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Interference of glyphosate-resistant *conyza sumatrensis* in soybean crops in Central Brazil

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Abstract: **Background:** Studies on losses caused by competition of soybean with Sumatran fleabane plants in the Cerrado biome are scarce and need to be conducted to assist in choosing more effective weed management strategies.

Objective: Evaluate the effect of glyphosate-resistant Sumatran fleabane plants on soybean and describe their dynamics regarding emergence of new plants and mortality of adult plants in the hot summer rainy season in the Cerrado biome.

Methods: Three field experiments were conducted at the Embrapa Cerrados site (Brasília, DF, Brazil) over two years, using a randomized block experimental design with ten treatments, six competition periods and four controls, and four replications. The treatments consisted of periods of competition of soybean with Sumatran fleabane plants in the plots: until 10 (0–10), 20 (0–20), 30 (0–30), 45 (0–45), and 60 (0–60) days after soybean sowing (DAS) and until soybean harvest. Four control treatments were used to evaluate the dynamics of Sumatran fleabane and soybean plants, also considering other emerged weed species. Evaluations were carried out on Sumatran fleabane plants and soybean.

Results: None of the competition periods negatively affected the establishment and development of soybean. The Sumatran fleabane plant cycle ended from 45 to 60 DAS. Only one Sumatran fleabane emergence period (approximately 24 DAS) occurred throughout the soybean cycle, these plants died due to shading by the crop.

Conclusions: Sumatran fleabane plant densities of 13 to 23 plants m^{-2} at the soybean sowing did not interfere with the crop establishment and development.

Keywords: Cerrado. Competition Periods; No-till system; Weed Resistance.

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1. Introduction

Conyza sumatrensis (Sumatran fleabane), known as buva in Brazil, is an annual species native to South America, which reproduces by seeds that are produced in large quantities and are easily spread by wind (Anastasiu, Memedemin, 2011; Hao et al., 2009). Sumatran fleabane plants compete for water, light, and nutrients, can chemically suppress other plants, and are an alternative host of insect pests that cause yield and quality losses in several crops (Bajwa et al., 2016; Dalazen et al., 2017; Shaukat et al., 2003).

Little information is available about the competition dynamics of Sumatran fleabane in the Cerrado biome, which encompasses most of the agricultural areas of Brazil and presents specific edaphoclimatic characteristics. The limiting factor for the emergence of new Sumatran fleabane plants in this region is the typical dry season from May to September. Despite the favorable thermal conditions and energy availability for the plants (Silva et al., 2008), new emergences of Sumatran fleabane do not occur during this dry period, except in irrigated areas. Sumatran fleabane plants in rain-fed agricultural areas of central Brazil emerge from February to April, and their life cycle ends in the rainy season (up to October or November), generally at soybean pre-sowing, they would survive due to poor chemical or mechanical management which prolongs their biological cycle (Correia, 2020).

Herbicides are the primary method used to control Sumatran fleabane in agricultural areas; however, the exclusive and frequent use of herbicides with the same mechanism of action has selected resistant biotypes (Blainski et al., 2015). Resistance is an inherent and heritable capacity of some biotypes, within a population, to survive and reproduce after exposure to herbicide rates that would commonly be lethal to a normal (susceptible) population of the same species (Weed Science Society of America, 1998). The first case of *C. sumatrensis* resistant to herbicides in Brazil was reported in 2010 in the southern state of Paraná (Heap, 2023). Thereafter, the species have become problematic in the entire southern region of the country, with cases of resistance to several herbicides (glyphosate, chlorimuron, paraquat, and saflufenacil), including resistance to multiple herbicide groups/modes of action (glyphosate-chlorimuron, glyphosate-chlorimuron-paraquat, diuron-paraquat-saflufenacil-glyphosate-2,4-D) (Albrecht et al., 2020; Heap, 2023).

Increases in infestations of resistant biotypes in agricultural production systems increase production costs due to the need for other weed management strategies, or to decreases in yield of crops of economic interest, caused by competition with surviving weeds (Gazziero et al., 2019). The control of resistant plants is difficult and requires changes in the choice of herbicides and in field management practices, in the medium- and long-term. Thus, information on the pattern of emergence of Sumatran fleabane plants and their potential for interference with soybean can help to define the appropriate time for application of post emergence herbicides and establishment of their residual in the soil to control new emergences (Gianelli et al., 2017). This is particularly important for the Cerrado biome, as it has a well-defined dry season in the winter, which is the main limiting factor for emergence and development of new Sumatran fleabane plants (Silva et al., 2008).

Although Sumatran fleabane plants are present in almost all soybean production areas in Brazil (Lucio et al., 2019), in the Cerrado biome this weed is less aggressive, due to edaphoclimatic conditions, and does not cause severe reductions in soybean yields (Correia, 2020). This is contrary to the southern region of the country, with a subtropical climate, where Sumatran fleabane plants, with 15 to 20 cm tall at a density of 20 to 35 plants per m^2 at soybean sowing, can result in losses close to 50% in the grain yield (Blainski et al., 2015; Albrecht et al., 2022). In the Cerrado biome Sumatran fleabane plants are at the full reproductive development stage at soybean sowing. Thus, our hypothesis that adult Sumatran fleabane plants at soybean sowing in the Cerrado biome, do not interfere with the crop, and do not significantly reduce grain yield, regardless of the period of coexistence.

Studies on soybean yield losses caused by competition of soybean crops with Sumatran fleabane are scarce or nonexistent in the Cerrado biome and need to be developed to contribute to the implementation of effective weed management strategies. Therefore, the objective of this work was to evaluate the effect of glyphosate-resistant fleabane on soybean and describe their dynamics regarding emergence of new plants and mortality of adult plants in the hot rainy season, in the Cerrado biome, Brazil.

