Revista Ciência Agronômica, v. 56, e202394131, 2025
Centro de Ciências Agrárias - Universidade Federal do Ceará, Fortaleza, CE
www.ccarevista.ufc.br

Scientific Article
ISSN 1806-6690

Chemical control of species of genus *Commelina*[1]

Rúbia de Moura Carneiro[2*], Gabriela de Souza da Silva[2], Francisco Freire de Oliveira Junior[2], Fernando Ramos de Souza[2], Luana Jessica da Silva Ferreira[2], Ana Claudia Langaro[2], Camila Ferreira de Pinho[2]

ABSTRACT - The aim of this study was to evaluate control of the species Commelina benghalensis and Commelina diffusa using post-emergent herbicides applied alone and in mixture. Two replicated experiments (EI and EII) were conducted to evaluate two species of Commelina, with four to six leaves (EI) and six to ten leaves (EII). The experiments included 27 treatments with the following post-emergent herbicides that were applied alone or in mixture: glyphosate; 2.4-D; triclopyr; dicamba; carfentrazone; saflufenacil; flumioxazine; chlorimuron; cloransulam and diclosulam+halauxifen. Plant control and the transient fluorescence of chlorophyll-a were visually analysed 21 and 42 days after application (DAA). At 42 DAA, plants were collected to determine the shoot dry weight. The data were submitted to ANOVA ($p \leq 0.05$) and compared using the Scott-Knott test. The triple mixtures were effective in controlling both species. The triple mixtures that included carfentrazone afforded faster effective control compared to mixtures containing saflufenacil and flumioxazine. Triclopyr gave faster control of both species compared to the other auxinic herbicides. Both species respond differently to auxinic herbicides, and are more difficult to control when they have between six and ten leaves.

Key words: *C. benghalensis*. *C. diffusa*. Tolerance. Post-emergent.

DOI: 10.5935/1806-6690.20250068
Editor-in-Chief: Agricultural Engineer. Manoel Barbosa Filho - manoel.filho@ufc.br
*Author for correspondence
Received for publication 15/05/2023; approved on 22/12/2024
[1]This research was extracted from the master's dissertation of the lead author presented to the Postgraduate Program in Agricultural and Environmental Engineering (PGEAAmb - UFRRJ). Funded with resources from the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – Brazil (CAPES) – Funding code 001
[2]Department of Plant Science, Institute of Agronomy, Federal Rural University of Rio de Janeiro (UFRRJ), Seropédica-RJ, Brazil, *mourarubia@yahoo.com.br (ORCID ID 0000-0001-7787-8733), gabrielasouza.ufrrj@gmail.com (ORCID ID 0000-0003-0268-5405), freirejr@gmail.com (ORCID ID 0000-0001-7951-5573), fernando.agrorural@gmail.com (ORCID ID 0000-0001-5984-1646), luanaj.agro@gmail.com (ORCID ID 0000-0002-3833-6058), langaro.ac@gmail.com (ORCID ID 0000-0002-6746-5692), camilafepi@hotmail.com (ORCID ID 0000-0003-2861-2212)

INTRODUCTION

Invasive plants of genus *Commelina*, such as the species *Commelina benghalensis* and *Commelina diffusa*, are known to be difficult to control due to their ease of propagation and tolerance to the herbicide glyphosate (Santos *et al*., 2004). In agricultural areas where the herbicide is used repeatedly, these plants have become predominant and remain uncontrolled.

Tolerance is the innate ability of a weed species to develop and reproduce following the application of a herbicide at the dose recommended on the label, which might be lethal to other species (Christoffoleti *et al*., 2016). There is no selection process that makes a given species tolerant to a herbicide; this is a natural characteristic, independent of previous herbicide use (Christoffoleti *et al*., 2016). In *C. benghalensis*, tolerance to the herbicide glyphosate occurs due to differential absorption (slower than in other species) and the ability to metabolise part of the herbicide (Monquero *et al*., 2004). There are, however, few studies that explain how tolerance to the herbicide glyphosate occurs in *C. diffusa*.

As the species are tolerant to glyphosate, control of these plants is limited to other mechanisms of action that target eudicotyledonous species. However, effective weed control is directly linked to the phenological stage of the plant, where in the early stages, control is easier (Takano *et al*., 2013). Desiccation is the ideal time to control these species due to the choice of mechanisms of action, and the possibility of mixing two or more herbicides, or even of sequential applications (Gazziero, 2015). Due to the difficulty of controlling *C. benghalensis* and *C. diffusa*, double and triple mixtures of herbicides are preferable, particularly because of their broader spectrum, affording effective control with less chance of regrowth.

The aim of this study was to assess control of the weeds *C. benghalensis* and *C. diffusa* using post-emergent herbicides employed in pre-planting desiccation in the soya bean, applied both alone and in mixture.

MATERIAL AND METHODS

The experiment was conducted in a greenhouse at the Federal Rural University of Rio de Janeiro. Post-emergent herbicides were used in the trials to evaluate control of the two species, *C. benghalensis* and *C. diffusa*. The herbicides were applied at two stages (4-6 leaves and 6-10 leaves) and were considered two separate experiments: EI (four to six leaves) and EII (6 to 10 leaves). The experiments were conducted in a randomised block design (RBD), with four replications, using 1-L plastic pots as the experimental unit, these were filled with a Haplic Eutrophic Planosol (Santos *et al*., 2018), whose characteristics are described in Table 1.

The plants of *C. benghalensis* came from seeds purchased from a specialised company, with a germination percentage of 70%. The plants of *C. diffusa* were obtained by transplanting, collecting stems from plants grown in an area that had not been treated with herbicides. The stems were cut up, and one node was transplanted per pot. Twenty-six post-emergent treatments were evaluated, plus the control with no herbicide, as shown in Table 2.

The herbicides were applied at two distinct phenological stages: the first when the plants had four to six leaves (EI), and the second when the plants had 6 to 10 leaves (EII). A pressurised CO_2 backpack sprayer equipped with four XR 110.015 nozzles spaced 0.5 m apart was used to apply the treatments at a pressure of 2.8 bar and a spray volume of 100 L ha^{-1}.

The following response variables were evaluated:

Analysis of the chlorophyll-a fluorescence transient

The chlorophyll-a fluorescence transient was measured using a portable fluorometer (HandyPEA, Hanstech, King's Lynn, Norkfolk, UK) 42 days after application (DAA) of the treatments in both experiments (EI and EII). The kinetics of the chlorophyll-a fluorescence transient was evaluated, again using a portable fluorometer (HandyPEA, Hanstech, King's Lynn, Norkfolk, UK). The clips used in these measurements were placed on the middle third of young, fully expanded leaves in the morning, the readings being taken 20 min after the leaves had adapted to the dark. Fluorescence emission was induced in a 4-mm diameter area of the leaf by exposing the sample to a saturating light pulse of 3,000 μmol m^{-2} s^{-1}. From the transient fluorescence emission curve obtained after the pulse, the intensity determined at 50 μs (initial fluorescence - F0), 100 μs, 300 μs, 2 ms (FJ), 30 ms (FI) and MF (maximum fluorescence) was used to calculate the parameters established by the JIP test (Strasser; Strasser, 1995).

