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Selectivity of herbicides isolated and/or with the addition of adjuvants for *Physalis angulata* crop

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ABSTRACT

Physalis angulata is a Solanaceae that produces fruits with a high commercial value. The interference of weeds in the cultivation of this species is one of the main factors limiting its growth. There are no herbicides registered for this crop in Brazil. Thus, the objective of this study was to evaluate the selectivity of herbicides and the use of adjuvants for the cultivation of *P. angulata*. We conducted three experiments: two in pots, evaluating the selectivity of the herbicides fluazifop-p-butyl, metribuzin, fomesafen + fluazifop-p-butyl, trifluralin and clethodim; and one in field conditions using the most selective herbicides from previous experiments. In the pots, we performed assessments of phytotoxicity, height, stem diameter, and total chlorophyll content every seven days up to 42 days after application. At the end of the three experiments, we evaluated leaf area, number of fruits, and dry matter of leaves, stems, and fruits. The herbicides clethodim without adjuvant and fluazifop-p-butyl are selective for *P. angulata* crop. Under field conditions, the application of fluazifop-p-butyl + fomesafen did not negatively affect crop production and growth, being selective to *P. angulata*. Metribuzin do not have the potential to be used for this crop.

Keywords: Solanaceae, phyto-intoxication, camapu, weeds, competition.

RESUMO

Seletividade de herbicidas isolados e/ou com adição de adjuvantes para *Physalis angulata*

Physalis angulata é uma Solanaceae, que produz frutos de alto valor comercial. A interferência de plantas daninhas no cultivo dessa espécie é um dos principais fatores limitantes e não há herbicidas registrados. O objetivo deste estudo foi avaliar a seletividade de herbicidas e o uso de adjuvantes no cultivo de *P. angulata*. Foram conduzidos três experimentos: dois em vasos, avaliando a seletividade dos herbicidas fluazifop-p-butílico, metribuzim, fomesafem+fluazifop-p-butílico, trifluralina e cletodim; e um a campo, com os herbicidas mais seletivos dos ensaios anteriores. Em vaso, foram realizadas avaliações visuais de fitotoxicidade, além da altura das plantas, diâmetro do caule e teor de clorofila, a cada 7 dias, até os 42 dias após aplicação. Ao término dos três experimentos, além dessas características, foram avaliados a área foliar, número de frutos e massa seca de folhas, caule e frutos. Os herbicidas clethodim sem adjuvante e fluazifop-p-butil são seletivos para *P. angulata*. Em condições de campo, a aplicação de fluazifop-p-butil + fomesafen não afetou negativamente a produtividade e o crescimento da cultura, sendo seletivo a *P. angulata*. O metribuzin não demonstrou potencial para ser utilizado nesta cultura.

Palavras-chave: Solanaceae, fitointoxicação, camapu, plantas daninhas, competição.

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The genus *Physalis* belongs to the Solanaceae family and corresponds to a group of vegetables of great economic importance in Brazil (Muniz *et al.*, 2015). *Physalis angulata* is a species of this family and is popularly known as balloon cherry, cutleaf groundcherry and gooseberry. In Brazil, it is sold mainly *in natura* as an exotic fruit and is widely exported to Europe, which justifies its high commercialization value, reaching up to R$ 70.00 kg^{-1} (Ramadan & Mörsel, 2003; Muniz *et al.*, 2015). As for tomatoes (*Solanum lycopersicum*), this crop has its development limited mainly by the occurrence of nutritional deficiencies, diseases, nematodes, pests and weeds (Cavalcante *et al.*, 2018).

Among cultural treatments, weed control is extremely important, as weed interference can cause decreases in crop yields, affecting agricultural production (Castro *et al.*, 2011). As it occurs for tomato (Castro *et al.*, 2016), potato (Correia & Carvalho, 2019) and other vegetable crops, weeds can directly interfere with crops by competing for water, light, and nutrients, or releasing allelochemicals in the soil. Indirectly, they can serve as hosts for pests and diseases, decreasing harvest efficiency and depreciating the final product (Pitelli, 1987).