2. Material and Methods

Three experiments were conducted under field conditions at the Embrapa Cerrados, Brasília, DF, Brazil: Experiments 1 and 2, in neighboring fields, from October 2020 to February 2021; and Experiment 3 from November 2021 to March 2022. The Sumatran fleabane population densities at the time of soybean pre-sowing burndown herbicide applications in the areas of Experiments 1, 2, and 3 were 13, 22, and 23 plants m^{-2}, respectively.

The areas of Experiments 1, 2, and 3 were located at 15°36’08.1’’S 47°42’46.1’’W, 15°36’05.9’’S 47°42’48.9’’W, and 15°36’35.2’’S 47°44’27.9’’W, at 994, 998, and 1,121 m of altitude, respectively. The climate of the region is Aw, tropical wet, with a dry winter, according to the Köppen classification (Cardoso et al., 2014). Total weekly precipitation depths and mean weekly maximum and minimum temperatures over the periods of the experiments were recorded by meteorological stations and are shown in Figure 1.

The soil for Experiments 1 and 2 is a Typic Hapludox (Latossolo Vermelho Escuro; Santos et al., 2018) of clay texture, and the soil analysis indicated pH ($CaCl_2$) of 5.5 and 5.7; 2.9 and 3.0 dag kg^{-1} of organic matter; 17.97 and 19.46 mg dm^{-3} of P (Mehlich); 66 and 78 mg dm^{-3} of K; 2.95 and 4.11 $cmol_c$ dm^{-3} of Ca; and 0.69 and 1.41 $cmol_c$ dm^{-3} of Mg, respectively. The soil of Experiment 3 is a Typic Hapludox (Latossolo Vermelho Amarelo; Santos et al., 2018) of clay texture, and the soil analysis indicated pH ($CaCl_2$) of 4.7; 3.1 dag kg^{-1} of organic matter; 8.81 mg dm^{-3} of P (Mehlich); and 0.29, 1.63, and 0,65 $cmol_c$ dm^{-3} of K, Ca, and Mg, respectively.

In the first year of experiment, soybean was grown in a summer rotation following maize, which left 5,400 kg ha^{-1} of mulch on the soil. The soybean cultivar DM 68i69 IPRO (DonMario Semillas, Buenos Aires, Argentina) was used in these experiments; in the following year, the cultivar CD 2728 IPRO (Corteva Agriscience, São Paulo, Brazil) was used. Both cultivars are resistant to the herbicide glyphosate and have the Bt (Cry1Ac) protein for control of insects. Soybean was sown using a 5-row pneumatic seeder, under a no-till system, to a depth of 5 cm, with 0.5 m between rows. The seeds were treated with insecticides and fungicides and then inoculated with *Bradyrhyzobium japonicum*. Application of soil fertilizer consisted of 12 kg ha^{-1} of N, 90 kg ha^{-1} of P_2O_5, 48 kg ha^{-1} of K_2O plus 0.15 kg ha^{-1} of Zn applied to the sown rows in Experiments 1 and 2; and 16 kg ha^{-1} of N, 120 kg ha^{-1} of P_2O_5, 64 kg ha^{-1} of K_2O plus 0.2 kg ha^{-1} of Zn for Experiment 3.

The area of each plot was 3 m wide and 5 meters long (15 m^2), and the evaluation area consisted of the central 8.0 m^2 (four meters of the four central rows).

Experiments were conducted using randomized block designs with ten treatments, six competition periods and four controls, and four replications. The treatments consisted of the following periods of competition of soybean with Sumatran fleabane plants: until 10 days after soybean sowing (DAS) (0-10 DAS; V_1 phenological stage), 20 DAS (0-20 DAS; up to V_3), 30 DAS (0-30 DAS; up to V_8 - V_9), 45 DAS (0-45 DAS; up to R_2), and 60 DAS (0-60 DAS; up to R_4), and until soybean harvest (at 116 DAS in the first year, and 126 DAS in the second, at the R_8 stage).

Four control treatments were used to evaluate the dynamics of Sumatran fleabane and soybean plants, also considering other emerged weed species. Control-1 and