Table 1 - Chemical analysis of the soil used in the experiments. Seropédica, RJ, 2021

Class	Depth (cm)	Na	Ca	Mg	K	H + Al	Al	S	T	V	m	n	pH water	Organic carbon	P	K
		$Cmol_c/dm^3$											1,2:5	%	mg/L	
Sandy	0 - 20	1.233	2.5	1.2	0.22	3.5	0.0	5.15	8.71	59	0	14	5.8	0.56	23	84
Sandy	20 - 40	0.882	1.6	1.5	0.19	3.7	0.0	4.17	7.92	53	0	11	5.4	0.20	16	75

Table 2 - Herbicide treatments used in experiments EI and EII. Seropédica, RJ, 2021

TREATMENT	ACTIVE INGREDIENT	DOSE (g ai/ae.ha^{-1})
1	-	-
2	Glyphosate	2160
3	Glyphosate + Saflufenacil[2]	2160 + 35
4	Glyphosate + Carfentrazone[1]	2160 + 30
5	2.4-D	1005
6	Glyphosate + 2.4-D	2160 + 1005
7	Glyphosate + 2.4-D + Saflufenacil[2]	2160 + 1005 + 35
8	Glyphosate + 2.4-D + Carfentrazone[1]	2160 + 1005
9	Triclopyr[1]	960
10	Glyphosate + Triclopyr[1]	2160 + 960
11	Glyphosate + Triclopyr1 + Saflufenacil[2]	2160 + 960 + 35
12	Glyphosate + Triclopyr1 + Carfentrazone[1]	2160 + 960 + 30
13	Dicamba	720
14	Glyphosate + Dicamba	2160 + 720
15	Glyphosate + Dicamba + Saflufenacil[2]	2160 + 720 + 35
16	Glyphosate + Dicamba + Carfentrazone[1]	2160 + 720 + 30
17	Flumioxazine[1]	50
18	Glyphosate + Flumioxazine[1]	2160 + 50
19	Glyphosate + Flumioxazine1 + Saflufenacil[2]	2160 + 50 + 35
20	Glyphosate + Flumioxazine1 + Carfentrazone[1]	2160 + 50 + 30
21	Glyphosate + Chlorimuron[1]	2160 + 20
22	Glyphosate + Cloransulam[3]	2160 + 38.39
23	Diclosulam + halauxifen	44
24	Glyphosate + (Diclosulam + halauxifen)	2160 + 44
25	Glyphosate + (Diclosulam + halauxifen) + Saflufenacil	2160 + 44 + 352
26	Glyphosate + (Diclosulam + halauxifen) + Flumioxazine	2160 + 44 + 501
27	Glyphosate + (Diclosulam + halauxifen) + Carfentrazone	2160 + 44 + 301

[1]0.5% v/v Assist® (emulsifiable mineral oil); [2]1.0% v/v Dash® (non-ionic adjuvant); [3]0.2% v/v Agral® (non-ionic surfactant)

Visual analysis of plant control

A visual evaluation of plant control was carried out 21 and 42 DAA, attributing scores based on the level of plant damage, ranging from 0% to 100%, where 0% represents the lack of any symptoms and 100% represents the death of the plant (Frans; Crowley, 1986).

Shoot dry weight (SDW)

Shoot dry weight was assessed at 42 DAA. The plants were cut close to the ground, packed in paper bags and placed in a forced air circulation oven at 65 ± 5 ºC to constant weight. An analytical balance was used to determine the dry weight of the shoots.

Statistical analysis

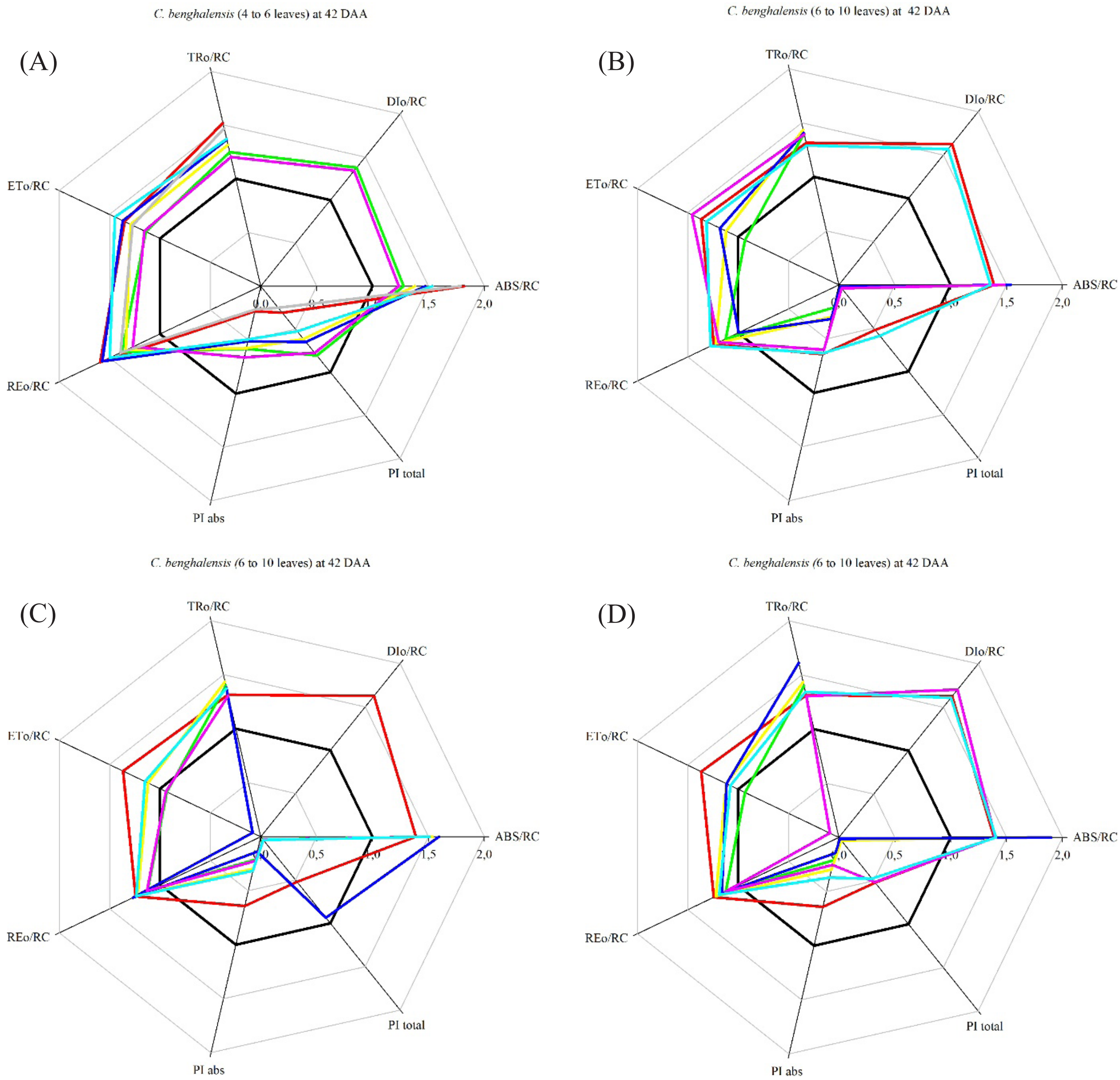
The data from the experiments were subjected to ANOVA ($p \leq 0.05$), and when statistically significant, the mean values were compared by Scott-Knott test at 5% probability ($p \leq 0.05$) using the Sisvar statistical software. The graphs were generated using the SigmaPlot 12.5 statistical software.

