Journal of Plant Protection Research ISSN 1427-4345

ORIGINAL ARTICLE

Selectivity of diphenyl-ether herbicides with postemergence applications in chickpea

Luís Gustavo Barroso Silva[1], Lucas da Silva Araújo[2]*, Daniel José Gonçalves[1], Mateus Souza Valente[1], Anderson Rodrigo da Silva[1], Warley Marcos Nascimento[3], Paulo César Ribeiro da Cunha[1]

[1] Department of Crop Science, Institute Federal Goiano, Urutaí, Brazil

[2] Department of Crop Science, University of São Paulo, College of Agriculture "Luiz de Queiroz", Piracicaba, Brazil

[3] Department of Horticultural Sciences, Embrapa Hortaliças, Brasília, Brazil

Vol. 59, No. 3: 350–354, 2019

DOI: 10.24425/jppr.2019.129749

Received: February 11, 2019
Accepted: August 26, 2019

*Corresponding address:
l.s.araujo@usp.br

Abstract

There are few reports in literature about the selectivity of postemergence application of herbicides for the control of eudicotyledon weeds (broadleaf) in chickpea. For this reason, the aim of this study was to investigate the selectivity of diphenyl-ether herbicides in chickpea influenced by the herbicides and application rates. A field experiment was conducted from February to June 2017 in Urutaí, state of Goiás, Brazil. Cultivar BRS Aleppo was used in the experiment. The experiment was set up in a randomized block design with 2 × 3 + 1 factorial arrangement and three replications. The first factor was herbicides (fomesafen and lactofen) with the second factor being herbicide rate (50, 75, and 100% of referenced rate) plus an untreated check as a comparison. The applied rates of herbicides were 250 and 180 g · ha^{-1} of fomesafen and lactofen, respectively. The selectivity of herbicides was evaluated according to agronomic characteristics (plant population, height, dry matter, number of pods per plant and 100-grain weight) and yields. Both herbicides, regardless of dosage, were selective in chickpea cultivation, even exhibiting leaf necrosis symptoms with visible injuries below 20% with no effect on yield.

Keywords: *Cicer arietinum*, diphenyl-ether herbicides, weeds

Introduction

Chickpea (*Cicer arietinum* L.) is the third most important grain legume in the world, grown on 12.65 million hectares with a production of over 12 million tons (FAO 2018). In chickpea production, weeds are a major concern since they can be a limiting factor. Chickpea yield losses may range from 25 to 97% if weeds are not properly managed (Al-Thahabi *et al.* 1994; Mohammadi *et al.* 2005; Paolini *et al.* 2006; Tepe *et al.* 2011).

In Brazil, the presence of weeds has adversely affected chickpea production, reducing it by an average of 70%, irrespective of the N rate, which makes the crop economically unviable (Amaral *et al.* 2018). Competition between weeds and crops is for water, light, nutrients and space (Mohammadi *et al.* 2005; Paolini *et al.* 2006). In the case of chickpeas, competition is even stronger because of the slow growth rate in the early stages of this plant and its open canopy architecture and short stature which are characteristics that impair the plants' ability to compete and favor the establishment of weeds in the crop area (Solh and Pala 1990). Therefore, weed control is an important management strategy in order to prevent chickpea yield losses.

Among weed control methods, chemical control is the most common due to its many advantages, e.g. it is quick, effective and cheap (Oliveira 2011a). However, when selecting the proper herbicide, the selectivity of the herbicide to chickpea is a major consideration.

Selectivity can be described as the herbicide characteristic that allows its application to eliminate weeds without causing damage to the crop of commercial interest (Oliveira and Inoue 2011). Knights (1991) mentions that significant chickpea harvest losses occur due to the lack of registered postemergence herbicides, especially for the control of broadleaf weeds.

There is a lack of registered herbicides for weed control in chickpeas in Brazil (Agrofit 2018; Rodrigues and Almeida 2018). However, there are reports about the potential use of diphenyl-ether herbicides applied postemergence. Fomesafen and acifluorfen herbicides have shown potential for postemergence control of broadleaf weeds in chickpea crops (Malik *et al.* 2001; Boydston *et al.* 2017; Nath *et al.* 2018). However, it should be emphasized that these studies were not conducted under Brazilian conditions, and different chickpea genetic materials were used.