According to Ronchi *et al.* (2010), there are several types of weed management that can be performed on Solanaceaes, namely preventive, mechanical, cultural, and chemical. Such controls are important to minimize the interference of these weed plants with crops and to keep their populations at levels below those that are likely to cause economic damage. Among them, chemical control is widely used as it is effective in planting lines, has a high operational yield and also requires less labor compared to other control methods (Oliveira & Brighenti, 2011).

Despite having previously been considered a weed in various parts of the world (Bukun, 2004; Brandenberger *et al.*, 2005; Webber *et al.*, 2014), the cultivation of *P. angulata* is recent in Brazil. Its popularity is greater in the North and Northeast Brazilian regions, however, it is widely found in supermarkets in São Paulo and Rio de Janeiro being mostly imported from Colombia (Rockenbach *et al.,* 2009; Muniz *et al.*, 2015). As a result, there are still few scientific studies on weed management for this crop. Generally, due to the lack of information, producers adopt the same agrochemical management as that used for tomato crop, including the chemical control of weeds.

According to MAPA (2022), the following herbicides are registered in Brazil for tomato crop: clethodim, flazasulfuron, fenoxaprop-p-ethyl, fluazifop-p-butyl, metam sodium, metribuzin, quizalofop-p-ethyl, and trifluralin. Among them, the most often used are metribuzin, clethodim, fluazifop-p-butyl, trifluralin, and flazasulfuron (Ronchi *et al.*, 2010). For tomato crop, the herbicides metribuzin and flazasulfuron are registered for the control of eudicotyledonous plants, while the others are registered for the control of grasses. The number of products registered shows that there are few selective active ingredients for tomato, especially for the control of broad leaves (Ronchi *et al.*, 2010). Furthermore, it is important to mention that there are no herbicides registered for *P. angulata* crop (MAPA, 2022).

It is believed that herbicides registered for tomato may be selective for *P. angulata* crop. Therefore, given the expansion of this crop in Brazil and the need to control weeds, studies on selectivity may contribute greatly to improvements in the cultivation of *P. angulata*. Therefore, the objective of this study was to evaluate the selectivity of herbicides isolated and/or with the addition of adjuvants for *P. angulata* crop.

MATERIAL AND METHODS

Three experiments were installed sequentially at UNESP in Jaboticabal-SP (21°15’22’’S, 48°18’58’’W and 595 m altitude). Two of them were conducted in pots (Experiments I and II) in an open area, and a third (Experiment III) in the field.

To produce seedlings in the three experiments, expanded polystyrene trays with 144 cells were filled with horticultural substrate (PlantMax®) and two seeds were deposited per cell. When seedlings presented four fully expanded leaves, they were transplanted manually to pots or to the field. We planted one seedling per pot or hole.

Experiments in pots

For both experiments (I and II), polypropylene pots with a volume of five liters, a diameter of 28 cm, and a height of 22 cm were used. In experiment I, the seedlings were transplanted on July 22, 2017, and in experiment II the transplant was on September 1, 2017. On the transplant day, fertilization was carried out in pots using a formulated 04-20-20 (N-P-K) solution at a dose of 400 kg ha^{-1}, as recommended for tomato crop. During both experiments (conducted sequentially), average values of 22.4ºC of temperature (30.4ºC maximum and 15.8ºC minimum), 57.8% relative humidity and 72.1 mm precipitation were recorded.

During the experimental period, preventive and curative treatments were done as prescribed for the cultivation of tomatoes. In experiments I and II, complementary fertilization was carried out through the application of Hoagland & Arnon (1950) nutritive solution. For this, 200 mL per pot were applied per day at the following concentrations: 20% of complete solution from 10 days after seedlings planting (DAP) until 17 DAP; 30% from 17 to 25 DAP; 50% from 25 to 30 DAP; and 100% of the complete solution from 30 to 40 DAP. At 15 DAP, nitrogen fertilization was also applied using urea at a volume equivalent to 310 kg ha^{-1} or 150 kg N ha^{-1}. Irrigation was performed daily.

