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Selectivity of Post-emergence Herbicides for the Chickpea

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Abstract

Few herbicide options are available for controlling post-emergence weeds in the chickpea. The aim of this work therefore, was to study the selectivity of herbicides applied post-emergence for the chickpea 'BRS Aleppo'. Two experiments were carried out, one in the greenhouse and the other in the field (winter-spring crop). A completely randomised experimental design was used for the screening experiment (greenhouse), with 15 treatments and four replications. Fourteen treatments with herbicides (g a.i. ha^{-1}) were evaluated: bentazon (360 and 720), chlorimuron (10 and 20), clethodim (54 and 108), fluazifop (94 and 188), fomesafen (125 and 250), haloxyfop (30 and 60) and lactofen (90 and 180), in addition to the control with no application. From this experiment, herbicides that did not impair growth in the chickpea were selected for the field experiment based on plant height and shoot dry matter. During the field stage, a randomised block design was used, with 11 treatments and three replications. Ten treatments including the herbicides clethodim, fluazifop, fomesafen, haloxyfop and lactofen were evaluated in two rates, in addition to the control with no application. Based on the results of the two experiments, it was concluded that the ACCase inhibitors (clethodim, fluazifop and haloxyfop) caused no lesions or damage to the chickpea, while the latifolicides (fomesafen and lactofen) caused visual lesions which did not result in significant loss in yield. Bentazon (360 and 720 g a.i. ha^{-1}) and chlorimuron-ethyl (10 and 20 a.i. g ha^{-1}) were not selective, causing severe damage to the chickpea plants.

Keywords: *Cicer arietinum* L., chemical control, tolerance, weeds

1. Introduction

The chickpea (*Cicer arietinum* L.) is one of the world's leading grain legumes for human consumption and a major source of protein, fibre, vitamins, carbohydrates, minerals, unsaturated fatty acids and β-carotene (Jukanti et al., 2012). In 2017, 14.8 million tons were harvested on 14.6 million hectares around the world (FAO, 2019).

However, the low yield of the chickpea worldwide, of approximately 1014 kg ha^{-1}, is due in part to the problems faced with weeds, which is considered to be one of the most limiting factors in crop production (Solh and Pala, 1990). When present in areas of chickpea cultivation, weeds cause losses in production of from 25 to 97% (Al-Thahabi et al., 1994; Mohammadi et al., 2005; Paolini et al., 2006; Tepe et al., 2011). In Brazil, losses in chickpea yield due to weed interference have been estimated at 70%, on average, irrespective of nitrogen fertiliser management (Amaral et al., 2018).

Weeds can therefore make cultivation of the chickpea economically inviable. The chickpea is an annual legume, with slow initial growth, open canopy architecture and small plants, and is thus highly susceptible to weed interference (Knights, 1991). In the case of poor crop management, greater attention should be paid to weed control to avoid a loss in yield.

Among the methods of control, the use of herbicides may be an alternative for controlling weeds in the chickpea, because, in addition to being more effective, it is faster and cheaper (Oliveira et al., 2011). However, in order to guarantee the success of chemical control, it is important to consider the selectivity of the herbicides for the crop in question; these should provide adequate weed control and, at the same time, not harm the crop of commercial interest (Oliveira Jr. & Inoue, 2011).

To date in Brazil, there are no registered herbicides for weed control in the chickpea (Agrofit, 2019; Rodrigues & Almeida, 2018). In the United States there is a shortage of registered herbicides for post-emergence broadleaf control in the chickpea (Boydston et al., 2017). In Canada, metribuzin is the only registered herbicide for post-emergence broadleaf control in the chickpea (Saskatchewan Ministry of Agriculture, 2019). Globally therefore, post-emergence herbicides in chickpea cultivation are limited, especially those whose spectrum includes the control of broadleaf weeds.

Earlier research has shown the potential of graminicides (fluazifop, fenoxaprop and quizalofop) for controlling weeds of the Poaceae family with no adverse effect on the chickpea (Plew et al., 1994; Malik et al., 2001; Khan et al., 2018; Nath et al., 2018); of fomesafen and acifluorfen for the control of broadleaf weeds, even when causing visual lesions at the start of chickpea development (Malik et al., 2001; Boydston et al., 2017; Nath et al., 2018); while the potential of the herbicides imazethapyr, imazamox and metribuzin depends strongly on the correct choice of genotype, a poorly managed trait can compromise yield in areas of chickpea cultivation (Tar'an et al., 2010; Tar'an et al., 2013; Jain & Tar'an, 2013; Gaur et al., 2013; Jefferies et al., 2016).

