3, 144 hours after exposure to ethylene, leaf abscission showed different sensitivity levels, being the cultivars grouped into three distinct classes for the 5 and 20 mg L⁻¹ PBZ and two classes for the 10 mg L⁻¹ PBZ (Table 3). When compared to the control plants, the ‘Pérola negra’ cultivar showed a decrease in leaf abscission by 46%, 46% and 42%, when treated with 5, 10 or 20 mg L⁻¹ PBZ, respectively (Table 3 and Figure 2).

Table 3 – Means of eleven cultivars for leaf abscission (LA) and fruit abscission (FA) of pepper, 144 hours after exposure to ethylene, with application of 0, 5, 10 and 20 mg L⁻¹ of PBZ. Equal letters in columns do not differ statistically by Scott-Knott criterion at 1% probability. *followed on the same line indicates significance by the Dunnett test at 5% probability.

Cultivars	144 hours							
	0 mg L ⁻¹		5 mg L ⁻¹		10 mg L ⁻¹		20 mg L ⁻¹	
	LA	FA	LA	FA	LA	FA	LA	FA
Pirâmide ornamental	66.85b	62.0a	75.52b ^{ns}	26.51b*	90.10a*	24.44b*	89.81a ^{ns}	33.27b ^{ns}
Pérola negra	93.16a	49.22a	50.13c*	9.71b*	50.19b*	14.52b*	53.70b*	38.70b ^{ns}
Dedo de moça	94.16a	49.19a	72.70b ^{ns}	33.0b ^{ns}	74.52a ^{ns}	23.23b ^{ns}	89.66a ^{ns}	18.04b ^{ns}
Bode vermelha	61.35b	58.44a	69.29b*	58.18a ^{ns}	56.90b*	71.72a ^{ns}	63.59b*	63.40a ^{ns}
Peloteira	19.44c	9.12b	50.65c*	40.47a ^{ns}	47.97b*	32.98b ^{ns}	29.62c ^{ns}	20.90b ^{ns}
Jalapeño	90.67a	30.60b	95.83a ^{ns}	51.33a ^{ns}	88.19a ^{ns}	42.19b ^{ns}	86.77a ^{ns}	46.11b ^{ns}
Biquinho vermelha	100a	62.86a	98.81a ^{ns}	51.63a ^{ns}	99.79a ^{ns}	66.94a ^{ns}	100a ^{ns}	92.46a ^{ns}
Tabasco	74.33b	74.26a	89.42a ^{ns}	54.52a ^{ns}	84.03a ^{ns}	26.93b*	87.58a ^{ns}	40.53b ^{ns}
Stromboli	91.40a	23.55b	91.60a ^{ns}	9.31b ^{ns}	91.90a ^{ns}	10.95b ^{ns}	84.84a ^{ns}	6.30b ^{ns}
Malagueta	84.06a	34.69b	96.58a ^{ns}	44.97a ^{ns}	94.15a ^{ns}	44.36b ^{ns}	92.57a ^{ns}	66.66a ^{ns}
Rocoto vermelha	92.73a	36.38b	96.05a ^{ns}	58.33a ^{ns}	98.86a ^{ns}	76.30a*	96.47a ^{ns}	81.66a*

Source: Authors.