RESULTS AND DISCUSSION

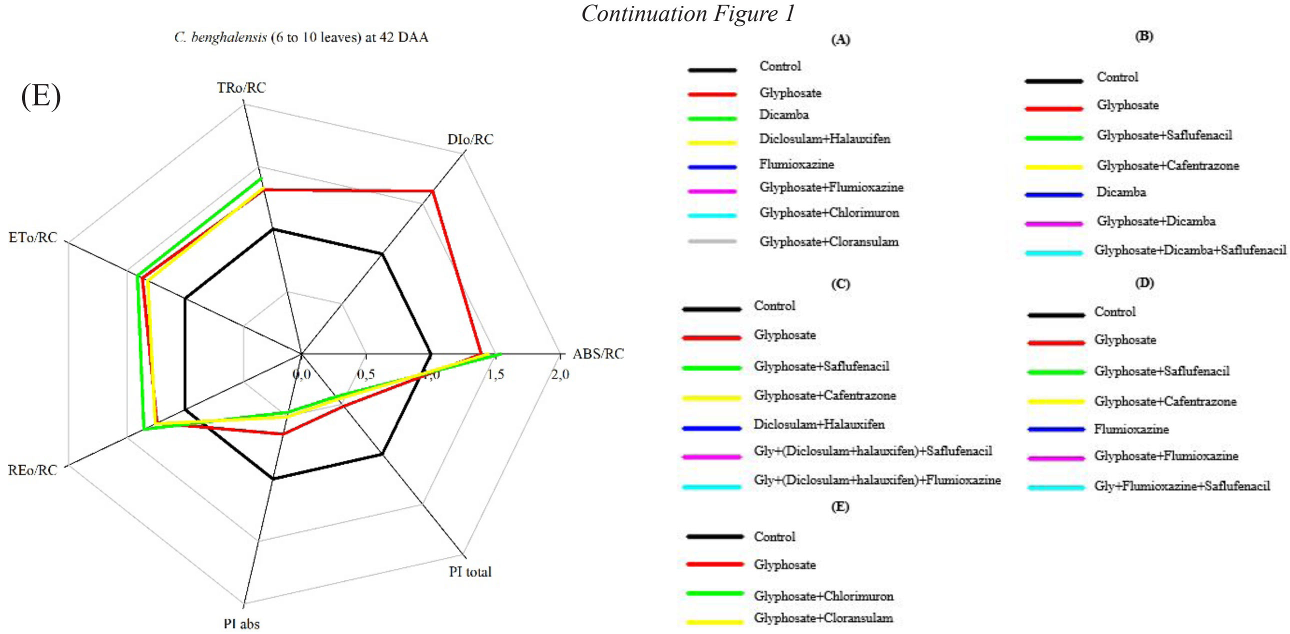
Analysis of the chlorophyll-a fluorescence transient for each species

The results of the JIP test showed changes in the photosynthetic metabolism of the plants of both species. In the plants of *C. benghalensis* with four to six leaves, there was an increase of over 50% in the transient, related to the apparent size of the antenna system (ABS/RC) and caused by the treatments with flumioxazine and glyphosate + chlorimuron; the increase in the treatments with glyphosate and glyphosate + chloransulam was over 80% compared to the control (Figure 1-A).

Figure 1 - Chlorophyll-a fluorescence in plants of *C. benghalensis* at the four to six-leaf stage (A) and the 6 to 10-leaf stage (B - E), subjected to the herbicides glyphosate, 2.4-D, triclopyr, dicamba, diclosulam + halauxifen, carfentrazone, saflufenacil, flumioxazine, chlorimuron and chloransulam, applied alone or in mixture. Figures B–E refer to the herbicide grouping based on the auxinic herbicides under evaluation. Treatments that resulted in plant death are not shown, as they would make any analysis impossible. ABS/RC - Measurement of the apparent size of the antenna system; TR_0/RC - Maximum rate of capture of one exciton by the RC, resulting in a reduction in plastoquinone (Q_A^-); DI_0/RC - Ratio of the total dissipation of uncaptured excitation energy to the total excitation energy; RE_0/RC - Specific energy flux for the transport of electrons from Q_A^- to the electron acceptors of PSI; ET_0/RC - Specific energy flux for the transport of electrons per active reaction centre. PI_{abs} – Photosynthetic performance index; PI_{total} – Total photosynthetic performance index. Seropédica, RJ, 2021



Continuation Figure 1



The ABS/RC parameter is related to the apparent increase in the antenna complex; when under the action of herbicides, plants seek to capture more photons in an attempt to normalise the imbalance triggered by the reduction in photosynthesis (Christen *et al*., 2007). The plants also showed an increase in ET_0/RC, this parameter is related to the reoxidation of Q_A^- via electron transport in an active reaction centre. A 40% increase was caused by the glyphosate, flumioxazine and glyphosate + chlorimuron treatments when compared to the control (Figure 1-A). TR_0/RC represents the captured energy flux per reaction centre; there was an increase in TR_0/RC of more than 40% for the glyphosate, glyphosate + chloransulam, glyphosate + chlorimuron and flumioxazine treatments compared to the control (Figure 1-A).

There was a reduction in PI_{ABS} and PI_{TOTAL}, with values greater than 80% seen for the glyphosate, flumioxazine, glyphosate + chlorimuron and glyphosate + chloransulam treatments compared to the control (Figure 1-A). The PI_{ABS} and PI_{TOTAL} performance indices result from the product of terms that express partial potentials for the conservation of energy from an exciton for a reduction in the electron acceptor intersystem, and a reduction in the final electron acceptors of PSI, respectively (Tsimilli-Michael; Strasser, 2008).

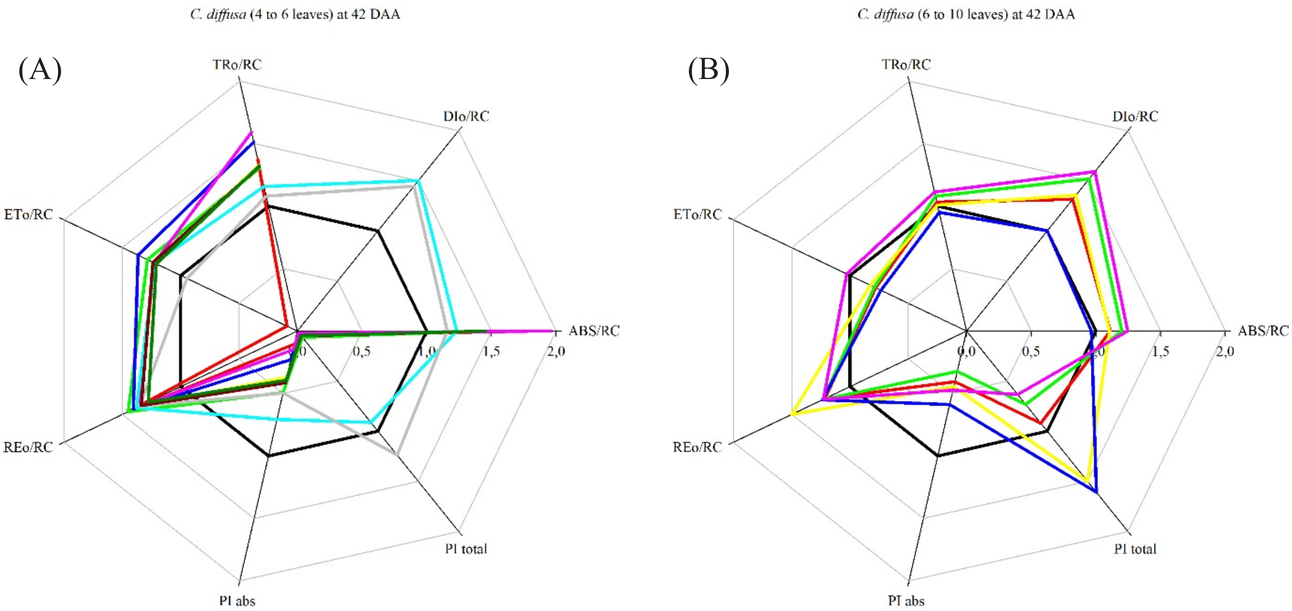
As with the plants of *C. benghalensis* with four to six leaves, plants with six to ten leaves also showed a reduction in PI_{ABS} and PI_{TOTAL}. There were reductions of more than 70% in PI_{ABS} with the glyphosate + Saflufenacil, glyphosate + carfentrazone, dicamba, diclosulam + halauxifen, glyphosate + (diclosulam+halauxifen) + Saflufenacil, glyphosate + (diclosulam+halauxifen) + flumioxazine, flumioxazine, glyphosate + flumioxazine treatments compared to the control (Figure 1 – B, C, D). While for PI_{TOTAL}, reductions of more than 90% were caused by the treatments with glyphosate + Saflufenacil, glyphosate + carfentrazone, dicamba, glyphosate + dicamba, glyphosate + (diclosulam+halauxifen) + Saflufenacil, glyphosate + (diclosulam+halauxifen) + flumioxazine and flumioxazine compared to the control (Figure 1 – B, C, D). The treatments that included glyphosate + Saflufenacil, glyphosate + carfentrazone, dicamba, glyphosate + dicamba, glyphosate + dicamba + Saflufenacil, diclosulam + halauxifen, glyphosate + (diclosulam + halauxifen) + Saflufenacil, glyphosate + (diclosulam + halauxifen) + flumioxazine, flumioxazine, glyphosate + chlorimuron and glyphosate + chloransulam resulted in an increase of more than 100% in DI_0/RC, again compared to the control (Figure 1 – B, C, D, E). The reduction in the performance indices indicates a loss of photochemical efficiency by the plants (Thach *et al*., 2007), for which they compensate by losing energy in the form of heat; these two processes compete during the photochemical phase of photosynthesis and result in a loss of photosynthetic efficiency. The increase in DI_0/RC may also be an attempt by the plants to avoid accumulating excess unused energy in the reaction centre, so as not to form reactive oxygen species (Szabó; Bergantino; Giacometti, 2005). ET_0/RC was reduced by more than 40%, a result of the glyphosate + dicamba and glyphosate + chlorimuron treatments, and by more than 90% by diclosulam + halauxifen and glyphosate + flumioxazine compared to the control (Figure 1 – B, C, D, E). There was an increase in TR_0/RC, with values greater than 40% in the treatments with glyphosate + Saflufenacil, glyphosate