At 21 DAP, when seedlings had six to seven expanded leaves, the herbicides were applied at the following doses: 1) fluazifop-p-butyl at 187.5 g a.i. ha^{-1} (Fusilade® 250 EW); 2) metribuzin at 400 g a.i. ha^{-1} (Sencor® 480 SC); 3) fluazifop-p-butyl + fomesafen at 125.0 + 125.0 g a.i. ha^{-1} (Fusiflex®); 4) fluazifop-p-butyl + fomesafen at 125.0 + 125.0 g a.i. ha^{-1} (Fusiflex®) + 0.2% mineral oil at 428.0 g a.i. ha^{-1} (Nimbus®); 5) trifluralin 1,800 g a.i. ha^{-1} (Premerlin® 600 EC); 6) clethodim at 84.0 g a.i. ha^{-1} (Select® 240 EC); 7) clethodim at 84.0 g a.i. ha^{-1} (Select® 240 EC) + 0.5% mineral oil at 428.0 g a.i. ha^{-1} (Nimbus®); and 8) control without herbicide application.

The herbicides were applied using a pressurized backpack sprayer at a constant pressure of 2.8 kgf cm^{-2} (compressed CO_2), equipped with a bar with four spray tips (Teejet® AIXR 110,015) spaced 0.5 m apart. The distribution of spray liquid was equivalent to 200 L ha^{-1}. At the time of application, the following data were recorded for experiments I, II and III, respectively: temperature of 14, 16 and 19ºC and relative humidity of 78, 67 and 80%.

The eight treatments were arranged in a completely randomized design with six replications. Each pot corresponded to a plot. Visual phytotoxicity scores were assigned according to the scale proposed by the European Weed Research Council (EWRC, 1964) at 7, 14, 21, 28, 35 and 42 days after application (DAA) of herbicides in both experiments (I and II). Score 1 was attributed to zero phytotoxicity, and score 9 to total plant death. Plant height, stem diameter, and relative total chlorophyll content (mod. ClorofiLog, Falker®) were determined. The chlorophyll content was measured on the third fully expanded leaf on a branch in the middle portion of plants.

At the end of the experimental period (42 DAA), the total number of fruits, leaf area (LiCor®, mod. LI3100A) and dry mass of stems, leaves, and fruits were obtained after oven-drying with forced air circulation at 60ºC±5 for 96 hours.

The collected data were subjected to analysis of variance using the F test. When statistically significant, the means were subjected to Tukey test at 5% probability. The choice of the most selective herbicides was carried out considering mean phytotoxicity values closest to the control.

Field experiment

The soil of the experimental area was prepared in a conventional way (plowing, followed by leveling harrows). Subsequently, a composite sample was taken for routine chemical analysis. The correction of base saturation (V%) of the area was carried out to raise the V% to values recommended for tomato crop (80%), since the soil analysis showed a 60% base saturation. Thus, the V% correction was carried out by applying 1.19 t ha^{-1} of dolomitic limestone. For the planting process, we used a furrower that marked lines every two meters apart. Holes were manually opened at every meter, and one seedling per hole was transplanted on January 29, 2018. During the experimental period, average values of 24.7ºC of temperature (maximum 31.2ºC and minimum of 20.2ºC), 76.7% relative humidity and precipitation of 137.8 mm were recorded.

The experimental plots consisted of four planting lines four meters long, totaling an area of 24 m^2. Only the two central lines were considered as useful plots for evaluation purposes, that is, two meters from each end were disregarded. In all, each plot had 16 plants and among them, two plants were evaluated. Spacing consisted of 1 meter between plants and 2 meters between planting rows. The experimental design was randomized blocks with four replications. The treatments used in the field research were 1) fluazifop-p-butyl at 187.5 g a.i. ha^{-1} (Fusilade® 250 EW); 2) fluazifop-p-butyl + fomesafen at 125.0 + 125.0 g a.i. ha^{-1} (Fusiflex®); 3) fluazifop-p-butyl + fomesafen at 125.0 + 125.0 g a.i. ha^{-1} (Fusiflex®) + 0.2% mineral oil at 428.0 g a.i. ha^{-1} (Nimbus®); 4) clethodim at 84.0 g a.i. ha^{-1} (Select®240 EC); 5) clethodim at 84.0 g a.i. ha^{-1} (Select®240 EC) + 0.5% mineral oil at 428.0 g a.i. ha^{-1} (Nimbus®); 6) control without weeding; and 7) control with weeding. These treatments were selected based on experiments I and II, conducted in pots.

The application of herbicides was carried out 25 days after seedling transplant using the same procedures as previously described for experiments conducted in pots. At the time of spraying the products, temperature values of 19.1ºC and relative humidity of 80% were recorded.