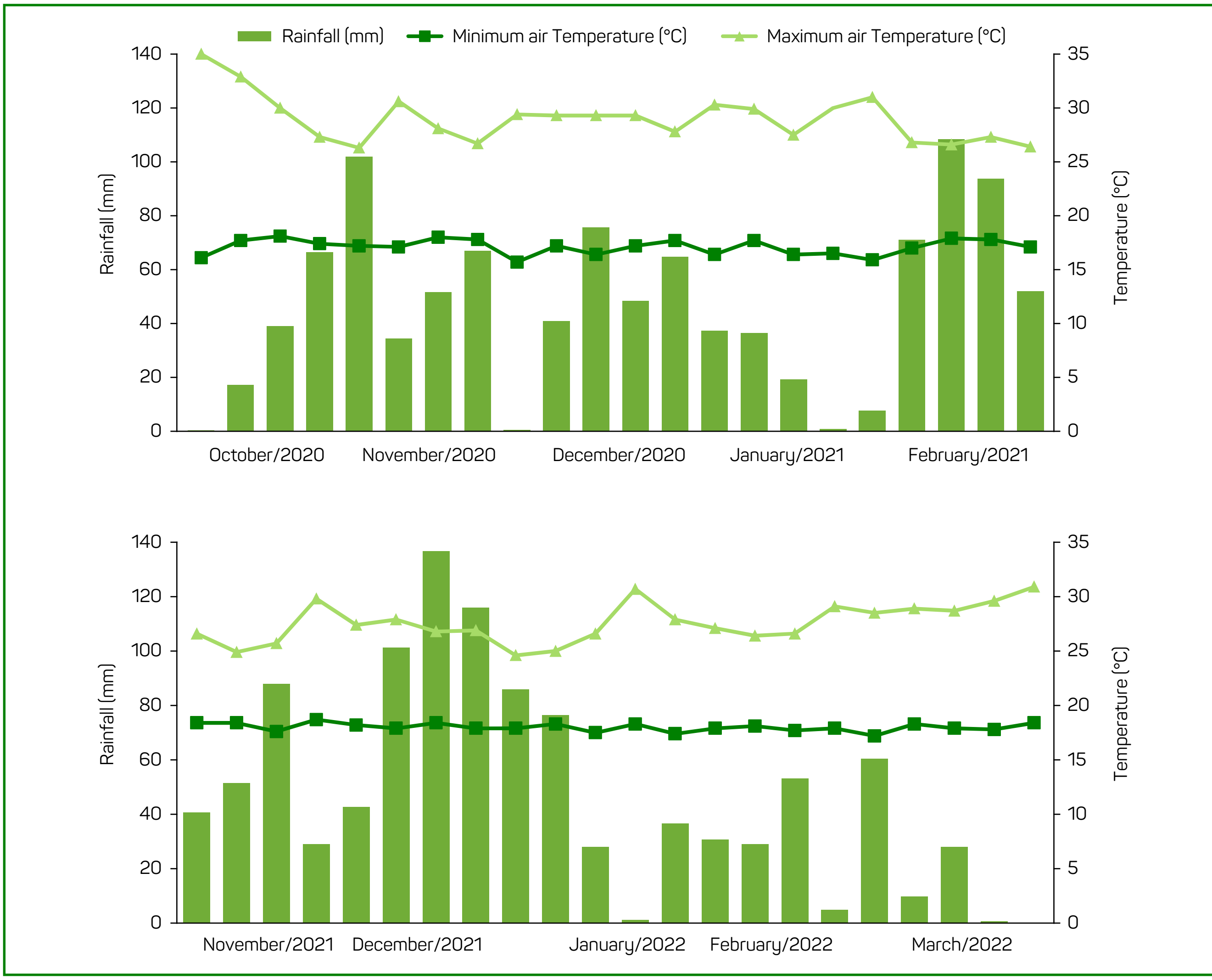


Figure 1 - Total weekly precipitation amounts and mean weekly minimum and maximum air temperatures recorded by the meteorological stations of the Embrapa Cerrados from October 01, 2020 to February 28, 2021, and November 01, 2021 to March 31, 2022.

Control-2 consisted of soybean sown in clean areas, i.e., with no weeds in the plots, and with no chemical or mechanical management of weeds at the soybean post-emergence. The difference between these two controls plots was the control of Sumatran fleabane that emerged after soybean sowing; in Control-1, new Sumatran fleabane plants were uprooted manually, and in Control-2, no Sumatran fleabane removal was done. Control-3 was maintained clean without any weed species throughout the soybean cycle. Control-4 was maintained with weeds, with no weed management at the pre-sowing or application of post-emergence herbicide to the crop.

The other weed species were controlled by applying glyphosate to plots of the periods of competition and to the clean control (Control-3) at the pre-sowing and post-emergence of the soybean crop (at 21 DAS in the first year, and 22 DAS in the second), combined with manual removal of plants that survived or were partially controlled by the herbicide. Glyphosate did not affect the Sumatran fleabane plants, as they were resistant to the herbicide; the commercial product used was Nufosate WG® (Sumitomo, Tokyo, Japan), applied at both timings and at the rate of 1.44 kg a.e. ha^{-1}.

Glyphosate was applied using a CO_2-pressurized backpack sprayer equipped with a spray boom with six flat fan nozzles (TTI110015; Teejet®, Wheaton, USA) spaced 0.5 m apart, operating at constant pressure (196 kPa) for an application volume equivalent to 150 L ha^{-1}. The edaphoclimatic conditions at the time of pre-sowing and post-emergence applications were: air temperatures of 22 to 28 °C, soil temperatures of 23 to 26 °C, relative air humidity of 62% to 88%, 100% to 50% cloudiness, and wind speeds of 2 to 8 km ha^{-1}. Soybean plants were at V3 to V4 phenological stage at the post-emergence application timing.

The other weed species were controlled using glyphosate to select the Sumatran fleabane plants, preserve the maize straw (from the previous crop) on the soil, and cause low soil disturbance, which could affect weed seed dormancy, germination, and emergence.

Sumatran fleabane plants were at the full reproductive development stage at soybean sowing, with flowers, fruits, and seed production, and mean heights of 79 cm in the first year (Figure 2a) and 50 cm in the second. In the first year, new Sumatran fleabane plants emerged in the experimental areas throughout the maize crops in the previous season, from February to April, 2020. The Sumatran fleabane plants had been cut back during mechanized harvest of maize in May 2020 and had re-sprouted, prolonging their life cycle. In the second year, Sumatran fleabane plants emerged in the same time, but they were hoed in July, stimulating the regrowth of the plants due to the cleaning of the experimental area.

The weed community was similar in both experimental areas in the first year, with occurrence of the species *Tridax procumbens*, *Richardia brasiliensis*, *Commelina benghalensis*, *Euphorbia heterophylla*, *Acanthospermum hispidum*, volunteer *Zea mays*, *Bidens subalternans*, *Chamaesyce hirta*, *Alternanthera tenella*, *Marsypianthes chamaedrys*, *Desmodium tortuosum*, *Digitaria* sp., *Eleusine indica*, and *Cenchrus echinatus*. In the second year, the other weed species found were *Digitaria insularis*, *T. procumbens*, *C. benghalensis*, *Ipomoea triloba*, *Richardia brasiliensis*, *C. hirta*, *B. subalternans*, *M. chamaedrys*, and *Galinsoga parviflora*.

All Sumatran fleabane plants in the plots were uprooted at the end of each competition period; the plants were counted and separated into adult, dead, and young (small plants < 10 leaves) in two areas of 0.45 m^2 randomly chosen within the evaluation area. The plots were maintained with no Sumatran fleabane plants after the competition period until soybean canopy closure (at 60 DAS) (Figure 2b). The other weed species were manually uprooted as needed until soybean canopy closure. The plants in the treatments 0–116 DAS (first year) and 0–126 DAS (second year) were counted at three timings (at soybean sowing, and at 30 and 116 or 126 DAS) due to difficulties in counting the dead plants, some of which were totally or partially decomposed on the soil at the soybean harvest.