+ carfentrazone, dicamba and glyphosate + chlorimuron, and an increase of 60% for flumioxazine compared to the control (Figure 1 – B, C, D, E). The reduction in PI_{ABS}, PI_{TOTAL} and ET_0/RC, together with the increase in DI_0/RC and TR_0/RC, can be understood as a reduction in the rate of electron capture and transport at each reaction centre, plus severe damage to the photosynthetic apparatus, indicating a loss of photochemical efficiency in the plants (Thach *et al*., 2007). The sharp reduction in the performance indices (PI_{ABS} and PI_{TOTAL}) and the increased energy dissipation may indicate that the absorbed energy was not being used efficiently, as shown by the decrease in photosynthetic activity and the increase in energy dissipated in the form of heat (Lawlor; Tezara, 2009).

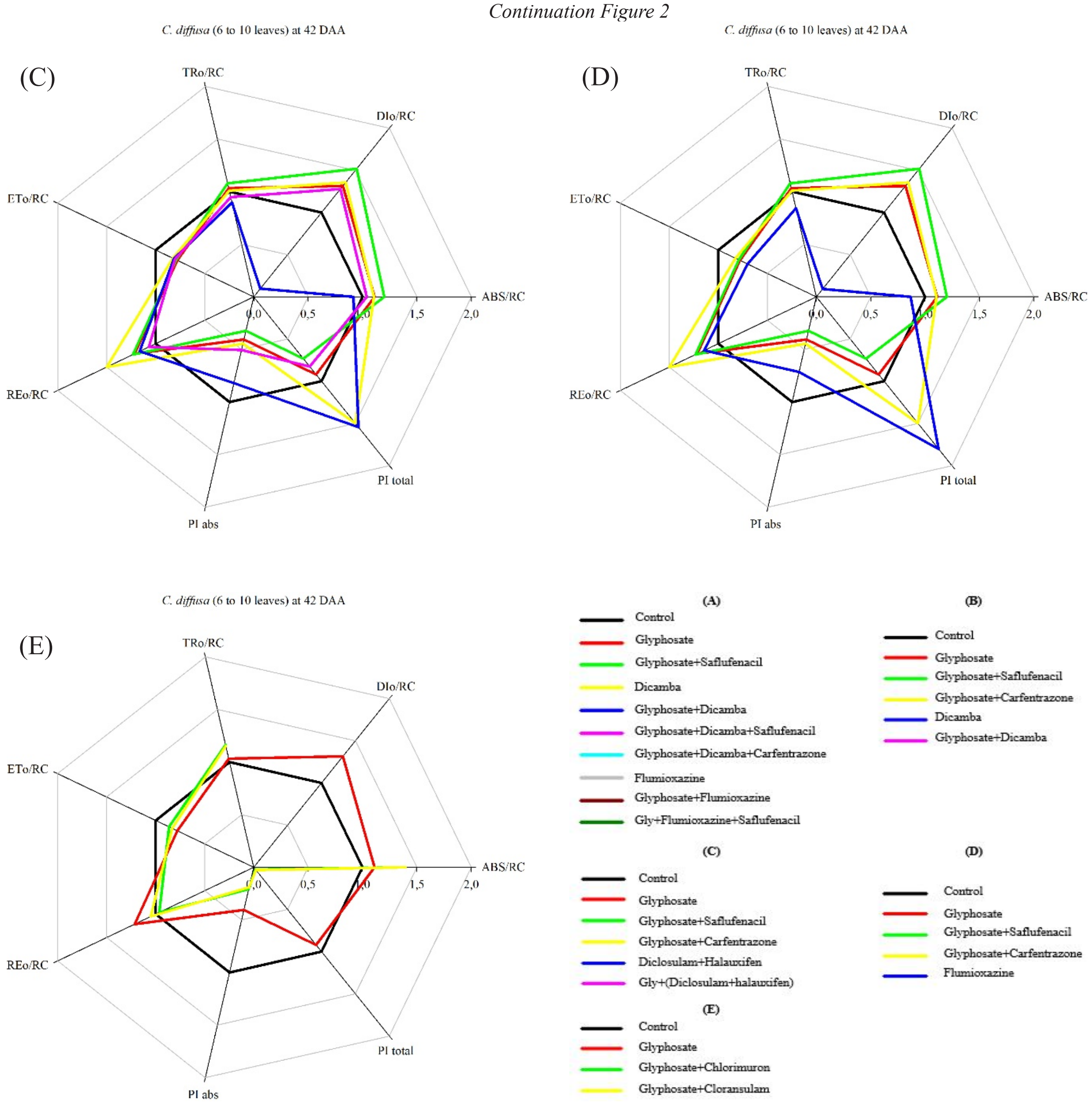
Plants of *C. diffusa* with four to six leaves showed similar behaviour to those of *C. benghalensis* at the same stage, with an increase in ET_0/RC; however, glyphosate caused a more than 90% reduction compared to the control (Figure 2-A). There was an increase of more than 50% in TR_0/R caused by the glyphosate + dicamba and glyphosate + dicamba + Saflufenacil mixtures compared to the control (Figure 2-A). At this stage, the plants also showed a reduction in PI_{ABS} and PI_{TOTAL}, with severe reductions of over 80% in PI_{ABS} caused by the glyphosate, glyphosate + dicamba and glyphosate + dicamba + Saflufenacil treatments (Figure 2-A), while PI_{TOTAL} showed an increase of over 90% compared to the control, except in the treatments with glyphosate + dicamba + carfentrazone and flumioxazine (Figure 2-A).

