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Scientific Article

Morphophysiological responses of bean cultivars in competition with *Conyza bonariensis*

Respostas morfofisiológicas de cultivares de feijão em competição com *Conyza bonariensis*

Ilana G. Gasparetto[1], Leandro Galon[1], Caroline Müller[1]*, Daiani Brandler[2], Rodrigo J. Tonin[1], Gismael F. Perin[1]

[1]Universidade Federal da Fronteira Sul, Erechim, RS, Brazil. [2]Universidade Tecnológica Federal do Paraná, Pato Branco, PR, Brazil.

ABSTRACT – Weeds are responsible for large losses in grain quality and quantity of beans produced. Therefore, studies on competition between beans and weeds are important to achieve more efficient crop management while reducing the use of herbicides. Thus, the aim of this work was to evaluate the competitive ability of bean cultivars (BRS Estilo, IPR Urutau, IAC 1850 and IPR Tangará) in the presence of hairy fleabane (*Conyza bonariensis*) with different proportions of plants in the association. The experiments were conducted in a greenhouse in a randomized block design with four replicates. The treatments were arranged in different proportions of common bean and hairy fleabane plants: 20:00, 15:5, 10:10, 5:15, and 0:20 plants pot^{-1}. The competitive ability of the species was analyzed using diagrams applied in substitution experiments and relative competitive ability indices. Plant height, stem diameter, leaf area, gas exchange and shoot dry matter were measured 40 days after plant emergence. Negative effects were observed for both the crop and hairy fleabane, as both species competed for the same resources available in the environment. Interspecific competition caused greater damage to plant height, stem diameter, leaf area and dry matter of the species than intraspecific competition. Common bean achieved higher photosynthetic rates and water use efficiency in the presence of hairy fleabane. Common bean cultivars have a greater competitive ability against hairy fleabane.

Keywords: *Phaseolus vulgaris*. Hairy fleabane. Competitive interaction.

RESUMO – As plantas daninhas são responsáveis por grandes perdas na qualidade e na quantidade de grãos de feijão produzido. Portanto, estudos sobre a competição entre o feijoeiro e as plantas daninhas são importantes para alcançar um manejo mais eficiente da cultura e, ao mesmo tempo, reduzir o uso de herbicidas. Assim, o objetivo deste trabalho foi avaliar a habilidade competitiva de cultivares de feijão (BRS Estilo, IPR Urutau, IAC 1850 e IPR Tangará) na presença de buva (*Conyza bonariensis*), em diferentes proporções de plantas na associação. Os experimentos foram conduzidos em casa de vegetação, em delineamento de blocos casualizados, com quatro repetições. Os tratamentos foram arranjados em diferentes proporções de plantas de feijão e buva: 20:00, 15:5, 10:10, 5:15 e 0:20 plantas vaso^{-1}. A habilidade competitiva das espécies foi analisada por meio de diagramas aplicados em experimentos substitutivos e índices de competitividade relativa. A altura das plantas, o diâmetro do caule, a área foliar, as trocas gasosas e a massa seca da parte aérea foram medidos 40 dias após a emergência das plantas. Foram observados efeitos negativos tanto para a cultura quanto para a buva, uma vez que ambas as espécies competiram pelos mesmos recursos disponíveis no meio. A competição interespecífica causou maiores prejuízos à altura das plantas, diâmetro do caule, área foliar e massa seca das espécies em relação à competição intraespecífica. O feijoeiro manteve maiores taxas fotossintéticas e maior eficiência no uso da água na presença da buva. As cultivares de feijoeiro apresentam maior habilidade competitiva em relação à buva.

Palavras-chave: *Phaseolus vulgaris*. Buva. Interação competitiva.

Conflict of interest: The authors declare no conflict of interest related to the publication of this manuscript.