Pests and diseases in the experimental areas were monitored weekly and a single occurrence of fungus (powdery mildew; *Erysiphe diffusa*) was encountered in the first year and was controlled by applying a fungicide.

A visual evaluation of weed control was carried out for all treatments at the end of the soybean cycle, using a scale of grades from 0% to 100%, where zero represents the absence of visual injuries and 100 the death of the plant (Sociedade Brasileira da Ciência das Plantas Daninhas, 1995). At the same time, Sumatran fleabane plants were counted in 4.0 m^2 of the evaluation center area of the plots, and the results were expressed as plants m^{-2}.

The soybean plant population, total grain yield, grain yield per plant, and 100-grain weight were evaluated. Soybean plants in the evaluation area (4 m of the three central rows) of each plot were counted, mechanically harvested, and weighed. Soybean yield was adjusted to 13% grain moisture.

The analyses of Sumatran fleabane density within the competition periods were carried out individually for each experiment, considering a split-plot in time arrangement, with plant types (adult, dead, and young) in the subplots and competition periods (0–10, 0–20, 0–30, 0–45, 0–60 and 0–116 or 0–126 DAS) in the plots. The data were analyzed using the statistical program Sisvar 5.7 (Ferreira,

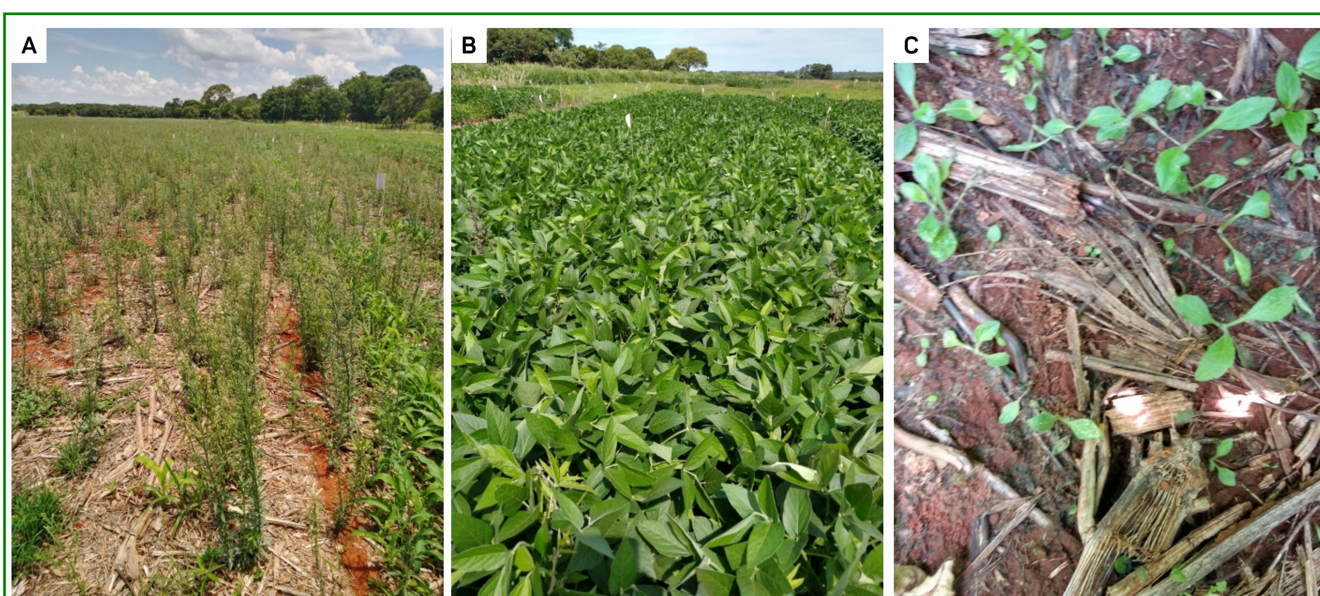


Figure 2 - Adult Sumatran fleabane plants before soybean sowing (a), soybean canopy closure at 60 days after sowing (DAS) (b), and young Sumatran fleabane plants at 60 DAS (c) in the first year.

2011). In addition the dynamics of the Sumatran fleabane adult and dead plants after soybean sowing were modeled in MS Excel® using the log-logistic continuous distribution function (Seefeldt et al., 1995) with the minimum plant number (min) set to zero. Variable parameters for the maximum plant number (max), slope b in units of DAS, and the inflection point, representing the DAS where 50% of the change in numbers of plants between the min and max occurred, were solved for the minimum prediction error square using the Solver function with the GRG nonlinear method to perform the iterations. Numbers of young plants were modeled using log-normal probability density function (Limpert et al., 2001) in MS Excel® in a similar manner, solving for the variable parameters of mean, standard deviation (std dev) and peak height (used to extrapolate to plant number).The significance of the fit of the observed and modeled data was determined with regression analysis using the Regression analysis tool in the Data Analysis package in Excel®.