Diphenyl-ether herbicides' mode of action is the inhibition of the protoporphyrinogen oxidase enzyme (Oliveira 2011b). In Brazil, two herbicides have been registered and marketed for use in legume crops, including fomesafen for beans (*Phaseolus vulgaris* L.) and soybeans (*Glycine max* L.) and lactofen also for soybeans (Rodrigues and Almeida 2018). Therefore, to achieve the desired success in chemical weed control, chickpea selectivity is of vital importance, and since there are no reports of research in Brazil with herbicides for use in chickpea production, this study was undertaken.

The hypothesis of this study was that chickpea is tolerant to postemergence applications of fomesafen and lactofen. For this reason, the selectivity of postemergence applications of fomesafen and lactofen were assessed under rainfed conditions.

Materials and Methods

A field experiment was conducted in the experimental area of the Instituto Federal Goiano in the municipality of Urutaí, state of Goiás, Brazil, with chickpea cultivar 'BRS Aleppo', from February to June 2017. The experiment was implemented at an altitude of 800 m, latitude 17° 28' 41" S and longitude 48° 11' 35" W. According to Köppen classification, the climate is Aw, humid tropical with dry winters (Alvarez *et al.* 2014). During the experiment, the temperature ranged from 13.84 to 30.85°C and precipitation was 0 to 141.3 mm.

The experimental area had a clayey texture, with deep, homogeneous soil of the red latosol type. The soil consisted of (in g · kg^{-1}) 370 clay, 140 silt and 490 sand; pH ($CaCl_2$) of 5.0; organic matter content of 14.8 g · dm^{-3} and P content (Mehlich 1) of 12.4 mg · dm^{-3}; contents of Ca^{+2}, Mg^{+2} and K^{+} of 1.5, 0.3 and 58 mg · dm^{-3}; respectively, and base saturation of 39.5%, at 0–20 cm depth.

The experimental design consisted of a randomized block design in 2 × 3 + 1 factorial arrangement with three replications. The first factor consisted of two herbicides (fomesafen and lactofen), while the second factor was three different rates (50, 75 and 100% of the reference rate). There was also an additional treatment without application of products. The reference rates consisted of 250 and 180 g a.i. · ha^{-1} of fomesafen and lactofen, respectively. The experimental units were 2 m in width (4 rows of chickpeas) and 3 m in length; therefore, total area was 6 m^2. The two central rows, disregarding 0.50 m of each end, were considered for the experiment, comprising a total net area of 1 m^2.

The experimental area was conventionally tilled and disked to a depth of 25 cm with a two-pass surface disking to break up the clods and loosen the soil. Then, planting grooves were opened with a mechanically driven 6-stranded tine furrow opener. Sowing was manual, with a spacing of 0.50 m between rows and a density of ten seeds per meter. Base fertilization was made with manual application of 200 kg · ha^{-1} of 04-30-16 N-P-K formulation. Cover fertilization consisted of 50 kg · ha^{-1} of N in the form of urea.

All experimental plots were kept free from weeds until chickpea harvest time. with manual elimination of any possible "failures" of the chemical control, and manual removal of all weeds in the untreated plot.

The herbicides were applied with a backpack sprayer under a constant pressure of 2.4 kgf · cm^{-2} (maintained by compressed CO_2), equipped with four spray nozzles (Magno ADIA 110015) on the boom, spaced 0.50 m and application rate of 150 l · ha^{-1}. The herbicides were applied at the phenological stage of 12 true leaves. At the time of application, the weather conditions were 72% of air relative humidity, 30.7°C of air temperature and 3.3 km · h^{-1} of wind speed.

Control of diseases and pests was carried out by treating the seeds with an application of abamectin + + pyraclostrobin + thiophanate methyl (0.5 + 0.05 + + 0.45 g a.i. · kg^{-1} of seeds); and three post-emergence sequential applications of chlorfenapyr pesticides (240 g a.i. · ha^{-1}), spinosad + teflubenzuron (28.8 + + 30 g a.i. · ha^{-1}) and chlorfenapyr + teflubenzuron (168 + 30 g a.i. · ha^{-1}) + 0.5% v · v^{-1} of mineral oil.