Crop treatments were carried out following the method recommended for the cultivation of tomatoes. Every week weeding was carried out in the plots for elimination of weeds. Sprinkler irrigation was performed every two days during two hours.

At the end of the experiment (42 DAP), plant height, stem diameter, leaf area (LiCor®, mod. LI3100A), and dry biomass of stems, leaves, and fruits were obtained after oven-drying with forced air circulation at 60ºC±5 for 96 hours.

The data were subjected to analysis of variance using the F test. When statistically significant, means were compared by Tukey test at 5% probability.

RESULTS AND DISCUSSION

Experiments in pots (EI and EII)

Although the experiments I and II were carried out at different times, the behavior of herbicides regarding the selectivity to *P. angulata* was similar. The most selective herbicides to *P. angulata* plants were clethodim and fluazifop-p-butyl in both experiments. These herbicides showed no visual symptoms of intoxication and obtained the lowest phytotoxicity scores (1), equaling the control (Figures 1A and 2A). Regarding the growth and productivity characteristics evaluated in *P. angulata* plants, higher values than the control without application were observed for the treatments that received these herbicides (except fruit dry matter

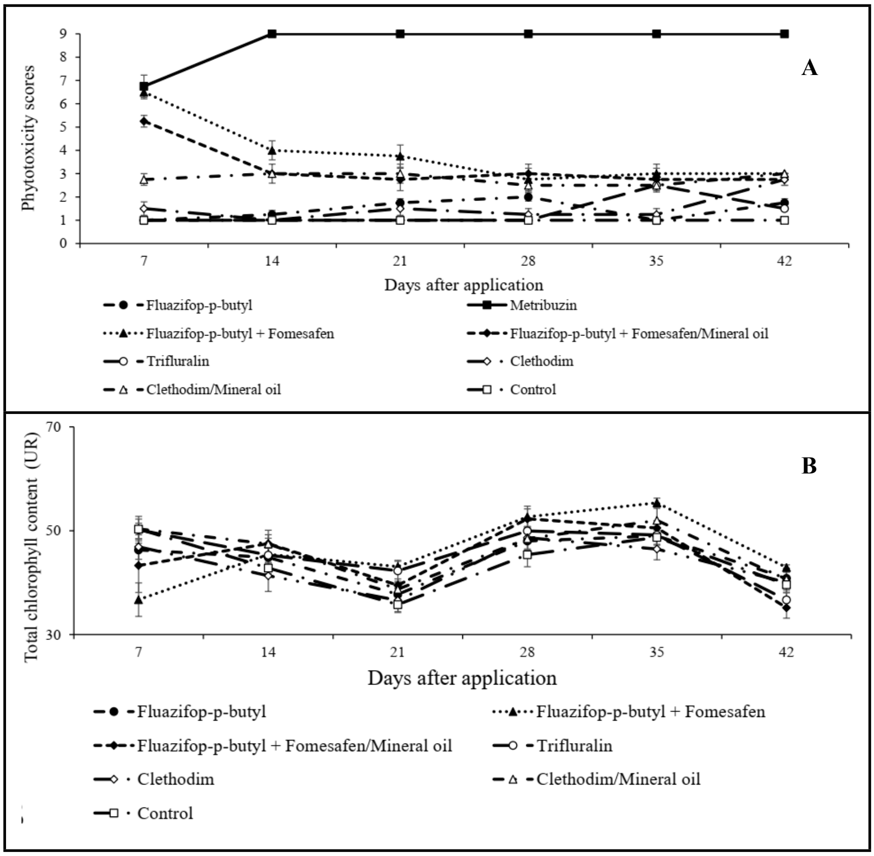

Figure 1. Phytotoxicity scores (A), total chlorophyll content (R.U. - B) of *Physalis angulata* plants submitted to the application of different herbicides. Experiment I, in pots. Jaboticabal, UNESP, 2018.

in experiment I) (Tables 1 and 2).