Plants of the same species at a more advanced stage (6 to 10 leaves) also showed a reduction in ET_0/RC of more than 20% for the glyphosate, dicamba and flumioxazine treatments compared to the control (Figure 2- B, D). There were also reductions in PI_{ABS} and PI_{TOTAL}. For PI_{ABS}, reductions greater than 50% were caused by the glyphosate, glyphosate + saflufenacil, glyphosate + carfentrazone, glyphosate + dicamba and glyphosate + (diclosulam + halauxifen) treatments compared to the control (Figure 2- B, C); while for PI_{TOTAL}, there were reductions of more than 50% in the glyphosate + carfentrazone, dicamba, diclosulam + halauxifen treatments, and of more than 80% in the flumioxazine treatment compared to the control (Figure 2- B, C, D). In addition, the glyphosate and glyphosate + dicamba treatments resulted in a 50% increase DI_0/RC. Only the flumioxazin and diclosulam + halauxifen treatments showed an increase of more than 90% compared to the control (Figure 2- B, C, D).

Figure 2 - Chlorophyll-a fluorescence in plants of *C. diffusa* at the four to six leaf stage (A) and the 6 to 10 leaf stage (B - E), subjected to the herbicides glyphosate, 2.4-D, triclopyr, dicamba, diclosulam + halauxifen, carfentrazone, saflufenacil, flumioxazine, chlorimuron and cloransulam, applied alone or in mixture. Figures B - E refer to the herbicide groupings based on the auxinic herbicides under evaluation. Treatments that resulted in plant death are not shown, as they would make any analysis impossible. ABS/RC - Measurement of the apparent size of the antenna system; TR_0/RC - Maximum rate of capture of one exciton by the RC, resulting in a reduction in plastoquinone (Q_A^-); DI_0/RC - Ratio of the total dissipation of uncaptured excitation energy to the total excitation energy; RE_0/RC - Specific energy flux for the transport of electrons from Q_A^- to the electron acceptors of PSI; ET_0/RC - Specific energy flux for the transport of electrons per active reaction centre. PI_{abs} – Photosynthetic performance index; PI_{total} – Total photosynthetic performance index. Seropédica, RJ, 2021



Continuation Figure 2



The increase in ABS/RC, TR_0/RC and ET_0/RC can therefore be understood as the effect of the herbicides on the plants of *C. diffusa* during the two development stages under evaluation, reflecting in the overall performance of photosystem II. These indices indicate a possible disruption of the plant chloroplasts, since the higher absorption (ABS/RC) and capture fluxes (TR_0/RC), and the electron transport flow (ET_0/RC) show that at the start of the electron transport chain, they are poorly utilised in the water photolysis process, so that by 42 DAA, the plants of *C. diffusa* showed no metabolic recovery, which was reflected in the reduction in PI_{ABS} and PI_{TOTAL}. Furthermore, the plants showed an abnormal electron transport flow, with an increase in heat dissipation.

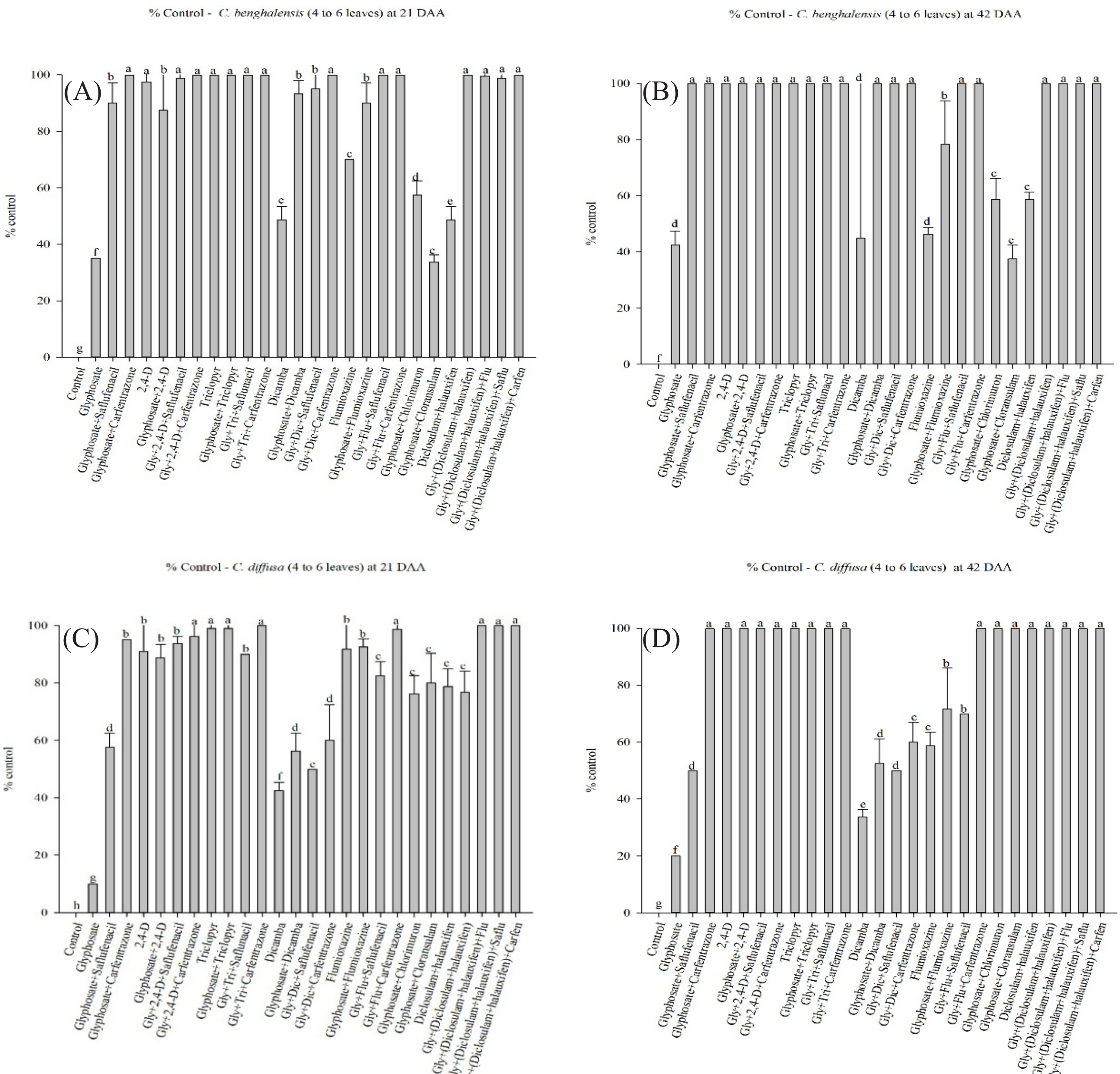
Visual analysis of plant control in each species

For *C. benghalensis* at 21 DAA, control was less than 100% in the glyphosate, dicamba, flumioxazine, diclosulam + halauxifen, glyphosate + chlorimuron and glyphosate+chloransulam treatments (Figure 3-A).

For *C. diffusa*, the treatments with glyphosate, glyphosate + saflufenacil, dicamba, glyphosate + dicamba, glyphosate + dicamba + saflufenacil, glyphosate + dicamba + carfentrazone, and glyphosate + chlorimuron resulted in unsatisfactory control, which was below 80% at 21 DAA (Figure 3-C).