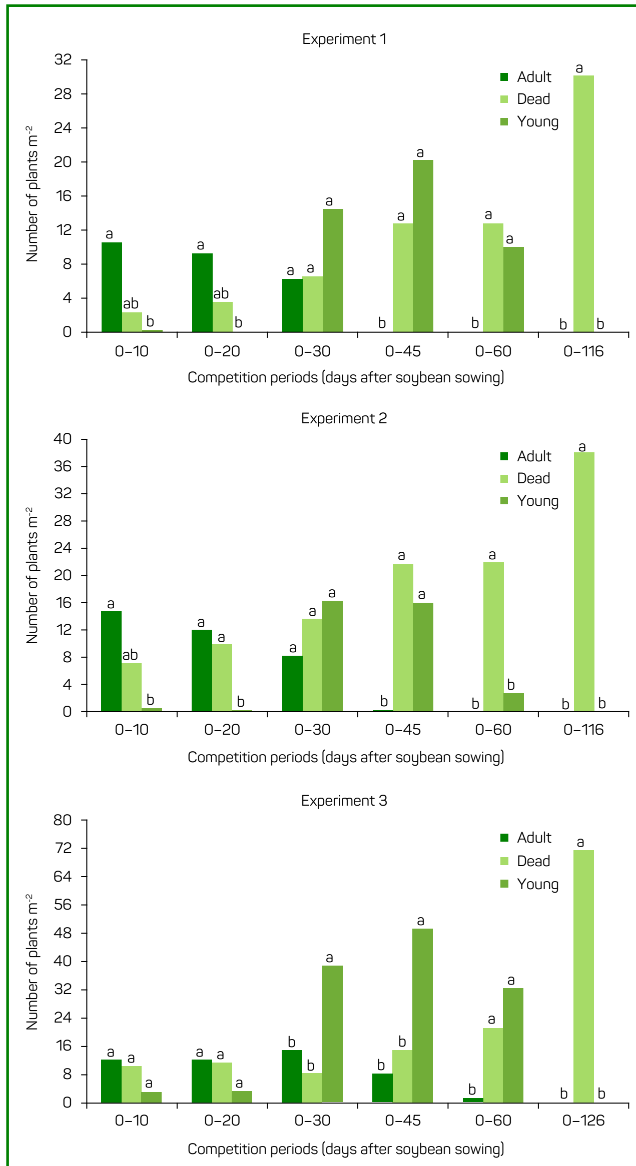
For weed control and soybean development data a joint analysis of variance of the experiments was carried out, using the statistical program Sisvar 5.7 (Ferreira, 2011), that considered the effects of the three experiments and competition periods of each experiment as fixed effects. The effects of the experiments, when significant, were compared by the Tukey's test at 5% significance level. Data from competition periods, when significant, were fit to regression models chosen based on the best biological response and the highest coefficient of determination. In addition, competition periods were compared to the controls (Control-1, Control-2, Control-3, and Control-4) by the Tukey's test at 5% significance level; a joint analysis of variance of the experiments was carried out considering the effects of the three experiments and treatments (competition periods and controls) of each experiment as fixed effects.

3. Results and Discussion

The plant types were compared for each competition period (Figure 3). The infestation of adult Sumatran fleabane plants predominated until 20 DAS in the three experiments, differing only in the number of young plants, due to the absence of new emergences in the plots. However, the number of young plants increased until 30 DAS, although with no significant differences between young plants and other plant types. In Experiment 3, the results were similar, but with significant differences between plant types, with higher densities of young plants due to the emergence observed at 30 DAS.

In the first two experiments (Experiments 1 and 2), few adult Sumatran fleabane plants were found at 45 and 60 DAS, and the numbers of dead and young plants were similar, except for Experiment 2 at 60 DAS, when the number of dead plants was higher than that of young plants. In Experiment 3, the number of adult plants did not differ from that of dead plants at 45 DAS. The highest decrease in number of adult plants, significantly difference from the other plant types, occurred at 60 DAS.

No adult or young Sumatran fleabane plants were present at soybean harvest (116 or 126 DAS); all plants died due to the termination of their biological cycle (adult plants) or early death (young plants) because of the closing of soybean canopy which caused absence of light required for their survival. The level of competition of the soybean



[(1)] Bars with the same letters, within each competition period, are not significantly different from each other by the Tukey's test at 5% significance level.

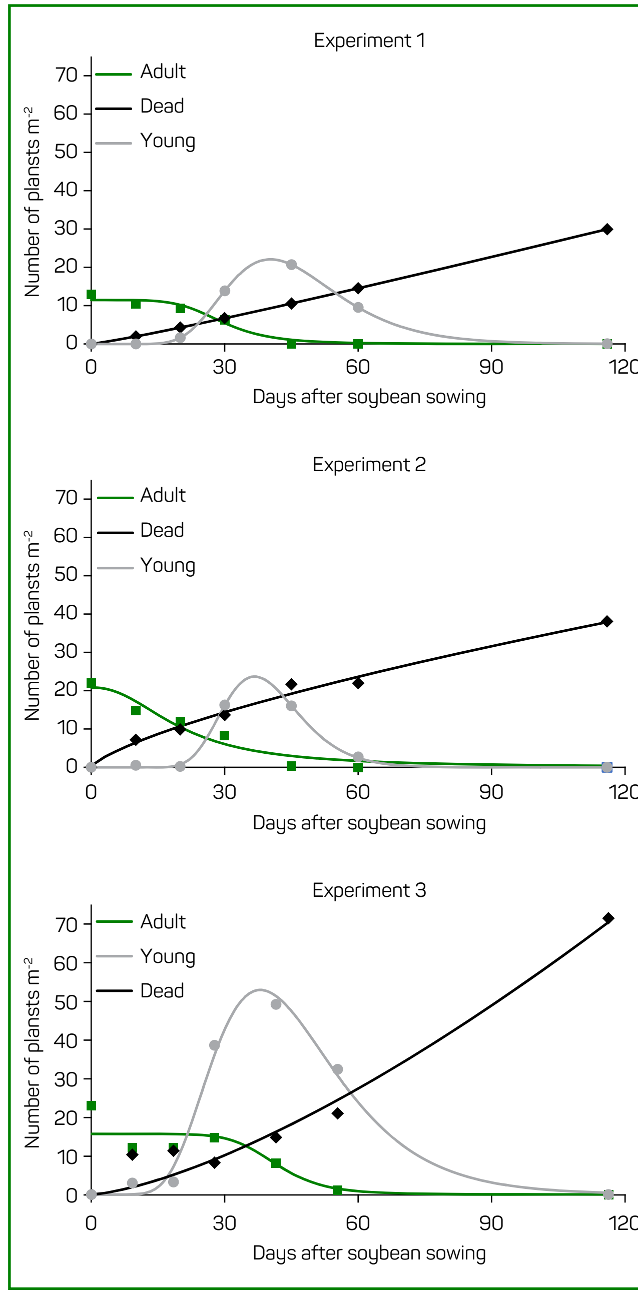
Figure 3 - Number of adult, dead, and young Sumatran fleabane plants at the end of periods of competition with soybean crops (10, 20, 30, 45, 60, and 116 or 126 days after sowing - DAS), in Experiments 1, 2, and 3, which presented initial Sumatran fleabane population densities of 13, 22 and 23 plants m^{-2}, respectively.