However, when fluazifop-p-butyl was applied with fomesafen with and without adjuvant, the result was different. There was a greater phytotoxicity in plants up to 14 DAA with scores between 5 and 7, which remained until 21 DAA in the second experiment, recovering in the following evaluations (Figure 2A). For the other herbicides, a mild phytotoxicity (scores 2 to 4) occurred up to 21 DAA. After that, *P. angulata* plants recovered over time (Figures 1A and 2A). In evaluations along the cycle, the chlorophyll content showed a tendency of decreasing values up to 21 DAA in experiment I, coinciding with the period during which there was a mild phytotoxicity caused by all herbicides (Figure 1A). For experiment II, there was a tendency to increase values up to 21 DAA, followed by maintenance until the last evaluation performed (Figure 2B). Height and diameter evaluations did not show statistical differences over time compared to the control in experiments I and II (data not shown), except for metribuzin, which caused the plants' death as early as at 7 DAA (Figures 1A and 2A).

Experiment II showed higher growth values than Experiment I, since the climate was more humid and hot in its conduction period, favoring the plants' development (Tables 1 and 2). Although the herbicide clethodim caused a mild phytotoxicity (Figure 1A), plants sprayed with this product obtained higher values for the number of fruits when compared to the control. For clethodim + adjuvant, despite low phytotoxicity scores, there was a detrimental effect on fruit dry mass (Table 1). In addition, it is worth mentioning that the absence of adjuvant in the use of clethodim in field conditions can alter its level of weed control. Thus, this should also be a factor to be taken into account, despite its low level of phytotoxicity demonstrated in the present experiment (Figures 1A and 2A, Tables 1 and 2).

The use of clethodim with and

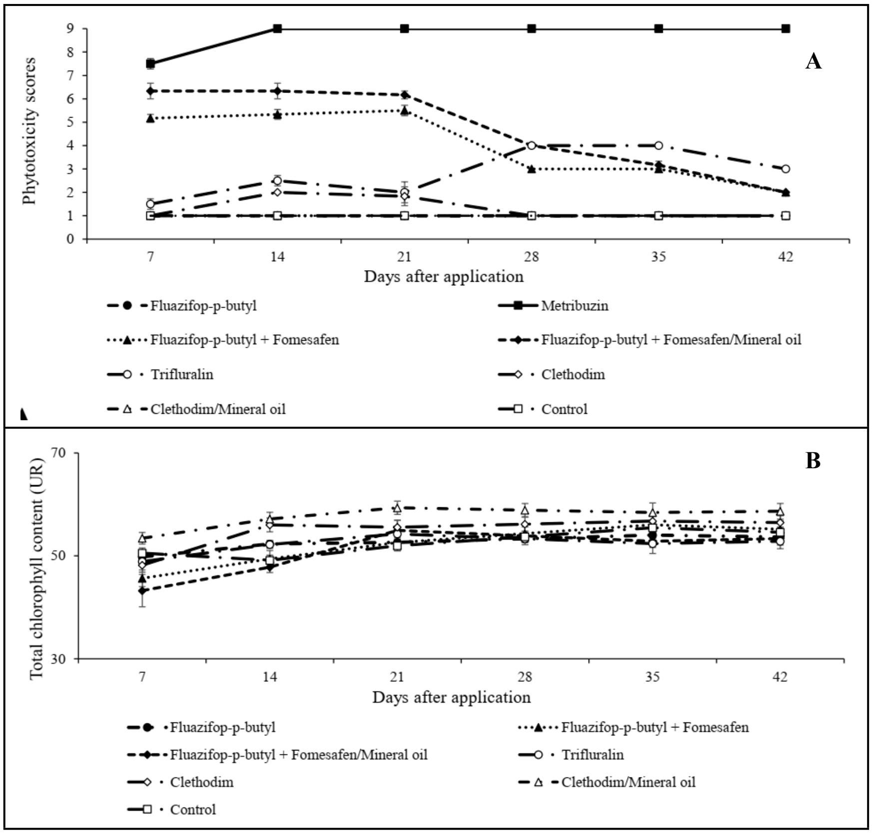

Figure 2. Phytotoxicity scores (A), total chlorophyll content (R.U. - B) of *Physalis angulata* plants submitted to the application of different herbicides. Experiment II, in pots. Jaboticabal, UNESP, 2018.