The herbicide dicamba resulted in the least control of *C. diffusa* of all the treatments under evaluation; the triple mixtures of dicamba with glyphosate and PPO-inhibiting herbicides also gave poor control, unlike in *C. benghalensis*, where mixtures containing the herbicide dicamba were effective in controlling the plants (Figure 3-A). It was found that when applied alone, the herbicides 2.4-D, triclopyr and diclosulam+halauxifen show satisfactory control of both species; however, when mixed with glyphosate, the control is increased (Figure 3- A, C). Mixing with glyphosate is therefore better than applying the auxin herbicides alone. This is due to the broader control spectrum of the mixture, which can prevent regrowth. Similar results were seen in a study where glyphosate was mixed with 2.4-D, which was decisive in accelerating

Figure 3 - Percentage control in plants of *C. benghalensis* and *C. diffusa* at the four to six-leaf stage, at 21 DAA (A and C) and 42 DAA (B and D). Similar letters do not differ statistically by Scott-Knott test at 5% probability. Seropédica, RJ, 2021



and improving the control of difficult-to-control weeds, such as *C. benghalensis*, *Richardia brasiliensis*, *Euphorbia heterophylla*, *Spermacoce latifolia*, *Ipomoea granfiolia* and *Conyza* spp. (Takano *et al*., 2013). With regard to the PPO herbicides in the mixture, for the two species under evaluation, the double or triple mixtures containing carfentrazone gave effective and faster control when mixed with saflufenacil or flumioxazin. Similar results were noted by Agostineto *et al*. (2016), who evaluated the control of a mixture of glyphosate + carfentrazone (2 L ha^{-1} + 50 g ha^{-1}) on *I. heredifolia*, a weed that is also tolerant to glyphosate, and found effective and rapid control in plants with from six to eight leaves. Furthermore, a mixture of glyphosate and PPO-inhibiting herbicides is recommended for controlling glyphosate-tolerant weeds due to the synergistic effect of the mixture (Agostineto *et al*., 2016).

When evaluated at 42 DAA, the only treatments that did not afford effective control of *C. benghalensis* were glyphosate, dicamba, flumioxazine, glyphosate + flumioxazine, glyphosate + chlorimuron, glyphosate + chloransulam and diclosulam + halauxifen (Figure 3-A). As was the case with *C. benghalensis*, flumioxazin did not provide effective control of *C. diffusa* (Figure 3-C).

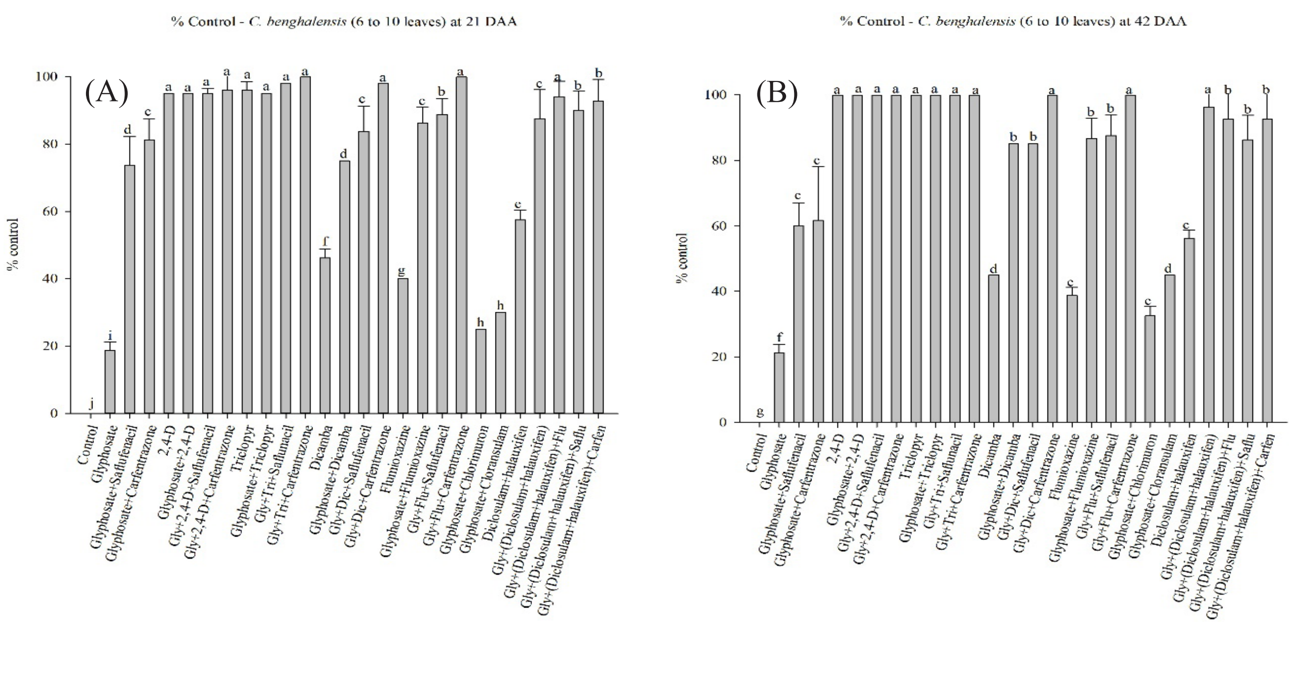
The poor control afforded by flumioxazin may be related to the action of the herbicide on the plant. Flumioxazin is a contact herbicide and not translocatable (Rodrigues; Almeida, 2018), which could potentially affect any control and allow the plants to regrow. In the case of *C. benghalensis*, flumioxazin, dicamba and diclosulam + halauxifen afforded effective control when mixed with glyphosate and the PPO inhibitors (Figure 3-A).

The treatments that included glyphosate, glyphosate + saflufenacil, dicamba and its respective mixtures, flumioxazine, glyphosate + flumioxazine and glyphosate + flumioxazine + saflufenacil (Figure 3-C) showed unsatisfactory control of *C. diffusa* at 42 DAA, whereas the remaining treatments gave 100% control. Like *C. benghalensis*, *C. diffusa* responded differently to the auxinic herbicides, with poorer control for the herbicide dicamba, which failed to provide effective control of the species, while the other auxinic herbicides (2.4-D, triclopyr and diclosulam + halauxifen) caused plant death.

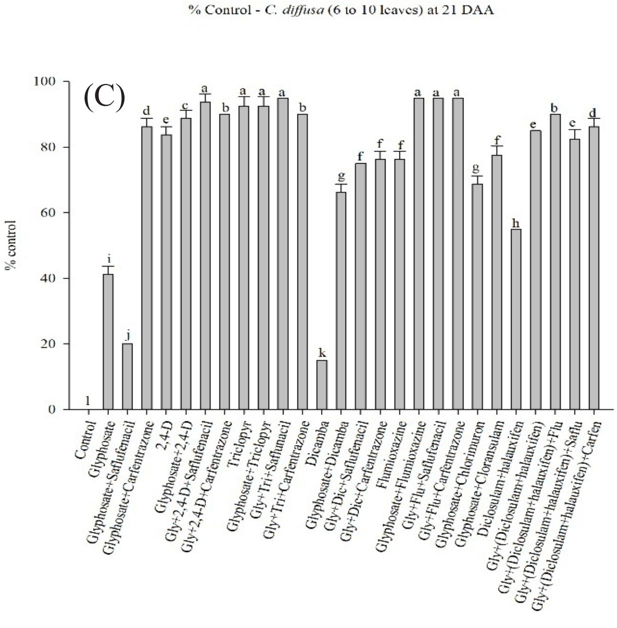
In the trial with *C. benghalensis* plants with six to ten leaves at 21DAA, the glyphosate, dicamba, flumioxazin, glyphosate + chlorimuron, glyphosate + chloransulam and diclosulam + halauxifen treatments showed the poorest control compared to the other treatments (Figure 4-A).