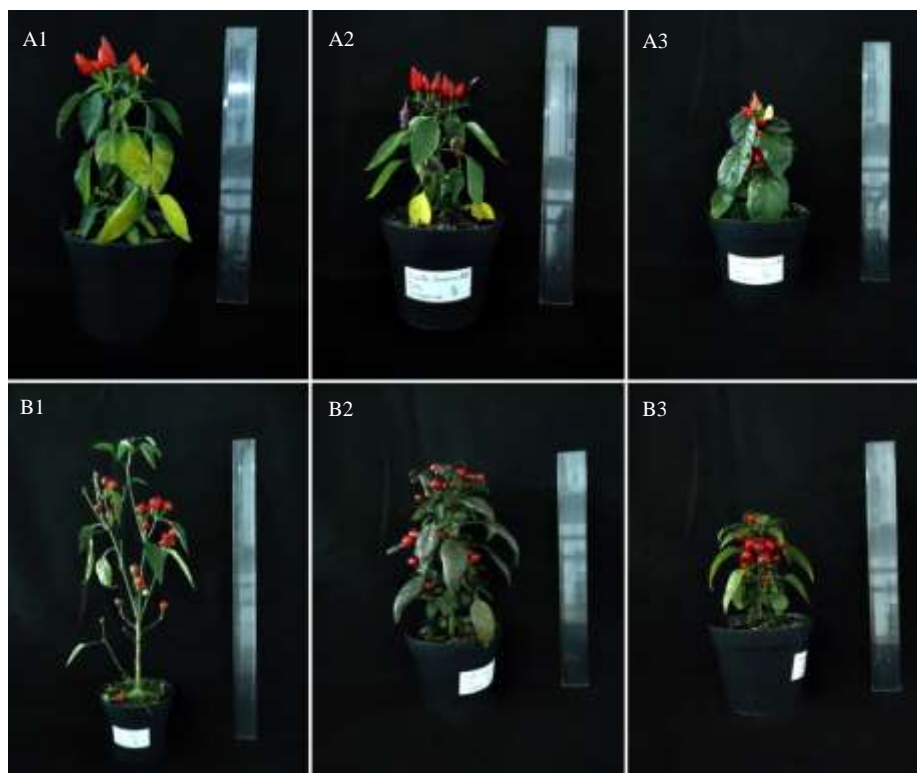
Figure 2 - Effect of ethylene action, 144 hours after exposure, on cultivar ‘Pérola’. A1 – Control treatment (0 mg L⁻¹ PBZ); A2 - 5 mg L⁻¹ PBZ; A3 - 10 mg L⁻¹ PBZ; A4 - 20 mg L⁻¹ PBZ.



Source: Authors.

Regarding the abscission of the fruits, cultivars were divided into two distinct classes when treated with 5, 10 or 20 mg L⁻¹ PBZ. Cultivars ‘Pirâmide ornamental’, ‘Pérola negra’, ‘Dedo de Moça’, ‘Peloteira’, ‘Jalapeño’, ‘Tabasco’ and ‘Stromboli’ are more resistant to the harmful action of ethylene (Table 3). On the other hand, the application of PBZ at concentrations 10 and 20 mg L⁻¹ increased the percentage of fruit abscission ‘Rocoto vermelha’. When compared to the control treatment, the cultivars ‘Pirâmide ornamental’ and ‘Pérola negra’ showed resistance to ethylene, with a reduction in fruit abscission varying between 57% and 80%, when treated with 5 and 10 mg L⁻¹ PBZ (Table 3 and Figure 3). Furthermore, the leaves of plants treated with PBZ did not show yellowing (visual observation, Figure 3), possibly the PBZ prevented the degradation of chlorophyll by exogenous ethylene.

Figure 3 - Effect of ethylene action, 144 hours after exposure, on cultivar ‘Pirâmide Ornamental’. A1 – Control treatment (0 mg L⁻¹ PBZ); A2 - 5 mg L⁻¹ PBZ; A3 - 10 mg L⁻¹ PBZ; A4 - 20 mg L⁻¹ PBZ.



Source: Authors.

Min and Bartholomew (1996), in studies with pineapple, reported that the production of ACC was not affected by the use of paclobutrazol, while the synthesis of ACC oxidase, which converts ACC to ethylene, was inhibited. In this case, PBZ is effective in inhibiting ethylene synthesis, but not its action, leaving its binding sites free for exogenous ethylene. It is possible that, under transport conditions, PBZ is an effective hormone in inhibiting endogenous ethylene synthesis, reducing excessive ethylene exposure by flowers and plants inside trucks, increasing plant shelf life.

PBZ also had no effect on the ethylene sensitivity of *Cuphea* (*Cuphea hyssopifolia* Kunth) and *Petunia* (*Petunia × hybrida* Vilm.) when the plants were exposed to exogenous ethylene for 20 hours (Ahmad et al., 2015). However, the same authors observed that PBZ inhibited fruit abscission in plants not treated with exogenous ethylene, PBZ interacted and reduced the production of endogenous ethylene, without affecting the ethylene receptors.

4. Final Considerations

The use of PBZ did not completely prevent the deleterious effects of exogenous ethylene on the plants. The 'Pérola negra' cultivar showed moderate sensitivity to leaf and fruit abscission. Likewise, just for leaf abscission, 'Bode vermelha' treated with 10 mg L⁻¹. The PBZ moderately prevented the abscission of fruits of the 'Pirâmide ornamental' at doses 5 and 10 mg L⁻¹, and of 'Tabasco' pepper at a concentration of 10 mg L⁻¹.