Table 1. Shoot dry mass (shoot DM, g), fruit dry mass (fruit DM, g plant^{-1}), leaf area (cm^2), number of fruits (NF), stem dry mass (stem DM, g) and leaf dry mass (leaf DM, g) of *Physalis angulata* plants evaluated at 42 days after application of different herbicides. All herbicides were applied in post-emergence of the crop. Experiment I, in pots. Jaboticabal, UNESP, 2018.

Treatment[1]	Shoot DM	Fruit DM	Leaf area	NF	Stem DM	Leaf DM
1	24.7 a	3.6 b	2,158.3 ab	7.0 a	12.9 ab	11.8 a
2	20.8 a	0.6 d	1,603.0 b	3.0 c	10.7 ab	10.1 a
3	22.4 a	2.3 bc	2,001.5 ab	4.0 bc	12.2 ab	10.1 a
4	20.1 a	1.0 cd	1,676.7 b	3.0 bc	10.1 b	10.0 a
5	27.2 a	6.2 a	2,572.7 a	7.0 a	14.1 a	13.0 a
6	27.1 a	3.2 b	2,391.1 a	4.0 b	15.1 ab	11.9 a
7	27.5 a	6.1 a	2,407.9 a	3.0 bc	14.5 ab	13.0 a
Mean	24.5	3.2	2,115.8	4.4	12.8	11.4
CV (%)	13.20	19.15	13.96	11.20	15.06	13.45

Means followed by the same letter in the column do not differ by Tukey test at 5% probability. [1]Treatments (1: fluazifop-p-butyl; 2: fluazifop-p-butyl + fomesafen; 3: fluazifop-p-butyl + fomesafen + adjuvant; 4: trifluralin; 5: clethodim; 6: clethodim + adjuvant; 7: control without application).

Table 2. Shoot dry mass (shoot DM, g), fruit dry mass (fruit DM, g plant^{-1}), leaf area (cm^2), number of fruits (NF), stem dry mass (stem DM, g) and leaf dry mass (leaf DM, g) of *Physalis angulata* plants evaluated 42 days after application of different herbicides. All herbicides were applied in post-emergence of the crop. Experiment II, in pots. Jaboticabal, UNESP, 2018.

Treatment[1]	Shoot DM	Fruit DM	Leaf area	NF	Stem DM	Leaf DM
1	59.8 a	1.8 cd	4,765.2 ab	7.0 d	42.9 a	16.8 a
2	44.7 b	0.8 e	3,690.9 ab	4.0 de	29.8 b	14.8 a
3	43.9 b	1.0 e	3,224.7 b	5.0 de	28.9 b	14.9 a
4	40.6 b	2.0 bc	3,250.3 b	2.0 e	25.5 b	15.0 a
5	59.0 a	2.6 ab	4,983.7 a	20.0 a	40.4 a	18.6 a
6	59.4 a	3.0 a	4,452.0 ab	16.0 b	39.3 a	20.0 a
7	60.0 a	1.3 de	4,672.5 ab	10.0 c	39.5 a	20.4 a
Mean	52.48	1.6	4,148.4	9.1	35.1	17.2
CV (%)	10.91	19.36	21.52	21.91	14.51	17.77

Means followed by the same letter in the column do not differ by Tukey test at 5% probability. [1]Treatments (1: fluazifop-p-butyl; 2: fluazifop-p-butyl + fomesafen; 3: fluazifop-p-butyl + fomesafen + adjuvant; 4: trifluralin; 5: clethodim; 6: clethodim + adjuvant; 7: control without herbicide application).

without adjuvant in experiment II provided a fruit dry mass greater than that of the control, as well as a greater number of fruits. The other characteristics did not differ significantly (Table 2). Fluazifop-p-butyl resulted in less fruits compared to the control, while fluazifop-p-butyl + fomesafen, despite having attenuated phytotoxicity symptoms, caused a reduction in several growth characteristics, such as stem dry mass, shoot dry mass and number of fruits. This response was also observed for fluazifop-p-butyl/fomesafen + adjuvant (Table 2).

The herbicide metribuzin did not show any degree of selectivity to this species in experiments conducted in pots, once at 7 DAA *P. angulata* plants were already dead. According to Castro *et al.* (2016), metribuzin is a herbicide registered for the control of dicots. Its absorption occurs mainly by roots, from where it is translocated through the xylem to stems and leaves, causing the inhibition of Hill's reaction in the photosynthetic process (Oliveira Junior, 2011).