crop was high, and despite the large number of Sumatran fleabane plants that emerged in the experiments, 18 to 49 plants m^{-2}, these plants did not survive. At 30 days after the beginning of weed emergence, the plants had 5 etiolated leaves in addition to those that had died (Figure 2c). The number of young plants decreased in all the experiments from 30 to 60 DAS, but the largest decrease was observed in Experiment 2.

The dynamics of the adult, dead, and young Sumatran fleabane plants were modeled using the log-logistic continuous distribution function for adult and dead plants and using the log-normal probability density function for the young plants, the latter could account better for a right-hand skew observed in the data (Figure 4). The modeling R2 values generally showed a strong correlation coefficient and ranged from 0.949-0.998, with the exception of the curve-fitting for adult plants in Experiment 3, and the regression analysis between observed and fit data were highly significant for all instances (Table 1), demonstrating that the functions described the data very well. The numbers of dead plants rose steadily (with some delay in Experiment 3) but continued throughout the study until harvest. The plots clearly show that the numbers of adult plants declined to zero before canopy closure by the soybean (approximately 60 DAS), and was likely a manifestation of the senesce phase, as previously mentioned. The numbers of young plants rose rapidly after 15–20 DAS and declined to zero slightly after canopy closure in Experiment 2. This and the lack of negative yield effects clearly suggests that soybean plants were able to out-compete the old and young Sumatran fleabane plants, suppress their growth and reduce further germination, eventually causing their death.

Effects of light on Sumatran fleabane seed germination have been described in several studies (Wu et al., 2007; Yamashita et al., 2011; Zinzolker et al., 1985); however, the present study showed an inhibitory effect of the absence of light on initial growth of Sumatran fleabane plants. Restricting solar radiation decreases plant growth and development (Pitelli, Pitelli, 2008), suppressing the growth and development of young Sumatran fleabane plants under a crop canopy like soybean. The degree of effects of Sumatran fleabane emergence on a soybean crop in the central region of Brazil depends on the time that the weeds emerge in the field and the corresponding soybean plant size and canopy cover at that time. Younger soybean plants or plants from less competitive cultivars will give less suppression of Sumatran fleabane.

The capacity of several soybean cultivars to compete with Sumatran fleabane plants has been reported by Trezzi et al. (2013), who found that the genotypes evaluated reduced the dry matter of Sumatran fleabane plants by 53% to 74%. Highly competitive cultivars with fast initial growth, intense uptake of nutrients and water, and high sunlight interception prevent weeds from accessing such resources (Pitelli, Pitelli, 2008).



(1) Numbers of adult and dead plants were modeled using the log-logistic equation, and number of young plants using the log-normal function.

Figure 4 - Dynamics of Sumatran fleabane plants (adult, dead, young) over time at soybean crop in Experiments 1, 2, and 3.

The effect of Sumatran fleabane plants on soybean crops varies according to the competitive capacity of the genotype. Agostinetto et al. (2017) found that one fleabane (*Conyza bonariensis*) plant per square meter can result in soybean grain yield losses of 1% to 26%, depending on the cultivar.

Only the control with no weeds (Control-3) had Sumatran fleabane emergence at the same time as in the competition period treatments. The other controls, those with soybean and weed plants covering the soil (Control-1, Control-2,

Table 1 - Models parameters[1] for prediction of numbers of Sumatran fleabane plants (adult, dead, young) in Experiments 1, 2, and 3

Experiments	Plant types	Log-Logistic				Log-Normal			Model R^2
		Max	Min	b	D_{50}	Mean	Std Dev	Peak Height	
Experiment 1	Adult	11.48	0	5.34	29.5	-	-	-	0.97**
	Dead	947	0	-1.12	2435	-	-	-	0.99**
	Young	-	-	-	-	3.791	0.307	22.11	0.99**
Experiment 2	Adult	20.83	0	2.22	20.1	-	-	-	0.95**
	Dead	1548	0	-0.73	18293	-	-	-	0.99**
	Young	-	-	-	-	3.657	0.232	23.66	0.99**
Experiment 3	Adult	15.66	0	7.79	45.0	-	-	-	0.79**
	Dead	46714	0	-1.43	11883	-	-	-	0.97**
	Young	-	-	-	-	3.849	0.362	52.90	0.99**

[1] The log-logistic function was used for adult and dead plants, and the minimum (min) was fixed at zero. The maximum (max), b (slope). and $D_{50,}$ change in plant numbers between min and max in units of days after sowing (DAS), were iteratively solved to obtain the lowest error sums of squares. The log-normal function was used for young plants, iteratively solving for mean, standard deviation (std dev) and peak height (used for extrapolation to fit plant numbers)

** Statistically significant at 1% significance level by regression.

and Control-4), showed no Sumatran fleabane emergence, confirming that the presence of soybean and weeds covering the soil affects the emergence of Sumatran fleabane, even under favorable edaphoclimatic conditions. In addition, the treatments with Sumatran fleabane emergence had only one emergence period, at approximately 24 DAS, probably due to an adequate combination of temperature and soil moisture that favored weed seed germination at that particular time.