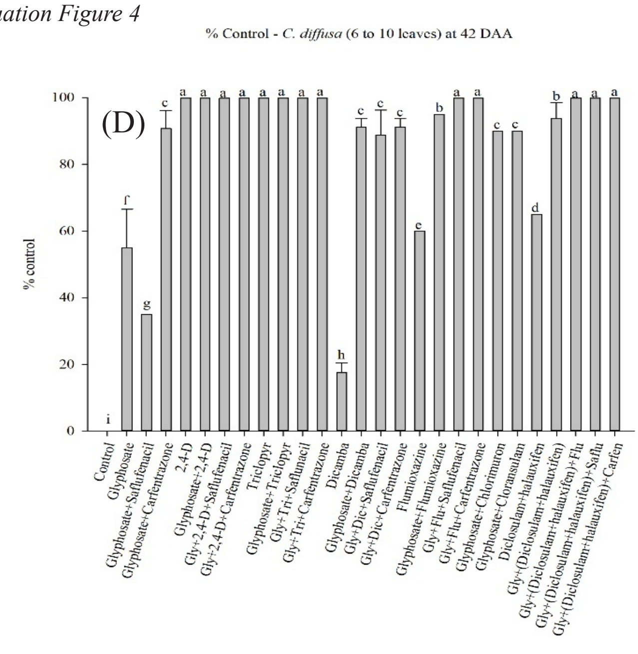
More than 80% control was obtained with 2.4-D, glyphosate + 2.4-D, glyphosate + 2.4-D + carfentrazone, triclopyr and its respective mixtures, glyphosate + dicamba + carfentrazone, glyphosate + flumioxazin, glyphosate + flumioxazin + saflufenacil, glyphosate + (diclosulam +halauxifen), glyphosate + (diclosulam+halauxifen) + saflufenacil, glyphosate + (diclosulam +halauxifen) + flumioxazin and glyphosate + (diclosulam+halauxifen) + carfentrazone (Figure 4-A).

Figure 4 - Percentage control in plants of *C. benghalensis* and *C. diffusa* with six to ten leaves, at 21 DAA (A and C) and 42 DAA (B and D). Similar letters do not differ statistically by Scott-Knott test at 5% probability. Seropédica, RJ, 2021



Continuation Figure 4





Only the glyphosate + flumioxazin + carfentrazone treatment caused plant death in *C. benghalensis* at 21 DAA. As seen in the experiment on plants with four to six leaves, the triple mixtures controlled the plants of *C. benghalensis* faster than the double mixtures. Although the mechanism of action is the same, triclopyr afforded greater control more quickly compared to the 2.4-D, dicamba and diclosulam + halauxifen herbicides. Similar results were found by Walker *et al*. (2012), who noted that auxinic herbicides were the main choice for post-emergent control of glyphosate-resistant dicotyledonous weeds.

None of the treatments under evaluation caused plant death in *C. diffusa* at 21 DAA. However, control was greater than 80% in the following treatments: 2.4-D and triclopyr and their respective mixtures, glyphosate + flumioxazine, glyphosate + flumioxazine + saflufenacil, glyphosate + flumioxazine + carfentrazone, glyphosate + (diclosulam + halauxifen), glyphosate + (diclosulam + halauxifen) + flumioxazine, glyphosate + (diclosulam + halauxifen) + saflufenacil and glyphosate + (diclosulam + halauxifen) + carfentrazone (Figure 4-C). The treatment with dicamba showed the poorest control among the auxinic herbicides under evaluation, particularly of plants of *C. diffusa* with four to six leaves.

For *C. benghalensis* at 42 DAA, the treatments with 2.4-D and triclopyr and their respective mixtures, glyphosate + dicamba + carfentrazone and glyphosate + flumioxazine + carfentrazone afforded 100% control (Figure 4-B). The following treatments afforded the lowest percentage control: glyphosate, glyphosate + saflufenacil, glyphosate + carfentrazone, dicamba, flumioxazine, glyphosate + chlorimuron, glyphosate + chloransulam and (diclosulam + halauxifen). Of the auxinic herbicides evaluated in this study, dicamba, whether alone or mixed with glyphosate, did not cause any plant death (Figure 4-B).

Similar results were found by Osipe *et al*. (2017), who evaluated dicamba alone and mixed with glyphosate and found no increase in the control of the mixture compared to glyphosate + 2.4-D; albeit, when applied alone, dicamba afforded limited control. It was found that a mixture of glyphosate + saflufenacil and glyphosate + carfentrazone did not afford effective control of plants of *C. benghalensis* with six to ten leaves, unlike in the trial with a smaller number of leaves. This means that at a later stage of development, plants are generally more tolerant to treatments with post-emergent herbicides (Martins; Christoffoleti, 2014). However, for the triple mixture of glyphosate, auxinic herbicides and PPO inhibitors, control was effective. As such, for plants of *C. benghalensis* and *C. diffusa* with a greater number of leaves, it is necessary to add a third herbicide to ensure effective control.

In the final control assessment for *C. diffusa* at 42 DAA, glyphosate, glyphosate + saflufenacil, dicamba, flumioxazine and diclosulam + halauxifen afforded the poorest control compared to the other treatments (Figure 4-D).

Plant death occurred with 2.4-D and triclopyr and their respective mixtures, glyphosate + flumioxazine + saflufenacil, glyphosate + flumioxazine + carfentrazone, glyphosate + (diclosulam + halauxifen) + saflufenacil, glyphosate + (diclosulam + halauxifen) + flumioxazine and glyphosate + (diclosulam + halauxifen) + carfentrazone (Figure 4-D). Dicamba showed the poorest control of all the herbicides under evaluation. As seen in the trial with four to six leaves, the triple mixtures were efficient in controlling *C. diffusa*, and are possible options for post-emergence management. Unlike in *C. benghalensis* with six to ten leaves, the mixture of glyphosate + carfentrazone was effective in controlling *C. diffusa*; however, the glyphosate + saflufenacil mixture was ineffective in both species at the later stage (Figure 4- B, D).

Shoot dry weight in both species

For *C. benghalensis* with four to six leaves, none of the treatments that resulted in no plant control differed significantly for SDW, as shown in Table 3.

The treatments that did not cause plant death in *C. diffusa*, namely glyphosate, glyphosate + saflufenacil, dicamba, glyphosate + dicamba + saflufenacil, glyphosate + dicamba + carfentrazone, flumioxazine, glyphosate + flumioxazine and glyphosate + flumioxazine + saflufenacil, differed statistically from the control for SDW (Table 3). The herbicide dicamba had the second highest mean value for SDW, consistent with the poor control seen for these plants. There was no significant difference between the remaining treatments that did not result in plant death.

Table 3 - SDW in plants of C. benghalensis and C. diffusa with four to six leaves (EI) and six to ten leaves (EII). Seropédica, RJ, 2021

Treatment	C. benghalensis (EI)	C. benghalensis (EII)	C. diffusa (EI)	C. diffusa (EII)
Control	4.69 a	8.39 a	2.05 a	4.50 a
Glyphosate	1.34 b	1.41 e	0.49 c	1.95 b
GS	0 c	2.08 d	0.56 c	2.10 b
GCar	0 c	1.63 e	0 d	1.84 b
2,4-D	0 c	0 e	0 d	0 d
G2,4-D	0 c	0 e	0 d	0 d
G2,4-DS	0 c	0 e	0 d	0 d
G2,4-DC	0 c	0 e	0 d	0 d
Triclopyr	0 c	0 e	0 d	0 d
GT	0 c	0 e	0 d	0 d
GTS	0 c	0 e	0 d	0 d
GTCar	0 c	0 e	0 d	0 d
Dicamba	1.33 b	4.87 b	0.86 b	4.82 a
GDi	0 c	2.79 c	0.48 c	2.35 b
GDiS	0 c	3.06 c	0.56 c	1.76 b
GDiCar	0 c	0.95e	0.39 c	1.25 c
Flumioxazine	1.15 b	3.93 b	0.35 c	3.89 a
GF	1.14 b	1.97 e	0.32 c	1.58 c
GFS	0 c	1.66 e	0.37 c	0 d
GFCar	0 c	0 e	0 d	0 d
Diclosulam + halauxifen	1.17 b	5.48 b	0 d	2.32 b
GDih	0 c	0.90 e	0 d	1.49 c
GDihS	0 c	2.06 e	0 d	0 d
GDihF	0 c	0.60 e	0 d	0 d
GDihCar	0 c	1.58 e	0 d	0 d
Gli + Chlorimuron	1.11 b	3.74 b	0 d	1.08 c
Gli + Cloransulam	1.04 b	2.88 c	0 d	2.09 b
CV (%)	5.01	7.75	5.58	13.44