Possible visible injuries on the chickpea plants were assessed 7 and 21 days after application (DAA) of the herbicides, using a scale of 0 to 100%, where score zero represented the absence of visible injury and 100 represented plant death (Velini *et al.* 1995). During full blooming, the height of the aboveground portion of the plants was determined, using a centimeter-graduated tape, measuring from the soil surface to the insertion of the last leaf in the main stem. For dry matter evaluation two samples (one row of 1.0 m length) of the aerial part of the plant were collected and oven dried at 70°C to a constant mass and then weighed.

Harvesting was done manually by removing all plants of the net plot area in each experimental unit; afterwards, ten plants were chosen at random to determine the average number of pods per plant. The 100-grain weight was also determined by the average of two samples per plot. Chickpea yield was determined by weighing all grains obtained from the net area of each experimental plot and then yields were calculated in kg · ha^{-1}. The 100-grain weight and grain yield were corrected for water content of 130 g · kg^{-1} of grains.

The results were subjected to the *F*-test of analysis of variance. The normality of residuals was verified by the Shapiro-Wilk test and homogeneity by the Bartlett test. The effects of the herbicides and dosages, when significant, were compared by the Tukey's test at α = 0.05. To compare the control treatment (without application of herbicides) with the treatments with herbicides, the *F*-test was applied for contrasts. The statistical analyses were carried out in the R software, version 3.0.3 (R Core Team 2017).

Results

Although fomesafen and lactofen caused visible injury there was no interaction with the dosage (Table 1). At 7 and 21 DAA, injury increased as the herbicide rates increased, and lactofen caused more damage to the plants than fomesafen. However, at 21 DAA, there was no difference between the herbicides and injury did not exceed 21%.

After the initial injury, chickpea recovered and grain yields did not change with application of fomesafen (up to the rate of 250 g a.i. · ha^{-1}) and lactofen (up to the rate of 180 g · ha^{-1}). No agronomic characteristic changed with the herbicide application rates. However, a small reduction of 1.12% was observed in the 100-grain weight with fomesafen compared to lactofen. The chickpea agronomic characteristics did not differ from the control treatment (no herbicide application), except for dry matter, which exhibited a 28.8% reduction with the use of herbicides. Therefore, postemergence applications of fomesafen (up to 250 g a.i. · ha^{-1}) and lactofen (up to 180 g a.i. · ha^{-1}) caused a reduction of dry matter per plant but did not affect chickpea yield.

Discussion

The results of this field experiment confirmed that diphenyl-ether herbicides have little selectivity to chickpea when in direct contact with the leaves but do not cause plant death. In this study, the fomesafen and lactofen herbicides, regardless of the rate of the commercial products, caused whitish necrotic lesions affecting the leaf area at the early stages of chickpea growth. The symptoms observed in the field can be

Table 1. Percentage of injuries in chickpea crop at 7 and 21 days after treatment (DAA), plant population, height, dry matter and number of pods per plant, 100-grain weight and yields of chickpeas treated with three different rates (50, 75 and 100% of reference rate) of fomesafen (250 g a.i. · ha^{-1}) and lactofen (180 g a.i. · ha^{-1}) herbicides

Source	Crop injury 7 DAA [%]	Crop injury 21 DAA [%]	Population [1,000 × plant · ha^{-1}]	Height [cm]	Dry matter [g · plant^{-1}]	Pods [no. · plant^{-1}]	Mass of 100 grains [g]	Yield [kg · ha^{-1}]
Herbicides:								
Fomesafen	15.11 a	8.40	102.22	40.88	9.59	33.51	32.18 b	1115.28
Lactofen	18.77 b	9.02	115.56	38.12	9.60	28.51	32.56 a	944.67
F-test	122.28**	3.16 ns	1.31 ns	3.90 ns	0.00 ns	1.23 ns	5.71*	1.46 ns
Rate [% of prescribed rate]								
50	13.11 a	6.75 a	106.66	39.57	9.31	27.58	32.19	931.82
75	16.77 b	8.85 b	110.00	40.45	9.78	31.62	32.65	1059.14
100	20.95 c	10.55 c	110.00	38.48	9.68	33.83	32.27	1098.97
F-test	188.35**	40.60**	0.04 ns	0.67 ns	0.07 ns	0.66 ns	3.22 ns	0.51 ns
Herbicide × rate	2.76 ns	3.57 ns	0.11 ns	2.17 ns	2.66 ns	0.46 ns	0.02 ns	0.14 ns
Control vs. Treatments	1503.39**	363.70**	2.07 ns	0.65 ns	7.75*	0.71 ns	0.01 ns	0.47 ns
Control	0.00	0.00	86.67	40.98	13.47	36.03	32.37	1158.23
C.V. [%]	4.83	9.81	23.41	7.45	21.98	30.12	1.02	28.53