The cumulative precipitation from the second week before soybean sowing was greater than 30 mm in both years; thus, soil moisture was not a limiting factor (Figure 1). Temperature was one major factor that likely influenced Sumatran fleabane seed germination. The germination response to temperature is a key adaptive characteristic for winter annual or biennial species, such as *Conyza* spp. (Tozzi et al., 2013). In the first year of experimentation, the mean maximum air temperatures from November 17 to 23 which preceded the beginning of Sumatran fleabane emergence was 3.2 °C lower than that the mean from October 01 to November 16, and the difference in minimum air temperature between these periods was only 0.8 °C. The same result was found over the 7 days before the beginning of emergence in the second year, with variations of 2.7 °C in maximum air temperature and only 0.1 °C in minimum air temperature. Thus, the milder maximum air temperatures may have favored the beginning of seed germination. The optimal temperature for germination of seeds of *Conyza* spp. has been described as 20 °C, ranging between 10 °C and 25 °C, up to 30 °C (Ottavini et al., 2019; Wu et al., 2007; Zinzolker et al., 1985).

The inhibitory action of the green vegetation cover and the single Sumatran fleabane emergence period showed that there will be no emergence of Sumatran fleabane in the late pre-sowing management of soybean, with dense living plant cover on the soil. This was previously reported by Correia (2020), who found no Sumatran fleabane emergence in soybean sown in the second half of November. This can be explained by the light requirement to initiate Sumatran fleabane seed germination, as they are photoblastic positive and show higher emergence in soils managed under more conservation agricultural systems, such as no-tillage systems with lower soil disturbance (Bajwa et al., 2016; Wu et al., 2007). However, the inhibitory effect on seed germination found in the present study was due to the soybean and weed plants covering the soil, which may have affected the amount and quality of the sunlight that reached the soil, inhibiting the seed germination (Yamashita et al., 2011).

The interaction between experiments and competition periods was not significant for any characteristic evaluated at soybean pre- and post-harvest, indicating that the initial Sumatran fleabane population showed similar effects for all competition periods, regardless of the number of plants per square meter (Table 2). Considering the factors independently, the experiments differed in soybean grain production per plant, total grain yield, 100-grain weight, and Sumatran fleabane density. Sumatran fleabane density was higher in the Experiment 1 than 2, and the density in Experiment 3 was intermediate and similar to that in the other two experiments. The different soybean development between experiments cannot be attributed to the different initial Sumatran fleabane plant density, since the experiments with higher initial density showed higher total grain yield, grain yield per plant, and 100-grain weight. Factors related to soil fertility, variations in infestation of other weed species in the control treatments, and differences in the production potential of the soybean cultivars probably affected the mean soybean yield.

Table 2 - Analysis of variance (F test) for soybean plant population, grain yield per plant, 100-grain weight, total grain yield, weed control, and density of Sumatran fleabane plants at soybean harvest, as a function of periods of competition of soybean with Sumatran fleabane in three experiments with different initial Sumatran fleabane population densities[1]

Sources of variation	soybean plant population	Grain production per plant	100-grain weight	Grain yield	Weed control	Weed density
Experiments	0.56	12.18**	4.50*	14.82**	2.50	3.95*
Block (Exp.)	1.47	0.67	0.81	0.23	1.51	0.48
Periods	1.15	0.52	0.89	0.29	0.92	1.78
Exp. x Per.	1.17	0.76	0.76	0.63	0.23	0.68
CV (%)	5.24	11.80	3.61	11.34	2.13	62.59
Experiment	**Mean values**					
	1,000 plants ha^{-1}	**g**	**g**	**kg ha^{-1}**	**%**	**Plants m^{-2}**
First	293.51 a[2]	11.45 b	16.49 b	3350.58 b	96.46 a	0.61 b
Second	291.74 a	12.76 a	16.99 a	3714.82 a	95.23 a	0.00 a
Third	296.39 a	13.55 a	16.87 ab	4006.68 a	95.44 a	0.45 ab
MSD	10.90	1.01	0.42	292.82	1.42	0.55

*, ** Statistically significant at 5% and 1% significance level by the F test, respectively; MSD = minimum significant difference

[1] Initial Sumatran fleabane densities in Experiments 1, 2, and 3 were 13, 22, and 23 plants m^{-2}, respectively

[2] Means followed by the same letter in the columns are not significantly different from each other by the Tukey's test at 5% significance level.

Table 3 - Analysis of variance (F test) for soybean plant population, grain yield per plant, 100-grain weight, total grain yield, weed control, and density of Sumatran fleabane plants at soybean grain harvest, as a function of treatments (competition periods of soybean crops with Sumatran fleabane plants, and controls) in three experiments with different initial Sumatran fleabane population density[1]

Sources of variation	Soybean plant population	Grain production per plant	100-grain weight	Grain yield	Weed control	Weed density
Experiments	0.81	53.33**	11.53**	47.70**	3.63*	4.57*
Treatments	7.58**	21.52**	10.48**	31.34**	192.62**	2.78**
Exp. x Trat.	2.28	3.60	2.66	1.89	1.34	0.99
Block	2.95	2.43	1.31	2.29	1.05	0.53
CV (%)	5.39	11.90	4.87	11.72	12.38	60.90

*, ** Statistically significant at 5% and 1% significance level by the F test, respectively

[1] Initial Sumatran fleabane populational densities in Experiments 1, 2, and 3 were 13, 22, and 23 plants m^{-2}, respectively.

The competition periods did not affect any characteristic evaluated at soybean pre- and post-harvest, indicating that the initial density of Sumatran fleabane plants and the periods in which they competed with soybean did not affect the crop. The data did not fit well with either of the tested regression models (Boltzmann sigmoid and log-logistic regression), as there was no variation between competition periods. Thus, the competition of Sumatran fleabane with soybean plants from 0 to 10 DAS or until the soybean harvest (116 or 120 DAS) did not cause any observed damage to the crop or yield loss, regardless of the initial weed population. The opposite was found in other regions of Brazil for *C. bonariensis* (Agostinetto et al., 2017; Trezzi et al., 2013). The results confirmed the variability of results depending on the *Conyza* species and the regional soil and climate conditions, in addition to the importance of knowing the *Conyza* species and the plants dynamics where will be to apply control measures.