In Brazil, there is still a lack of information on the selectivity of herbicides in the chickpea. Based on botanical nearness, the hypothesis of the present study was that herbicides commonly used in other legumes, such as the common bean (*Phaseolus vulgaris* L.) and soybean (*Glycine max* L.), may be selective for the chickpea. As such, the aim was to study selectivity for the chickpea in post-emergence herbicides.

2. Methods

Two experiments were carried out, one in the greenhouse of the Plant Production Department in 2015, and the other in the field (winter-spring crop) in 2016, both at the Goiano Federal Institute, in Urutaí, in the state of Goiás, Brazil.

2.1 Greenhouse Experiment

In the greenhouse, the experimental design was completely randomised, with four replications. Initially, 14 treatments with herbicides (a.i. ha^{-1}) were tested: 360 and 720 g bentazon, 10 and 20 g chlorimuron, 54 and 108 g clethodim, 94 and 188 g fluazifop, 125 and 250 g fomesafen, 30 and 60 g haloxyfop, and 90 and 180 g lactofen, in addition to the control with no product. Adjuvant (0.5% v v^{-1} of mineral oil) was added to the solution as per the manufacturer of each of the commercial products.

Each experimental unit consisted of a plastic pot with a capacity of 5.0 dm^3. Three plants of the chickpea 'BRS Aleppo' were maintained per vessel, which was filled only with soil belonging to the Class of Dystrophic Red Latosols removed from the 0.0 to 0.20 m layer, with a sandy loam texture (52% sand, 37% clay and 11% silt), a pH of 5.6, 4.9 g dm^{-3} organic matter and base saturation of 54%. To supply water to the plants, each pot was placed in a larger-diameter vessel with no holes. Soil moisture was controlled periodically, with the water in the vessels being replaced whenever necessary.

The herbicides were applied to the chickpea when the plants had from 8 to 10 true leaves. The applications were made using an ADIA 110.015 sprayer, with a constant pressure of 2.4 kgf cm^{-2} maintained by CO_2, equipped with a spray bar with four Magno flat-jet nozzles spaced 0.50 m apart, giving an application volume of 200 L ha^{-1}. At the time of application, a relative humidity of 51.2%, air temperature of 27.2 °C and a wind speed of up to 2.6 km h^{-1} were recorded. Fifty-six days after application (DAA) of the herbicides, plant height was determined, measured from the base of the plant to the insertion of the last leaf on the main stem; dry matter was determined by collecting the complete aerial part of the plant. The plant material was dried in an oven at 65 °C to constant weight, when the weight was determined. Herbicides that did not adversely affect plant growth, verified from the height and dry matter of the plants, were selected for use in the field.

2.2 Field Experiment

The field experiment was set up at 17°28′41″ S and 48°11′35″ W at a mean altitude of 800 metres. According to the Köppen classification, the climate is type Aw, humid tropical with dry winters (Alvarez et al., 2014). During the experiment, the temperature ranged from 15.6 to 34.1 °C. The experimental area was irrigated via central pivot. When necessary, a 10-mm irrigation depth was applied.

The soil of the experimental area also belongs to the class of dystrophic Red Latosols, with a clayey texture (49% sand, 37% clay and 14% silt). The initial values for the chemical attributes of the soil in the 0.0 to 0.20 m layer were: a pH of 5.1, 1.1 $cmol_c$ dm^{-3} $H^+ + Al^+$, 2.5 g dm^{-3} organic matter, 3.4 mg dm^{-3} P, 110 mg dm^{-3} K^+, 1.9 $cmol_c$ dm^{-3} Ca^{2+}, 0.8 $cmol_c$ dm^{-3} Mg^{2+} and a base saturation of 53%.

The experimental area was prepared conventionally by harrowing to a depth of ±0.25 m, followed by two passes of the harrow to break up the surface soil. Sixty kg ha^{-1} K_2O was then broadcast in the form of potassium chloride. Planting furrows were opened using a six-row, mechanically drawn bar plough. Sowing was by hand, at a spacing of 0.50 m between rows, with 22 seeds distributed per metre. Fertiliser was manually applied when sowing at a rate of 500 kg ha^{-1} single superphosphate (18% P_2O_5, 16% Ca^{2+} and 8% S). Twenty-four days after chickpea emergence, 70 kg ha^{-1} N was applied as cover in the form of urea.