In future work, higher doses of PBZ and its application via foliar spray could bring more effective results in order to avoid the deleterious effects of ethylene on peppers. In addition, it could provide more suitable characteristics for ornamental pepper plants.

Acknowledgments

The authors are grateful for the financial support by CNPq (National Council for Scientific and Technological Development) and CAPES (Coordination for the Improvement of Higher Education Personnel).

References

- Abeles, F., Morgan, P. W., & Saltveit Júnior, M. E. (1992). *Ethylene in plant biology*. (2nd ed). San Diego: Academic Press.
- Ahmad, I., Dole, J. M., & Whipker, B. E. (2015). Paclobutrazol or uniconazole effects on ethylene sensitivity of potted ornamental plants and plugs. *Scientia Horticulturae*, 192, 350-356.
- Antunes, A. M., Ono, E. O., & Sampaio, A. C. (2008). Efeito do paclobutrazol no controle da diferenciação floral natural do abacaxizeiro cv. smooth cayenne. *Revista Brasileira de Fruticultura*, 30(2), 90-295.
- Araujo, F. F., Freire, A. I., Guimarães, M. E. S., Lima, P. C. C., & Finger, F. L. (2019). Influence of 1-methylcyclopropene on the longevity of potted ornamental peppers. *Revista Brasileira de Ciências Agrárias*, 14(1), 1-7.
- Bosland, P. W. (1999). Encyclopedia of chiles. In: Hanson, B. (Coord.), *Chile peppers, Brooklyn Botanical Garden - Brooklyn Botanical Garden* (p. 17-21), Brooklyn - NY.
- Chen, Y. F., Etheridge, N., & Schaller, E. (2005). Ethylene signal perception. *Annals of Botany*, 95, 901-915.
- Costa, M. P. S. D., Rêgo, E. R., Guedes, J. F. S., Carvalho, M. G., Silva, A. R., & Rêgo, M. M. (2021). Selection of genotypes with ornamental potential in an F₄ population of ornamental peppers (*Capsicum annum* L.) based on multivariate analysis. *Comunicata Scientiae*, 12, e3511, 1-8.
- Cruz, C. D. (2013). Genes: a software package for analysis in experimental statistics and quantitative genetics. *Acta Scientiarum*, 35(3), 271-276.
- Finger, F. L., Rêgo, E. R., Segatto, F. B., Nascimento, N. F. F., & Rêgo, M. M. (2012). Produção e potencial de mercado para pimenta ornamental. *Informe Agropecuário*, 33, 14-20.
- Finger, F. L., Silva, T. P., Segatto, F. B., & Barbosa, J. G. (2015). Inhibition of ethylene response by 1-methylcyclopropene in potted ornamental pepper. *Ciência Rural*, 45(6), 964-969.
- Finger, F. L., & Pereira, G. M. (2016). Physiology and Postharvest of pepper fruits. In: Rêgo, E. R., Rêgo, M. M., & Finger, F. L. (Coord), *Production and breeding of chilli peppers (Capsicum spp)* - Springer (p. 27-40), New York - USA.
- França, C. F. M., Costa, L. C., Ribeiro, W. S., Mendes, T. D. C., Santos, M. N. S., & Finger, F. L. (2017). Evaluation of paclobutrazol application method on quality characteristics of ornamental pepper. *Ornamental Horticulture*, 23(3), 307-310.
- França, C. F. M., Ribeiro, W. S., Santos, M. N. S., Petrucci, K. P. O. S., Rêgo, E. R., & Finger, F. L. (2018). Growth and quality of potted ornamental peppers treated with paclobutrazol. *Pesquisa Agropecuária Brasileira*, 53, 316-322.
- Iqbal, N., Khan, N. A., Ferrante, A., Trivellini, A., Francini, A., & Khan, M. (2017). Ethylene role in plant growth, development and senescence: interaction with other phytohormones. *Frontiers in Plant Science*, 8, e475, 1-19.
- Leatherwood, R., & Mattson, N. S. (2010). Cornell research update ethylene in the greenhouse: symptoms of short and long term exposure. *Indiana Flower Grow*, 4 (1), 4-8.
- Lima, P. C. C., Ribeiro, W. S., Oliveira, M. M. T., Costa, L. C., & Finger, F. L. (2017). Ethylene, 1-methylcyclopropene and silver thiosulfate on the post-production of ornamental pepper. *Ciência Rural*, 47(2), 1-8.
- Mahmoud, A. M., & El-Eslamboly, A. A. S. A. (2015). Production and evaluation of high yieldingsweet pepper hybrids undergreenhouse conditions. *American-Eurasian Journal of Agricultural & Environmental Sciences*, 15, 573-580.