Mean values with the same letters in a column do not differ by Scott-Knott test at 5% probability. GS = Glyphosate+saflufenacil; GCar = Glif+Carfentrazone; G2.4-D = Glif+2.4-D; G2.4-DS = Glif+2.4-D+saflufenacil; G2.4-DCar = Glif+2.4-D+Carfentrazone; GT = Glif+Triclopyr; GTS = Glif+Triclopyr+saflufenacil; GTCar = Glyphosate+Triclopyr+Carfentrazone; GDi = Glif+Dicamba; GDiS = Glif+Dicamba+saflufenacil; GDiCar = Glif+Dicamba+Carfentrazone; GF = Glif+Flumioxazine; GFS = Glif+Flumioxazine+saflufenacil; GFCar = Glif+Flumioxazine+Carfentrazone; GDih = Glif+(Diclosulam+halauxifen); GDihS = Glif+(Diclosulam+halauxifen)+saflufenacil; GDihF = Glif+(Diclosulam+halauxifen)+Flumioxazine; GDihCar = Glif+(Diclosulam+halauxifen)+Carfentrazone

For the plants of *C. benghalensis* with six to ten leaves, the treatments that did not result in plant death differed significantly from each other. The highest values for SDW were seen in the treatments with dicamba, flumioxazine, glyphosate + chlorimuron and diclosulam + halauxifen (Table 3). There was no statistical difference between the treatments with glyphosate, glyphosate + saflufenacil, glyphosate + carfentrazone, glyphosate + flumioxazine, glyphosate + flumioxazine + saflufenacil, glyphosate + (diclosulam+halauxifen) + saflufenacil and glyphosate + (diclosulam+halauxifen) + carfentrazone. The same was seen in the treatments with glyphosate + dicamba, glyphosate + dicamba + saflufenacil and glyphosate + cloransulam.

For the plants of *C. diffusa* with six to ten leaves, there was no statistical difference between the control and the treatments with dicamba and flumioxazine (Table 4). The treatments with glyphosate, glyphosate + saflufenacil, glyphosate + carfentrazone, glyphosate + dicamba, glyphosate + dicamba + saflufenacil, glyphosate + cloransulam and diclosulam + halauxifen were statistically equal, as were the treatments with glyphosate + dicamba + carfentrazone, glyphosate + flumioxazine and glyphosate + chlorimuron.

CONCLUSIONS

1. Glyphosate does not provide effective control of species *C. benghalensis* or *C. diffusa*, confirming their tolerance to the herbicide;
2. Triple mixtures of the herbicide glyphosate, auxin herbicides (2.4-D, triclopyr or (halauxifen+diclosulam)) and carfentrazone proved to be the most effective in controlling the two species under study;
3. Flumioxazine, when applied alone, does not effectively control plants of *C. benghalensis* or *C. diffusa*, however, depending on the weed community in the area, it can be a good alternative for replacing the auxins in the triple mixture;
4. When used alone, the herbicide dicamba does not afford effective control of either species; however when used in a triple mixture with glyphosate and PPO-inhibiting herbicides, it provides control *C. diffusa* only;
5. The mixtures of glyphosate with the ALS inhibitors (chlorimuron and cloransulam) were effective for *C. diffusa* in both of the phenological stages under evaluation;
6. Control of *C. benghalensis* and *C. diffusa* in post-emergence should be carried out on four to six leaves, as this is faster and more efficient.

REFERENCES

AGOSTINETO, M. C. *et al*. Sinergismo de misturas de glyphosate e herbicidas inibidores da PPO no controle de corda-de-viola. **Revista de Ciências Agroveterinárias**, v. 15, n. 1, p. 8-15, 2016.

CHRISTEN, D. *et al*. Characterization and early detection of grapevine (Vitis vinifera) stress responses to esca disease by in situ chlorophyll fluorescence and comparison with drought stress. **Environmental and Experimental Botany**, v. 60, p. 504-514, 2007.

CHRISTOFFOLETI, P. J. *et al*. Resistência das plantas daninhas a herbicida: termos e definições importantes. *In*: CHRISTOFFOLETI, P. J.; NICOLAI, M. (coord.). **Aspectos de resistência de plantas daninhas a herbicidas**. 4. ed. Piracicaba: HRAC-BR, 2016. p. 11-31.

FRANS, R.; CROWLEY, H. Experimental design and techniques for measuring and analyzing plant responses to weed control practices. *In*: SOUTHERN WEED SCIENCE SOCIETY. **Research methods in weed science**. 3. ed. Clemson, 1986. p. 29-45.

GAZZIERO, D. L. P. Misturas de agrotóxicos em tanque nas propriedades agrícolas do Brasil. **Planta Daninha**, v. 33, n. 1, p. 83-92, 2015.

LAWLOR, D. W.; TEZARA, W. Causes of decreased photosynthetic rate and metabolic capacity in water-deficient leaf cells: a critical evaluation of mechanisms and integration of processes. **Annals of Botany**, v. 103, p. 561-579, 2009.

MARTINS, B. A. B.; CHRISTOFFOLETI, P. J. Herbicide efficacy on Borreria densiflora control in pre- and post-emergence conditions. **Planta Daninha**, v. 32, n. 4, p. 817-825, 2014.

MONQUERO, P. A. *et al*. Absorção, translocação e metabolismo do glyphosate por plantas tolerantes e suscetíveis a este herbicida. **Planta Daninha**, v. 22, p. 445-451, 2004.

OSIPE, J. B. *et al*. Espectro de controle de plantas daninhas com os herbicidas 2,4-D e dicamba associados ou não ao glyphosate. **Planta Daninha**, v. 35, 2017.

RODRIGUES, B. N.; ALMEIDA, F. S. **Guia de herbicidas**. 7. ed. Londrina: [*s. n.*], 2018. 764 p.

SANTOS, H. G. *et al*. **Sistema brasileiro de classificação de solos**. 5. ed. Brasília, DF: Embrapa, 2018. 356 p.

SANTOS, L. D. *et al*. Efeito do glyphosate sobre a morfoanatomia das folhas e do caule de *Commelina diffusa* e *C. benghalensis*. **Planta Daninha**, v. 22, n. 1, p. 101-107, 2004.

STRASSER, B. J.; STRASSER, R. J. Measuring fast fluorescence transients to address environmental question: the JIP test. *In*: MATHIS, P. (ed.). **Photosynthesis**: from light to biosphere. Dordrecht: Kluwer Academic Publisher, 1995. v. 5, p. 977-980.

SZABÓ, I.; BERGANTINO, E.; GIACOMETTI, G. M. Light and oxygenic photosynthesis: energy dissipation as a protection mechanism against photo-oxidation. **EMBO reports**, v. 6, n. 7, p. 629-634, 2005.

TAKANO, H. K. *et al*. Efeito da adição do 2,4-D ao glyphosate para o controle de espécies de plantas daninhas de difícil controle. **Revista Brasileira de Herbicidas**, v. 11, p. 1-14, 2013.

THACH, L. B. *et al*. The OJIP fast fluorescence rise characterizes *Graptophyllum* species and their stress responses. **Photosynthesis Research**, v. 94, p. 423-436, 2007.

TSIMILLI-MICHAEL, M.; STRASSER, R. J. *In vivo* assessment of plants vitality: applications in detecting and evaluating the impact of Mycorrhization on host plants. *In*: VARMA, A. (ed.). **Mycorrhiza**: state of the art, genetics and molecular biology, eco-function, biotechnology, eco-physiology, structure and systematics. Dordrecht: Springer, 2008. v. 3, p. 679-703.

WALKER, S. *et al*. Weed age affects chemical control of *Conyza bonariensis* in fallows. **Crop Protection**, v. 38, p. 15-20, 2012.