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***Corresponding author:**
<carolinemulleram@gmail.com>

INTRODUCTION

Common bean (*Phaseolus vulgaris* L.) belongs to the Fabaceae family and is an economically important crop worldwide. In Brazil, it is still of social importance, as it is grown on a large scale by small-scale producers on family farms and has become one of the most important crops (TAVARES et al., 2013). In the 2022/22 harvest, bean production in Brazil amounted to 3.04 million tons, with an average productivity of 1125 kg ha^{-1}, a value lower than the productivity of the state of Rio Grande do Sul (1485 kg ha^{-1}) (CONAB, 2023). The lower national average productivity is due to regions where advanced management and/or cultivation technologies have not yet been implemented.

Weeds are the main limiting factors in the global agricultural production of bean grains, and the presence of weeds can lead to bean productivity losses of more than 70% (SOLTANI et al., 2018). These plants compete with crops mainly for light, water and nutrients (MEDEIROS et al., 2021). In the state of Rio Grande do Sul, the main weeds that infest beans are hairy fleabane species (*Conyza bonariensis*, *C. canadensis* and *C. sumatrensis*) from the Asteraceae family, which are widespread in the growing areas in Brazil. *Conyza bonariensis* is considered an aggressive species that competes strongly with crops, and there are reports of damage to the production of various crops around the world (VANHIE et al., 2021).

The initial stages of crop development are considered critical periods, as plants are more susceptible to competition. During this period, efficient weed control is important to avoid quantitative and qualitative production losses (SOLTANI et al., 2018; HENZ NETO et al., 2023). The critical period of competition varies depending on the climatic conditions and the crops used. In the northern region of the state of Rio Grande do Sul, this period is between 24 and 50 days after crop emergence (FRANCESCHETTI et al., 2019).

Several factors influence competition between crops and weeds, e.g. plant species, population density (BIANCHI et al., 2006) and management practices, including the use of more competitive cultivars. The selection of more competitive cultivars can reduce the degree of weed competition and the level of economic damage (GALON et al., 2016). Recent studies have shown that traits, such as plant height, growth and development speed, leaf area index, biomass distribution, and productivity, demonstrate greater crop competitive ability (MEDEIROS et al., 2021).

In addition, the choice of cultivars with greater competitiveness against weeds is also an important management alternative due to the increasing herbicide resistance of many weeds. This is particularly important for the control of *C. bonariensis*, as resistance to various mechanisms of action have already been described for this plant, such as herbicides that inhibit the enzymes 5-enolpyruvylshikimate-3-phosphate synthase (EPSPS) and acetolactate synthase (ALS) and inhibitors of photosystems I and II (HEAP, 2024). Therefore, the control of this species with alternative methods, as well as in conjunction with the chemical method, is crucial to avoid high productivity losses in crops or even to reduce the seed bank in the soil and thus avoid strong competition when this species infests crops of agricultural interest.

Most studies conducted to assess the impact of competition between weeds and crops have aimed to evaluate only the effects of weed competition on crop productivity and/or growth, quantifying only the consequences of the presence of weeds without evaluating the causes related to the physiological variables of the plants involved in the community (BIANCHI et al., 2006; AGOSTINETTO et al., 2013; MANABE et al., 2015). However, a more comprehensive study of competitive interactions between crop plants and weeds can be carried out using experiments in substitution series that consider the morphological and physiological characteristics of the competing communities. The application of this methodology makes it possible to obtain competition indices between species and to relate the effects of the density and ratio between plants in a weed community (AGOSTINETTO et al., 2013; FRANDALOSO et al., 2019). Understanding the mechanisms involved in competition through experiments in a series of substitutions makes it possible to determine the interactions that occur in competition between plants (inter- or intraspecific), to identify the most aggressive species, and thus to develop more efficient management methods or to combine different weed control methods to avoid grain yield losses (BIANCHI et al., 2006; AGOSTINETTO et al., 2013).

This study hypothesized that *C. bonariensis* adapts better to the environment and shows greater competitive ability against common beans when present in equal proportions. Therefore, this work aimed to evaluate the competitive ability of common bean cultivars in the presence of *C. bonariensis* with different proportions of plants in the association.