- Min, X. J., & Bartholomew, D. P. (1996). Effect of plant growth regulators on ethylene production, 1- aminocyclopropane-1-carboxylic acid oxidase activity, and initiation of inflorescence development of pineapple. *Journal of Plant Growth Regulation*, 15(3), 121-128.
- Nascimento, M. F., Santos, R. M. C., Araújo, F. F., Silva Neto, J. J., Finger, F. L., & Bruckner, C. H. (2018). Sensitivity of potted ornamental peppers to ethylene. *Ornamental Horticulture*, 24(4), 429-434.
- Neitzke, R. S., Fischer, S. Z., Vasconcelos, C. S., Barbieri, R. L., & Treptow, R. O. (2016). Ornamental peppers: acceptance and preferences by consumers. *Horticultura Brasileira*, 34: 102-109.
- Pinto, C. M. F., Santos, I. C., Araujo, F. F., & Silva, T. P. (2016). Pepper importance and growth (*Capsicum* spp.) In: Rêgo, E. R., Rêgo, M. M., & Finger, F. L (Coord), *Production and breeding of chilli peppers (Capsicum spp)* - Springer (p. 1-25), New York – USA.
- Rademacher, W. (2000). Growth retardants: effects on Gibberellin biosynthesis and other metabolic pathways. *Annual Review of Plant Physiology and Molecular Biology*, 51, 501-531.
- Rebouças, T. N. H., Valverde, R. M. V., & Teixeira, H. L. (2013). Bromatologia da pimenta malagueta in natura e processada em conserva. *Horticultura Brasileira*, 31, 163-165.
- Rêgo, E. R., Rêgo, M. M., & Barroso, P. A. (2016). Tissue culture of *Capsicum* spp. In: Rêgo ER, Rêgo MM, Finger FL (Coord.) *Production and breeding of chilli peppers (Capsicum spp.)* - Springer (p. 97-127), Cham.
- Rêgo, E. R., & Rêgo, M. M. (2016). Genetics and Breeding of Chili Pepper *Capsicum* spp. In: Rêgo, E. R., Rêgo, M. M., Finger, F.L. (Coord.). *Production and Breeding of Chilli Peppers (Capsicum spp.)* – Springer (p. 97-129), Nova York - USA.
- Rêgo, E. R. & Rêgo, M. M. (2018) Ornamental Pepper. In: Van Huylenbroeck J (Coord.) *Ornamental Crops*. Springer International Publishing (p. 529 – 565), Cham.
- Ribeiro, W. S., Carneiro, C. S., França, C. F. M., Pinto, C. M. F., Lima, P. C. C., Finger, F. L., & Costa, F. B. (2019a). Sensitivity of ornamental pepper to ethylene. *Horticultura Brasileira*, 37, 458-463.
- Ribeiro, W. S., Carneiro, C. S., França, C. F. M., Pinto, C. M. F., Lima, P. C. C., Finger, F. L., & Costa, F. B. (2019b). Paclobutrazol application in potted ornamental pepper. *Horticultura Brasileira*, 37, 464-468.
- Santos, R. M. C., Nascimento, N. F. F., Rêgo, E. R., Nascimento, M. F., Borém, A., Finger, F. L., & Costa, D. S. (2013). Ethylene resistance in a F2 population of ornamental Chili Pepper (*Capsicum annuum*). *Acta Horticulturae*, 1000, 433-438.
- Segatto, F. B., Finger, F. L., Barbosa, J. G., Rêgo, E. R., & Pinto, C. M. F. (2013). Effects of ethylene on the post-production of potted ornamental peppers (*Capsicum annuum* L.). *Acta Horticulturae*, 1000, 217-222.
- Stommel, J. R., & Bosland, P. W. (2006). Ornamental pepper, *Capsicum annuum*. In: Anderson N (Coord.) *Flower breeding and genetics: issues, challenges and opportunities for the 21st century* - Springer (pp 561–599), Dordrecht.
- Xin, T., Zhang, Z., Li, S., Zhang, S., Li, Q., Zhang, Z. H., Huang, S., & Yang, X. (2019). Genetic regulation of ethylene dosage for cucumber fruit elongation. *Plant Cell*, 31, 1063-1076.