The experimental design was of randomised blocks with three replications. Ten treatments with herbicides (a.i. ha^{-1}) were tested: 54 and 108 g clethodim, 94 and 188 g fluazifop, 125 and 250 g fomesafen, 30 and 60 g haloxyfop and 90 and 180 g lactofen, in addition to the control with no application. Adjuvant (0.5% v v^{-1} of mineral oil) was added to the solution as per the manufacturer of each of the commercial products. Each experimental plot was 2.0 m in width × 4.0 m in length, giving a total area of 8.0 m^2 and a working area of 1.5 m^2.

The herbicides were applied when the chickpea plants had between 8 and 10 leaves, similar to in the greenhouse. The same application technology described for the greenhouse experiment was used. At the time of application, a relative humidity of 32.8%, air temperature of 29.9 °C, and a wind speed of up to 3.6 km h^{-1} were recorded.

All the experimental plots were kept free of weeds until the chickpea was harvested, with the manual elimination of any weeds escaping chemical control, and the removal by hand of all the weeds in the treatment with no commercial product.

Possible visual damage in the chickpea plants was evaluated at 14, 28 and 42 days after application (DAA) of the herbicides, using a scale of 0 to 100%, where zero means no visual damage and 100 means the death of the plant (Velini et al., 1995). The chickpea was harvested 120 days after sowing.

The selectivity of the herbicides was evaluated using the following agronomic variables: days to flowering, when 50% of the plants in the working area of the plot had at least one open flower, considering the number of days from emergence to flowering; shoot dry matter, collected during full flowering (two samples of one metre from each row within the working area of each plot); grain yield, the weight of all of the grain from the working area of the experimental plots, with the values estimated in kg ha^{-1}; number of pods per plant, a count of all the pods from ten plants in the working area of each plot; and the 100-grain weight. The values for grain yield and weight were corrected for 13% moisture.

2.3 Data Analysis

The data were submitted to univariate analysis of variance (F-test). The residuals were tested for normality by the Shapiro-Wilk test, and homoscedasticity by Bartlett's test. The mean values of the treatments were compared by LSD (Least Significant Difference, $\alpha = 0.05$). Each treatment with herbicide was individually compared to the control using Dunnett's test ($\alpha = 0.05$). The statistical analysis was carried out using the R v3.0.3 software (R Core Team, 2017).

3. Results

In the greenhouse experiment, there was a significant effect between the herbicides ($p < 0.05$) on chickpea growth (Table 1). The treatments that included the ACCase inhibitors (54 and 108 g a.i. ha^{-1} clethodim, 94 and 188 g a.i. ha^{-1} fluazifop, and 30 and 60 g a.i. ha^{-1} haloxyfop) and the latifolicides (125 and 250 g a.i. ha^{-1} fomesafen, and 90 and 180 g a.i. ha^{-1} lactofen) had no effect on plant height or shoot dry matter, different to the herbicides bentazon and chlorimuron, that negatively affected chickpea growth. Due to the toxic effect on the plants, bentazon reduced plant height and shoot dry matter by, on average, 52% and 83% respectively, whereas chlorimuron gave a respective mean reduction of 68% and 96%.

Table 1. Screening to evaluate the potential of herbicides applied in post-emergence for chickpea cv. BRS Aleppo—greenhouse experiment

Treatment	Rate	Height	Dry matter
	g a.i. ha^{-1}	cm	g
Bentazon	360	20.9 $b^{(-)}$	5.1 $b^{(-)}$
Bentazon	720	13.5 $c^{(-)}$	1.0 $bc^{(-)}$
Chlorimuron	10	10.6 $c^{(-)}$	1.0 $bc^{(-)}$
Chlorimuron	20	12.0 $c^{(-)}$	0.6 $c^{(-)}$
Clethodim	54	34.1 a	17.9 a
Clethodim	108	33.7 a	15.4 a
Fluazifop	94	35.9 a	16.4 a
Fluazifop	188	37.1 a	16.4 a
Fomesafen	125	38.0 a	16.8 a
Fomesafen	250	37.2 a	15.5 a
Haloxyfop	30	34.6 a	17.7 a
Haloxyfop	60	38.3 a	18.1 a
Lactofen	90	35.2 a	16.6 a
Lactofen	180	35.0 a	14.0 a
Untreated	-	35.5 a	17.4 a
	F ($p < 0.05$)	0.000	0.000
	LSD	6.77	4.34
	CV (%)	8.44	12.89

Note. Means followed by the same letter in the column are not significantly different by the LSD test ($p < 0.05$).