Cavalieri *et al.* (2011) applied metribuzin (480 g a.i. ha^{-1}) and carfentrazone in tomato crop and observed that there was no phytotoxicity at 27 days after transplantation (DAT). Cavalieri & Sant'ana (2012) also reported similar results regarding the absence of phytotoxic effects of metribuzin (480 g a.i. ha^{-1}) on tomatoes. For the potato crop (*S. tuberosum*), which also belongs to the Solanaceae family, Correia & Carvalho (2018) observed that this herbicide was selective for both pre- and post-emergence application from the crop. However, for *P. angulata*, the application of metribuzin (480 g a.i. ha^{-1}) caused an intense chlorosis and a consequent severe phytotoxicity, leading to the plant's death at 7 DAA (Figures 1A and 2A). In this sense, it is worth mentioning that, in addition to the time of application (pre or post-emergence), different genetic materials (species or even cultivars) may present differences in translocation, compartmentalization, and metabolization of chemical molecules (Hutchinson *et al.*, 2005), justifying the differences in the results reported in the mentioned works.

The chlorosis in plants resulting from the application of herbicide can occur due to lipid peroxidation, which promotes the destruction of cell membranes and the consequent loss of chlorophylls (Oliveira & Brighenti, 2011). In addition, it is worth noting that although *P. angulata* belongs to the Solanaceae family, as well as tomatoes, its sensitivity to metribuzin is considerably higher than that of *Solanum lycopersicum*, thus elucidating the importance of previous studies that aim at adapting herbicides for small crops. As seen, the herbicide metribuzin was the one that generated the higher toxicity, followed by trifluralin, which although did not cause the plants death, it was detrimental to the development of *P. angulata* (Tables 1 and 2).

The mechanism of action of the herbicide trifluralin consists of inhibiting cell division in meristematic tissues, consequently preventing seed germination and formation of new cells in root and stem (Rodrigues & Almeida, 2011). This herbicide, when applied 21 days after planting, caused regular phytotoxicity (score 4) to *P. angulata* from 28 to 35 DAA (Figure 2A), being statistically different from the control regarding fruit dry mass in the first experiment (Table 1) and shoot and stem dry mass in the second experiment (Table 2). It should be noted that the application of trifluralin on seedlings is due to the fact that, in case there is no deleterious effect on *P. angulata* plants, it would be possible to suggest its application in the total area ("over the top"), after planting the seedlings.

In a different way, the application of this same herbicide in pre-emergence to potato crop did not cause symptoms of intoxication in plants at all doses tested by Alebrahim *et al.* (2012). These results corroborate with those of Uremis *et al.* (2009) and Ale Ebrahim *et al.* (2012) in which the authors performed pre-emergence application and reported no negative effect on productivity, being safe for use in commercial fields. It is possible to note that this selectivity occurred only in

Table 3. Shoot dry mass (shoot DM, g), fruit dry mass (fruit DM, g plant^{-1}), leaf area (cm^2), number of fruits (NF), stem dry mass (stem DM, g) and leaf dry mass (leaf DM, g) of *Physalis angulata* plants evaluated at 42 days after application of different herbicides. All herbicides were applied in post-emergence of the crop. Experiment III, in field conditions. Jaboticabal, UNESP, 2018.

Treatment[1]	Shoot DM	Fruit DM	Leaf area	NF	Stem DM	Leaf DM
1	345.6 a	45.8 a	25,121.4 a	66.0 a	217.8 a	127.7 a
2	179.9 bc	34.6 ab	19,419.1 b	39.0 b	126.4 b	53.4 d
3	305.5 a	27.2 bc	9,991.9 c	42.0 b	200.8 a	104.7 ab
4	225.6 b	34.4 ab	12,614.1 c	50.0 ab	156.0 ab	90.5 bc
5	197.2 bc	19.3 cd	12,249.9 c	37.0 b	130.8 b	66.4 cd
6	159.1 c	11.3 d	8,600.2 c	36.0 b	103.9 b	55.1 d
7	199.1 bc	38.0 ab	9,926.2 c	46.0 ab	130.6 b	63.0 cd
Mean	230.3	30.1	13,989	45.1	152.3	80.1
CV (%)	12.04	20.73	12.35	20.67	18.34	15.3