MATERIAL AND METHODS

Nine experiments were conducted from January to February 2021 in the greenhouse of the Universidade Federal da Fronteira Sul (UFFS), Erechim campus, RS, Brazil. The experimental units consisted of plastic pots (8 dm³) filled with an Oxisol Red Ferric Aluminum Humic substrate (SANTOS et al., 2018), previously corrected and fertilized according to the recommendations for bean cultivation (SBCS, 2016). The chemical and physical properties of the soil were: pH in water 4.8, OM = 4.9%, P = 7.1 mg dm^{-3}, K = 408.0 mg dm^{-3}, Al^{3+} = 0.4 $cmol_c$ dm^{-3}, Ca^{2+} = 38.6 $cmol_c$ dm^{-3}, Mg^{2+} = 12.3 $cmol_c$ dm^{-3}, $CEC_{effective}$ = 8.9 $cmol_c$ dm^{-3}, CEC_{pH7} = 14.8 $cmol_c$ dm^{-3}, H+Al = 6.2 $cmol_c$ dm^{-3}, base saturation = 58%, and clay = 56%.

The experimental design was a completely randomized block design with four replicates. Competitors tested included two black bean cultivars (BRS Esteio and IPR Urutau) and two carioca bean cultivars (IAC 1850 and IPR Tangará) competing with the weed hairy fleabane (*Conyza bonariensis* (L.) Cronquist). All cultivars have a normal cycle and indeterminate growth. The seeds of *C. bonariensis* used for the experiments were harvested on 05/21/2020 in a field where soybeans were previously grown (27°43'47"S, 52°17'37"W and 670 m), in the municipality of Erechim/RS.

Initially, five experiments were conducted in monocultures for the four bean cultivars and for *C. bonariensis* to determine the plant density at constant dry matter. The densities of 1, 2, 4, 8, 16, 24, 32, 40, 48, 56 and 64 plants per pot were used (corresponding to 25, 49, 98, 196, 392, 587, 784, 980, 1176, 1372 and 1568 plants m^{-2}). 40 days after emergence of the species, the aerial parts of the plants were collected, placed in kraft paper bags and dried in a forced circulation oven at a temperature of 65±5ºC to a constant matter. Average values of dry matter (DM) were used to verify constant production at a density of 20 plants per pot for the bean and *C. bonariensis*, corresponding to 463 plants m^{-2} (data not shown).

Four experiments were then conducted in a series of substitution, one for each bean cultivar, to evaluate the competitive ability of the cultivars with *C. bonariensis* plants. To achieve the desired density in each treatment and to ensure seedling uniformity, seeds were sown beforehand in trays and later transplanted into the pots. The experiments in series of substitution consisted of five treatments formed by the relative proportions (%) of common bean and *C. bonariensis*: 100:0, 75:25, 50:50, 25:75 and 0:100, corresponding to 20:0, 15 :5, 10:10, 5:15 and 0:20 plants per pot (crop versus weed).

Plant height (PH, cm), stem diameter (SD, mm), leaf area (LA, cm² pot^{-1}) and shoot dry matter (DM, g pot^{-1}) were measured on the 40th day after emergence (DAE) of the species. PH and SD were measured with a graduated ruler and a caliper, respectively. The LA was determined using a leaf area meter (LI-3100, Licor, Nebraska, NE, USA), and then the aerial parts of the plants were placed in kraft paper bags and dried in a forced circulation oven (60±5ºC) to obtain the DM.

Physiological variables were evaluated on fully developed leaves at 40 DAE to determine photosynthetic rate (A, µmol m^{-2} s^{-1}), stomatal conductance (g_S, mol m^{-2} s^{-1}), transpiration (E, mol m^{-2} s^{-1}) and internal CO_2 concentration (Ci, µmol mol^{-1}). Water use efficiency (WUE) was calculated using the A/E ratio. The evaluation of gas exchange was performed using an infrared gas analyzer (IRGA; LCA PRO, Analytical Development Co. Ltd, Hoddesdon, UK).