Means followed by (-) were lower than the control (without application of product), by the Dunnet test ($p < 0.05$).

In the field experiment, the herbicides fomesafen (125 and 250 g a.i. ha^{-1}) and lactofen (90 and 180 g a.i. ha^{-1}) caused visual damage to the plants but did not cause the death of the chickpea. At 14 DAA, the lesions were more pronounced, ranging from 16 to 41% (Table 1). On average, lactofen caused greater damage to the plants than did fomesafen. However, over time, at 28 and 42 DAA, the chickpea plants resumed satisfactory growth. On the other hand, the herbicides clethodim, fluazifop and haloxyfop caused no visual damage to the plants. The agronomic variables (days to flowering, dry matter, number of pods per plant, 100-grain weight and grain yield) were not altered by the application of the herbicides ($p \geq 0.05$), and therefore did not differ from the control (Table 2).

Table 2. Selectivity of herbicides applied in post-emergence for chickpea cv. BRS Aleppo—experiment in field conditions

Treatment	Rate (g a.i. ha^{-1})	Crop injury (%) 14 DAA	28 DAA	42 DAA	Days for flowering (n°)	Dry matter (g $plant^{-1}$)	Pods (n° $plant^{-1}$)	100-grain weight (g)	Yield (kg ha^{-1})
Clethodim	54	0.0 a	0.0 a	0.0	42	13.50	31.7	30.2	3017
Clethodim	108	0.0 a	0.0 a	0.0	42	13.03	27.3	30.4	3204
Fluazifop	94	0.0 a	0.0 a	0.0	42	13.03	29.3	31.0	2959
Fluazifop	188	0.0 a	0.0 a	0.0	42	12.20	30.7	31.3	2871
Fomesafen	125	16.0 b(+)	2.66 b(+)	0.0	42	13.56	39.0	31.0	3295
Fomesafen	250	19.7 a(+)	4.66 b(+)	0.0	42	12.40	27.3	31.1	2560
Haloxyfop	30	0.0 a	0.0 a	0.0	42	12.90	34.2	30.2	2898
Haloxyfop	60	0.0 a	0.0 a	0.0	42	13.50	34.7	32. 0	3010
Lactofen	90	29.3 d(+)	12.00 c(+)	0.0	42	10.66	28.9	30.8	3062
Lactofen	180	41.3 e(+)	17.33 d(+)	0.0	42	9.16	26.7	30.8	2488
Untreated	-	0.0 a	0.0 a	0.0	42	15.26	36.7	31.4	2917
	F ($p < 0.05$)	0.000	0.000	-	-	0.633	0.432	0.245	0.753
	LSD	2.94	2.11	-	-	9.91	22.02	2.49	1635.89
	CV (%)	9.57	19.90	-	-	24.64	22.00	2.54	17.55

Note. Means followed by the same letter in the column are not significantly different by the LSD test ($p < 0.05$).

Means followed by (+) were higher than the control (without application of product), by the Dunnet test ($p < 0.05$).

4. Discussion

The ACCase inhibitors (clethodim, fluazifop and haloxyfop), which only control species of family Poaceae, did not cause lesions in the chickpea plants; unlike the latifolicides (bentazon, chlorimuron, fomesafen and lactofen), which have a broader spectrum for the control of dicotyledonous species, and which caused lesions, especially chlorosis or necrosis.

In the greenhouse, the application of 360 and 720 g a.i. ha^{-1} bentazon caused severe lesions or death in the chickpea, and consequently affected growth, with plants of reduced size and less shoot dry matter at 56 DAA. Under field conditions, Tanveer et al. (2010) found 100% mortality in the chickpea cultivar Bital-98 with the application of 720 g a.i. ha^{-1} bentazon, corroborating the present study. Bentazon (1000 and 1500 g a.i. ha^{-1}), applied post-emergence, also caused severe damage or death in the Kabuli chickpea, with a loss in yield of 90.3% and 86.1% respectively (Plew et al., 1994). A loss of 68% in the yield of the chickpea cultivar L-144 was also seen with the application of 1500 g a.i. ha^{-1} bentazon (Yadav et al., 1983). As such, the results confirm the high susceptibility of the chickpea to the herbicide, bentazon.

Severe damage to the chickpea was also found from the application of 10 and 20 g a.i. ha^{-1} chlorimuron, with a negative effect on plant height and dry matter. Severe phytotoxic action of chlorimuron (3 and 4 g ha^{-1}) was recorded in the chickpea cultivar DCP 92-3 intercropped with mustard, resulting in a loss in yield of 90% and 92% respectively (Kumar et al., 2015).