The competition periods and control treatments showed significant differences for all evaluated variables at the end of the soybean cycle (Table 3). A lower population of soybean plants was found for the infested control (Control-4) throughout the soybean cycle, differing from the other controls and competition period (Table 4). Grain yield per plant and total grain yield formed three groups: one with the highest yields, defined by competition periods and the control without weeds (Control-3); one with intermediate yields, for the controls with and without Sumatran fleabane (Control-2 and Control-1, respectively), but containing other weed species; and one with the lowest yields, for the infested control (Control-4), which also resulted in the lowest 100-grain weight (Table 4).

Table 4 - Soybean plant population, grain yield per plant, 100-grain weight, total grain yield, weed control, and Sumatran fleabane plant density at soybean grain harvest as a function of competition periods of soybean crops with Sumatran fleabane plants after the crop sowing and four controls

Competition Periods/ Controls[1]	Soybean population (1,000 plants ha^{-1})	Grain yield per plant (g)	100-grain weight (g)	Total grain yield (kg ha^{-1})	Weed control (%)	Weed density (plants m^{-2})
0-10	293.54 a[2]	12.18 abc	16.46 ab	3580.64 a	94.92 a	0.58 ab
0-20	298.82 a	12.49 ab	16.83 ab	3715.71 a	94.71 a	0.82 b
0-30	291.18 a	12.99 a	16.93 ab	3776.41 a	94.38 a	0.38 ab
0-45	289.09 a	12.85 a	16.84 ab	3709.81 a	98.71 a	0.08 ab
0-60	300.56 a	12.34 ab	16.86 ab	3695.08 a	98.00 a	0.07 ab
0-116/126	290.07 a	12.67 a	16.79 ab	3666.52 a	93.54 a	0.19 ab
Control-1	282.78 a	10.43 c	15.89 b	2978.86 b	29.17 b	0.00 a
Control-2	286.94 a	10.73 bc	16.42 ab	3047.58 b	39.17 b	0.00 a
Control-3	287.64 a	12.94 a	16.99 a	3719.70 a	99.08 a	0.10 ab
Control-4	256.11 b	7.03 d	14.54 c	1746.67 c	0.00 c	0.02 a
MSD	20.55	1.84	1.06	522.62	12.17	0.78

[1] Control-1 - soybean seeds sown in clean areas, but with Sumatran fleabane and other weed species throughout the soybean cycle; Control-2 - soybean seeds sown in clean areas with no Sumatran fleabane, but with other weed species throughout the soybean cycle; Control-3 - without any weed species throughout the soybean cycle; Control-4 - soybean seeds sown in areas infested with Sumatran fleabane and other weed species throughout the soybean cycle

[2] Means followed by the same letter in the columns are not significantly different from each other by the Tukey's test at 5% significance level. MSD = minimum significant difference.

The Sumatran fleabane infestation after soybean sowing in Control-1 and Control-2 did not affect the soybean total grain yield, which was due to the lack of new emergences of Sumatran fleabane plants in the plots of these controls. The differences between these controls, which were not statistically significant, were due to the presence of other weed species that emerged in the plots after soybeans were sown. The total grain yield of soybean plants in the control with no weeds (Control-3) was 20%, 18%, and 53% higher than those in Control-1, Control-2, and Control-4, respectively, and was not statistically different to the yields in the competition period treatments (Table 4).

The end of the Sumatran fleabane plant cycle occurred from 45 to 60 DAS; these plants did not affect the soybean crop, suggesting that the weed could be left in the crop with no management at this period, during the growth and development of the soybean plants, without it negatively affecting yield. However, considering the high seed production of Sumatran fleabane plants, which can reach up to 230,000 seeds per plant (Bajwa et al., 2016; Ottavini et al., 2019; Weaver, 2001), which are easily dispersed by wind (Dauer et al., 2007), leaving adult plants with seeds in crop fields may result in increases the seed bank and intra- and inter-field disseminations. Therefore, weed chemical control in off-season crops (in the autumn-winter), both irrigated and rainfed crops, assists in the management of Sumatran fleabane plants by reducing their potential number in following seasons. Moreover, chemical treatments carried out after the soybean or maize harvest (summer or winter crop season) are more effective than in-crop treatments for the management of Sumatran fleabane than applications at pre-sowing of the summer crop in a competitive soybean crop (Correia, 2020).

The control of other weed species at soybean harvest in the infested control (Control-4) was used as reference, with a value of zero (0%). Thus, Control-1 and Control-2 showed control levels of 29% and 39%, respectively. No weed management was carried out for these controls after soybean sowing; thus, the effect on weeds found was only due to the competitive capacity and suppression of weed growth and further germination caused by soybean plants. The control with no weeds (Control-3) and the competition periods demonstrated similar control levels (94% to 99%). Sumatran fleabane plants were not considered in this evaluation, as they were evaluated separately by counting the plants in 4.0 m^2 of the evaluation center area of the plots, which presented significant differences between treatments, but with densities lower than 1 plant m^{-2}.

Adult plants of Sumatran fleabane at the full reproductive development stage at soybean sowing did not compete successfully with the crop because their vegetative growth had already been completed before soybean was sown, only maturation and seed dissemination remained to complete its life cycle. These stages in the termination phase do not appear to affect soybean. Thus, the hypothesis that adult Sumatran fleabane plants at soybean sowing, in the Cerrado biome do not interfere with the crop, without significant damage to grain yield, regardless of the period of coexistence was confirmed.

4. Conclusion

Initial Sumatran fleabane densities of 13 to 23 plants m^{-2} at the soybean sowing did not affect the establishment, development, and yield when coexisting with these weeds until the soybean harvest. The Sumatran fleabane plant life cycle ended from 45 to 60 DAS. Only one Sumatran fleabane emergence period occurred at approximately 24 DAS, and these plants died due to the shading from the crop.

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Conflicts of interest

No conflicts of interest have been declared.

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