Means followed by the same letter in the column do not differ by Tukey test at 5% probability. [1]Treatments (1: fluazifop-p-butyl; 2: fluazifop-p-butyl + fomesafen; 3: fluazifop-p-butyl + fomesafen + adjuvant; 4: clethodim; 5: clethodim + adjuvant; 6: control without weeding; 7: control with weeding).

experiments in which the herbicide was applied in pre-emergence, unlike the present work, in which this herbicide was applied in post-emergence of the crop. Thus, it is noteworthy that in addition to the species, the herbicide's time of application (whether in post or pre-emergence of the crop) is also a determining factor in observing, or not, the selectivity of the product to the cultivated species (Oliveira Junior & Inoue, 2011).

In view of the data presented in experiments I and II, the herbicides metribuzin and trifluralin were removed from experiment III. The other herbicides were maintained for verification of selectivity at field level.

Field experiment (EIII)

As observed in experiments I and II, in the field experiment the herbicides clethodim and fluazifop-p-butyl also stood out for number of fruits (Table 3). The number of fruits of the plants in the plots with the herbicide clethodim were 50 units, while for fluazifop-p-butyl, the number of fruits almost doubled (66) when compared to the control without weeding (36), being statistically different ($p<0.05$). Likewise, when fruit dry mass was evaluated, the treatment with the application of fluazifop-p-butyl provided better results (45.8 g plant^{-1}) than those with application of clethodim (34.4 g plant^{-1}), being both statistically different ($p<0.05$) when compared to control without weeding (11.3 g plant^{-1}) (Table 3).

The mixture of fluazifop-p-butyl with fomesafen with and without adjuvant caused a moderate intoxication to crop plants (Figures 1A and 2A) and the number of fruits did not differ from the control with weeding (Table 3). The intoxication observed in plants from experiments I and II was probably due to fomesafen, because, when applied alone, Castro *et al.* (2020) observed reductions of up to 62% in tomato plants, compared to the control without herbicides. When there is a mixture of fluazifop-p-butyl + fomesafen, the formulation acquires a broad spectrum of weed control (Silva & Silva, 2007), which may be a viable alternative for the cultivation of *P. angulata*, insofar as future works indicate the possibility of a later application compared to those used in this experiment, since the results in field proved to be promising (Table 3).

The difference from the aforementioned works is because the susceptibility or tolerance of plants to herbicides can vary according to several factors, such as time of application, size of plants at the time of spraying, and the product used, even those in a same chemical group or with a similar mechanism of action (Oliveira Junior & Inoue, 2011). In this sense, it is important to point out that studies indicating the critical period of weed interference (CPWI), that is, the period during which weed control would be essential to minimize interference in crop, are incipient for *P. angulata*. Thus, as future work indicates that the application of the herbicides can be carried out later, the tolerance to the products can be influenced (Oliveira Junior & Inoue, 2011).

The mechanism of action of the herbicides fluazifop-p-butyl and clethodim is characterized by the inhibition of the enzyme ACCase (acetyl-coenzyme A carboxylase), which acts fundamentally in the lipid synthesis process. Herbicides belonging to this class are popularly known as graminicides and are often selective for dicotyledonous crops (Vidal, 1997). Thus, in this work, the application of these two herbicides with and without adjuvant caused a considerably mild phytotoxicity to plants, not harming the development characteristics of the crop during the experimental periods (Tables 1 to 3).

Thus, the results obtained in the present study can be a starting point for future works on weed control in cultivation areas of *P. angulata* and can also be a basis for a possible registration of new herbicides for this crop.

We concluded that clethodim without adjuvant and fluazifop-p-butyl are selective for *P. angulata* crop, not negatively affecting its production, even though it caused mild phytotoxicity after application. It should be considered that the absence of adjuvant may affect the performance of clethodim in weed control. Metribuzin applied at a dose of 480 g a.i. ha^{-1} is not selective for *P. angulata* crop. The herbicides trifluralin and fluazifop-p-butyl + fomesafen did not lead to the plants' death, however, caused phytotoxicity harmful to the crop development in pot experiments. Under field conditions, the application of fluazifop-p-butyl + fomesafen did not negatively affect crop production and growth, being selective to *P. angulata*.

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