The data obtained from the substitution experiments were analyzed using the method of graphical analysis of variation or relative productivity (RP) and total relative productivity (TRP) (COUSENS, 1991; BIANCHI et al., 2006; AGOSTINETTO et al., 2013). If the RP result is a straight line, this means that the abilities of the species are equivalent. If the RP results in a concave line, the growth of one or both species is impaired. If, on the other hand, the RP results in a convex line, the growth of one or both species is advantageous. If the TRP is equal to 1 (straight line), there is competition for the same resources; if the TRP is greater than 1 (convex line), competition is avoided; and if the TRP is less than 1 (concave line), there is mutual impairment of growth (COUSENS, 1991).

In addition, the indices of relative competitiveness (RC), relative cluster coefficient (K), and aggressiveness (AG) of beans and *C. bonariensis* were calculated. The RC represents the comparative growth of the bean cultivars (x) relative to the competitor *C. bonariensis* (y); K indicates the relative dominance of one species over another, and AG indicates which of the species is more aggressive. The indices RC, K and AG thus indicate which species is more competitive, and their joint interpretation gives more precise indications of the competitive ability of beans or *C. bonariensis* (COUSENS, 1991). For example, bean cultivars (x) are more competitive than the competitor *C. bonariensis* (y) when RC > 1, Kx > Ky and AG > 0; on the other hand, the competitor *C. bonariensis* (y) is more competitive than the common bean cultivars (x) when RC < 1, Kx < Ky and AG < 0 (HOFFMAN; BUHLER, 2002; BIANCHI et al., 2006). The indices were RC = RPx/RPy, Kx = RPx/(1-RPx), Ky = RPy/(1 -RPy), and AG = RPx-RPy (COUSENS; O'NEILL, 1993), using an equal ratio between the species involved (50:50), i.e. densities of 10:10 plants per pot (bean versus *C. bonariensis*).

The procedure of statistical analysis of productivity or relative variation involved the calculation of the differences in RP values (DRP) obtained in the proportions of 25, 50, and 75% considering the values of the hypothetical line in the respective proportions, i.e. 0.25, 0.50, and 0.75 for RP (BIANCHI et al., 2006; AGOSTINETTO et al., 2013). The *t*-test was used to determine the relative differences of the RC, K, and AG indices (HOFFMAN; BUHLER, 2002; BIANCHI et al., 2006). The null hypothesis for testing AG differences was that the means are zero (Ho = 0); for RC, that the means are one (Ho = 1); and for K, that the means of the differences between Kx and Ky are zero [Ho = (Kx – Ky) = 0].

The criterion for assuming that the observed TRP and RP curves differed from the expected ones was when the expected values (represented by dotted lines) were outside the 95% confidence interval of the observed curves - solid, colored lines with confidence intervals of the same color (CONCENÇO et al., 2018). The criterion for considering the RP and TRP curves different from the hypothetical lines was that at least two proportions of the tested densities of the competing species did not touch the colored lines, adapted from Bianchi et al. (2006).

The morphological and physiological results of the bean cultivars and *C. bonariensis* were subjected to an analysis of variance using the F-test for each of the experiments (BRS Esteio, IPR Urutau, IAC 1850 and IPR Tangará in competition with *C. bonariensis*). When the F-test was significant, the means of the treatments were compared using Dunnett test, considering the monocultures as controls. All statistical analyzes were based on a significance level of 5%.

RESULTS AND DISCUSSION

Morphological characteristics

The graphical results of the relative productivity (RP) of the common bean cultivars BRS Esteio, IPR Urutau, IAC 1850 and IPR Tangará show the occurrence of competition with *C. bonariensis* in the different proportions of the plants. The presence of concave lines of relative total productivity (TRP) (Figures 1, 2, 3 and 4) indicates that there was competition for the same resources available in the environment, which mutually affected the variables plant height (PH), stem diameter (SD), leaf area (LA) and shoot dry matter (DM) in the two species involved.