Means followed by different letters in the same column are significantly different according to Tukey's test at 5% probability; ns – $p > 0.05$, **$p < 0.01$, *$p < 0.05$ for the *F*-test with 12 degrees of freedom for the residual term indicative of peroxidation of lipids, proteins, chlorophyll pigments and carotenoids, since there was inhibition of the protoporphyrinogen oxidase enzyme (PPO) (Oliveira 2011b).

In other studies, fomesafen (130 g a.i. · ha^{-1}) alone or combined with fluazifop-p-butyl caused small injuries in chickpeas (Malik *et al.* 2001). When a rate of 280 g · ha^{-1} of fomesafen was applied, the injuries (necrotic lesions) ranged from 8 to 25% in 2015 and 9 to 42% in 2016 at different cultivation sites (Boydston *et al.* 2017).

Acifluorfen, also a PPO-inhibiting herbicide, also caused injury to chickpeas (Boydston *et al.* 2017; Nath *et al.* 2018). Likewise, Dubey *et al.* (2018) reported visible injury caused by postemergence application of oxyfluorfen (200 g a.i. · ha^{-1}), corroborating Rathod *et al.* (2017), who reported 20% injury in chickpeas caused by the herbicide. Thus, the occurrence of visible lesions in plants seems to be indicative of a common crop response to diphenyl-ether herbicides, when sprayed postemergence.

On the other hand, over time, chickpea plants recover from injuries, suggesting a potential utilization of diphenyl-ether herbicides (Malik *et al.* 2001; Boydston *et al.* 2017; Rathod *et al.* 2017; Nath *et al.* 2018). Such good recovery can be attributed to the lack of translocation of foliar-applied products when sprayed postemergence (Matzenbacher *et al.* 2014), since the new leaves, those which were not in contact with the herbicide, were not affected.

In selectivity studies on fomesafen applied to chickpeas at rates of 130 and 280 g a.i. · ha^{-1} did not affect yields of cultivars CM-72 and Sierra, respectively (Malik *et al.* 2001; Boydston *et al.* 2017). This is important because the lesions found in the plants did not result in yield losses and, therefore, fomesafen and lactofen herbicides were useful to control eudicotyledon weeds when applied postemergence to chickpeas grown under rainfed conditions.

Other studies have also shown acifluorfen selectivity for chickpea crops, e.g., Boydston *et al.* (2017), in which 420 g a.i. · ha^{-1} of the referred to herbicide did not affect adversely the yields of cultivar Sierra. Nath *et al.* (2018) reported a vigorous growth of chickpea cultivar JG130 after application of acifluorfen + clodinafop-propargyl (500 g a.i. · ha^{-1} + 60 g a.i. · ha^{-1}) and found that this combination of herbicides provided excellent grain yield and can also be an option for weed control in chickpeas.

Rathod *et al.* (2017) observed that postemergence application of oxyfluorfen (250 g a.i. · ha^{-1}), besides causing lesions in the plants, was not effective in weed control, being conducive to yield losses and, therefore, did not show potential to be used in this kind of application in chickpea plants. However, preemergence application of this herbicide did not cause visible injuries in the plants and did not interfere adversely with chickpea yields (Ratnam *et al.* 2011). In fact, other authors confirm that preemergence application of oxyfluorfen is safe in terms of selectivity and effectiveness in weed control in chickpea crops (Kachhadiya *et al.* 2009; Rupareliya *et al.* 2017; Yadav *et al.* 2019).