The herbicides fomesafen (125 and 250 g a.i. ha^{-1}) and lactofen (90 and 180 g a.i. ha^{-1}) caused necrotic lesions on the leaves of the chickpea, but the symptoms decreased over time. Due to plant recovery, height and shoot dry matter were not affected, thereby showing satisfactory growth. The ACCase inhibitors (clethodim, fluazifop and haloxyfop), caused no visual lesions and as such, the chickpea plants again showed satisfactory growth.

Based on the results obtained in the greenhouse experiment, the chickpea did not tolerate the post-emergent application of 360 and 720 g a.i. ha^{-1} bentazon, or 10 and 20 g a.i. ha^{-1} chlorimuron, unlike the application of the herbicides clethodim, fluazifop, fomesafen, haloxyfop and lactofen, which were selected for the field experiment as they did not affect the growth (height or dry matter) of the chickpea plants.

Corroborating the field data, the herbicides clethodim, fluazifop and haloxyfop, irrespective of the rate, caused no visual damage to the chickpea. These results are confirmed by the natural tolerance mechanism found in dicotyledonous crops, which is the presence of an ACCase (acetyl-CoA carboxylase), in its prokaryotic form insensitive to graminicides and therefore unaffected by the herbicides (Sasaki et al., 1995).

In other studies, the chickpea proved to be tolerant to applications of clethodim (60 and 120 g a.i. ha^{-1}) and haloxyfop (150 and 300 g a.i. ha^{-1}), for the Kabuli (Plew et al., 1994), and fluazifop (50 and 75 g a.i. ha^{-1}) for 'CM-72' (Malik et al., 2001); as well as other ACCase inhibitors, such as fenoxaprop, for 'Karak-I' (Khan et al., 2018), and clodinafop or quizalofop for 'JG 130' (Nath et al., 2018).

On the other hand, the herbicides fomesafen (125 and 250 g a.i. ha^{-1}) and lactofen (90 and 180 g a.i. ha^{-1}) caused visual damage to the plants up to 28 DAA. These were no longer seen at 42 DAA as a result of plant recovery, possibly in response to non-translocation of the herbicides. The injury, characterised as whitish necrotic lesions, were restricted to the leaves that intercepted the spray jet, and new leaves, emitted after application, showed no visual damage.

Similar to the greenhouse data, visual damage was more marked as the rate of herbicide increased, with lactofen again causing the greatest visual damage. However, the chickpea grown in the field showed a greater capacity for recovery compared to under greenhouse conditions.

In fact, herbicides belonging to the diphenyl-ether chemical group, such as fomesafen and lactofen, show little selectivity when in direct contact with the leaves, but do not cause the death of the chickpea crop. Other studies have also demonstrated the potential of fomesafen for use in post-emergence spraying of the chickpea at a rate of 130 g a.i. ha^{-1} for 'CM-72' (Malik et al., 2001), and at 280 g a.i. ha^{-1} for 'Sierra' (Boydston et al., 2017). The same was seen for acifluorfen, sprayed post-emergence at rates of 500 and 420 g a.i. ha^{-1}, which also showed selectivity for the Sierra and JG 130 cultivars respectively (Boydston et al., 2017; Nath et al., 2018).

There were no significant effects from the herbicides on the agronomic variables: days to flowering, shoot dry matter, number of pods per plant, 100-grain weight or grain yield. The ACCase inhibitors (clethodim, fluazifop and haloxyfop) cause no lesions or damage to the chickpea, while the latifolicides (fomesafen and lactofen) cause visual damage that does not result in a significant loss in yield.

Based on the greenhouse and field data, it was found that the chickpea did not tolerate the post-emergence application of bentazon or chlorimuron; whereas the herbicides clethodim, fluazifop, fomesafen, haloxyfop and lactofen can be used as future options for chemical control of weeds in commercial chickpea areas.

5. Conclusion

Clethodim (54 and 108 g a.i. ha^{-1}), fluazifop (94 and 188 g a.i. ha^{-1}), fomesafen (125 and 250 g a.i. ha^{-1}), haloxyfop (30 and 60 g a.i. ha^{-1}) and lactofen (90 and 180 g a.i. ha^{-1}) were selective when applied post-emergence in the BRS Aleppo cultivar. The herbicides bentazon (360 and 720 g a.i. ha^{-1}) and chlorimuron (10 and 20 g a.i. ha^{-1}) were not selective for the chickpea.

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