In this study, selectivity based on agronomic characteristics, especially yields, showed that fomesafen (up to 250 g a.i. · ha^{-1}) and lactofen (up to 180 g a.i. · ha^{-1}) herbicides were selective for cultivar BRS Aleppo. Therefore, the herbicides tested can be used as future options for weed control of broadleaf weeds in commercial chickpea areas. However, further research is needed to evaluate the selectivity in different chickpea genotypes and clarify the mechanisms responsible for chickpea tolerance to diphenyl-ether herbicides in postemergence applications.

Conclusions

Fomesafen and lactofen were selective for postemergence application in chickpea, cultivar BRS Aleppo, at application rates of 250 and 180 g a.i. · ha^{-1}, respectively, causing less than 20% of visible injuries and no yield losses.

Acknowledgements

The authors wish to thank Embrapa Hortaliças for providing chickpea seeds for the conduction of the experiment.

References

Agrofit. 2018. Sistema de Agrotóxicos Fitossanitários. Registration of pesticides. Available on: http://agrofit.agricultura.gov.br/agrofit_cons/principal_agrofit_cons [Accessed: December 28, 2018]

Al-Thahabi A.S., Yasin I.Z., Abu-Irmaileh B.E., Haddad N.I., Saxena M.C. 1994. Effect of weed removal on productivity of chickpea (*Cicer arietinum* L.) and lentil (*Lens culinaris* Med.) in a mediterranean environment. Journal Agronomy & Crop Science 172 (5): 333–341. DOI: https://doi.org/10.1111/j.1439-037X.1994.tb00184.x

Alvarez C.A., Stape J.L., Sentelhas P.C., Gonçalves J.L.M., Sparovek G. 2014. Köppen's climate classification map for Brazil. Meteorologische Zeitschrift 22 (6): 711–728. DOI: https://doi.org/10.1127/0941-2948/2013/0507

Amaral C.L., Pavan G.B., Pereira F.C.M., Alves P.L.C.A. 2018. Periods of weed interference in chickpea grown under different doses of nitrogen fertilizer topdressing. Acta Scientiarum, Agronomy 40 (1): 1–10. DOI: http://dx.doi.org/10.4025/actasciagron.v40i1.35666

Boydston R.A., Nelson H., Chaves-Cordoba B. 2017. Tolerance of chickpeas to postemergence broadleaf herbicides. Weed Technology 32 (2): 190–194. DOI: https://doi.org/10.1017/wet.2017.99P

Dubey S.K., Kumar A., Singh D., Partap T., Chaurasiya A. 2018. Effect of different weed control measures on performance of chickpea under irrigated condition. International Journal of Current Microbiology and Applied Sciences 7 (5): 3103–3111. DOI: https://doi.org/10.20546/ijcmas.2018.705.362

FAO. 2018. Food and Agriculture Organization of The United Nations. Data base Faostat. Available on: http://www.fao.org/faostat/en/#data/QC [Accessed: December 15, 2018]

Kachhadiya S.P., Savaliya J.J., Bhalu V.B., Pansuriya A.G., Savaliya S.G. 2009. Evaluation of new herbicides for weed management in chickpea (*Cicer arietinum* L.). Legume Research 32 (4): 293–297.

Knights E. 1991. Chickpea. p. 27–38. In: "New Crops, Agronomy and Potential of Alternative Crop Species" (R.S. Jessop, R.L.Wright, eds.). Inkata Press, Melbourne, Austrália, 186 pp.

Malik M.R., Haqqani A.M., Rehman H., Ozair C.A., Malik B.A. 2001. Economic efficacy of different pre- and post-emergence herbicides to control weeds in chickpea (*Cicer arietinum* L.). Journal of Biological Sciences 1 (5): 372–377. DOI: https://doi.org/10.3923/jbs.2001.372.377

Matzenbacher F.O., Vidal R.A., Merotto Jr. A., Trezzi M.M. 2014. Environmental and physiological factors that affect the efficacy of herbicides that inhibit the enzyme protoporphyrinogen oxidase: a literature review. Planta Daninha 32 (2): 457–463. DOI: http://dx.doi.org/10.1590/S0100-83582014000200024

Mohammadi G., Javanshir A., Khooie F.R., Mohammadi S.A., Zehtab Salmasi S. 2005. Critical period of weed interference in chickpea. Weed Research 45 (1): 57–63. DOI: https://doi.org/10.1111/j.1365-3180.2004.00431.x

Nath C.P., Dubey R.P., Sharma A.R., Hazra K.K., Kumar N., Singh S.S. 2018. Evaluation of new generation post-emergence herbicides in chickpea (*Cicer arietinum* L.). National Academy Science Letters 41 (1): 1–5. DOI: https://doi.org/10.1007/s40009-017-0604-z

Oliveira Jr. R.S. 2011a. Introduction chemical control [Introdução ao controle químico]. p. 125–140. In: "Biologia e Manejo de Plantas Daninhas" (R.S. Oliveira Jr., J. Constantin, M.H. Inoue, eds.). Omnipax, Curitiba, Brazil, 348 pp.

Oliveira Jr. R.S. 2011b. Mode of action to herbicides [Mecanismos de ação dos herbicidas]. p. 141–191. In: "Biologia e Manejo de Plantas Daninhas" (R.S. Oliveira Jr., J. Constantin, M.H. Inoue, eds.). Omnipax, Curitiba, Brazil, 348 pp.

Oliveira Jr. R.S., Inoue, M.H. 2011. Selectivity of herbicides for crops and weeds [Seletividade de herbicidas para culturas e plantas daninhas]. p. 243–262. In: "Biologia e Manejo de Plantas Daninhas" (R.S. Oliveira Jr., J. Constantin, M.H. Inoue, eds.). Omnipax, Curitiba, Brazil, 348 pp.

Paolini R., Faustini F., Saccardo F., Crino P. 2006. Competitive interactions between chickpea genotypes and weeds. Weed Research 46 (4): 335–344. DOI: https://doi.org/10.1111/j.1365-3180.2006.00513.x

R Development Core Team. 2017. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Áustria. Available on: https://www.r-project.org/ [Accessed: November 7, 2018]

Rathod P.S., Patil D.H., Dodamani B.M. 2017. Integrated weed management in chickpea (*Cicer arietinum* L.) under rainfed conditions of Karnataka, India. Legume Research 40 (3): 580–585. DOI: https://doi.org/10.18805/lr.v0iOF.9611

Ratnam M., Rao A.S., Reddy T.Y. 2011. Integrated weed management in chickpea (*Cicer arietinum* L.). Indian Journal of Weed Science 43 (1–2): 70–72.

Rodrigues B.N., Almeida F.S. 2018. Guide to herbicides [Guia de herbicidas]. 7th ed. Londrina, Brazil, 764 pp.

Rupareliya V.V., Chovatia P.K., Vekariya S.J., Javiya P.P. 2017. Effects of different pre and post emergences herbicide on growth, yield attributes, yield and quality of chickpea (*Cicer arietinum* L.). International Journal of Science, Environment and Technology 6 (4): 2587–2593.

Solh M.B., Pala M. 1990. Weed control in chickpea. p. 93–99. In: "Present Status and Future Prospects of Chickpea Crop Production and Improvement in the Mediterranean Countries" (M.C. Saxena, J.I. Cubero, J. Wery, eds.). Ciheam, Zaragoza, Espanha, 175 pp.

Tepe I., Erman M., Yergin R., Bükün B. 2011. Critical period of weed control in chickpea under non-irrigated conditions. Turkish Journal of Agriculture and Forestry 35 (5): 525–534. DOI: https://doi.org/10.3906/tar-1007-956

Velini D.E., Osipe R., Gazziero D.L.P. 1995. Procedimentos para instalação, avaliação e análise de experimentos com herbicidas [Procedures for installation, evaluation and analysis of experiments with herbicides]. SBCPD, Londrina, Brazil. 42 pp.

Yadav V.L., Shukla U.N., Raiger P.R., Mandiwal M. 2019. Efficacy of pre and post-emergence herbicides on weed control in chickpea (*Cicer arietinum* L.). Indian Journal of Agricultural Research 53 (1): 112–115. DOI: https://doi.org/10.18805/a-5102