If the TRP line deviates from the expected line and the value is less than 1, this means that the species are competing for the same resources available in the environment. According to Rubin et al. (2014), if the TRP < 1, there is mutual antagonism between the species present in the community. Similar data were observed for competition between beans and *Bidens pilosa* (GALON et al., 2017), and maize and *Urochoa plantaginea* (FRANDALOSO et al., 2019).

The graphical results related to the variables PH, SD, LA and DM show that the bean cultivars had similar competitive ability and were less affected in the association than *C. bonariensis*. This was confirmed as the RP lines of the crop were closer to the expected lines and the weed lines were further away (Figures 1, 2, 3 and 4). The evaluated bean cultivars did not show RP losses for PH and SD, as their lines were very close to the estimated lines (Figures 1 and 2). On the other hand, the carioca cultivars IAC 1850 and IPR Tangará showed some RP loss for LA and DM compared to the black bean cultivars (BRS Esteio and IPR Urutau) (Figures 3 and 4). This suggests that different cultivars or commercial groups have intrinsic characteristics that differ from each other and may contribute to greater competitive ability against *C. bonariensis*. The phenotypic expression of the cultivar includes genetic/intrinsic factors in combination with environmental factors and genotype-environment interactions (WESTWOOD et al., 2018; PHILIPO et al. 2021).

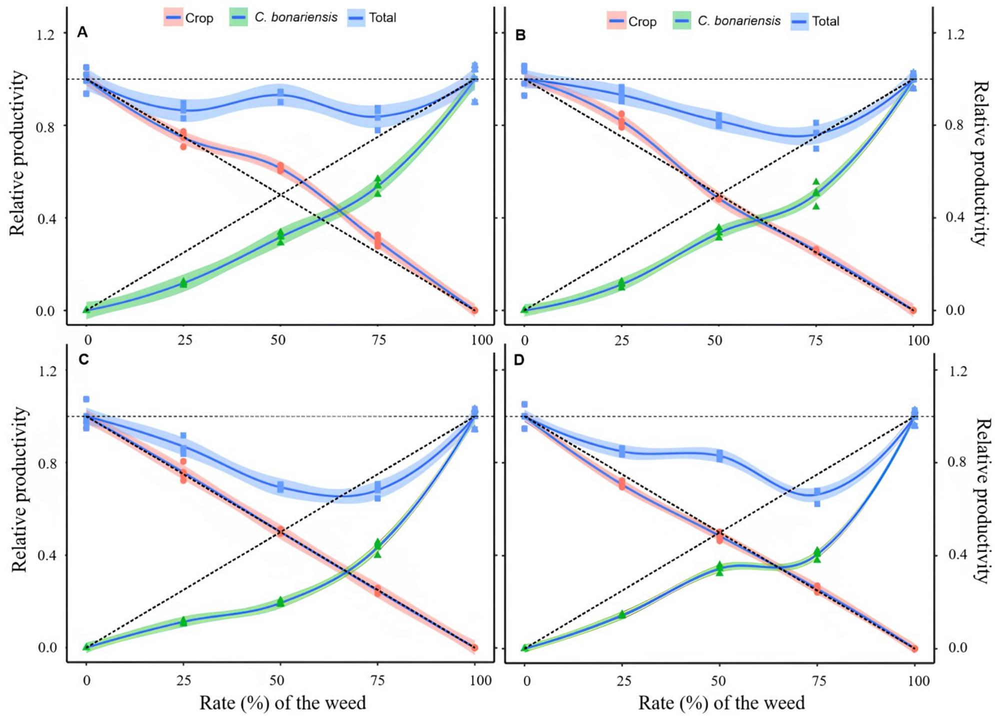

Figure 1. Relative productivity (RP) for plant height of the cultivars BRS Esteio (A), IPR Urutau (B), IAC 1850 (C), and IPR Tangará (D). Bean cultivar (●), *Conyza bonariensis* (▲), and total relative productivity (TRP) of the community (■), as a function of the proportion of associated plants (beans: *C. bonariensis*). Dashed lines represent the expected values in the absence of competition, solid lines represent the values observed when the species competed in different plant proportions, and colored bands represent the standard deviation of the observations.

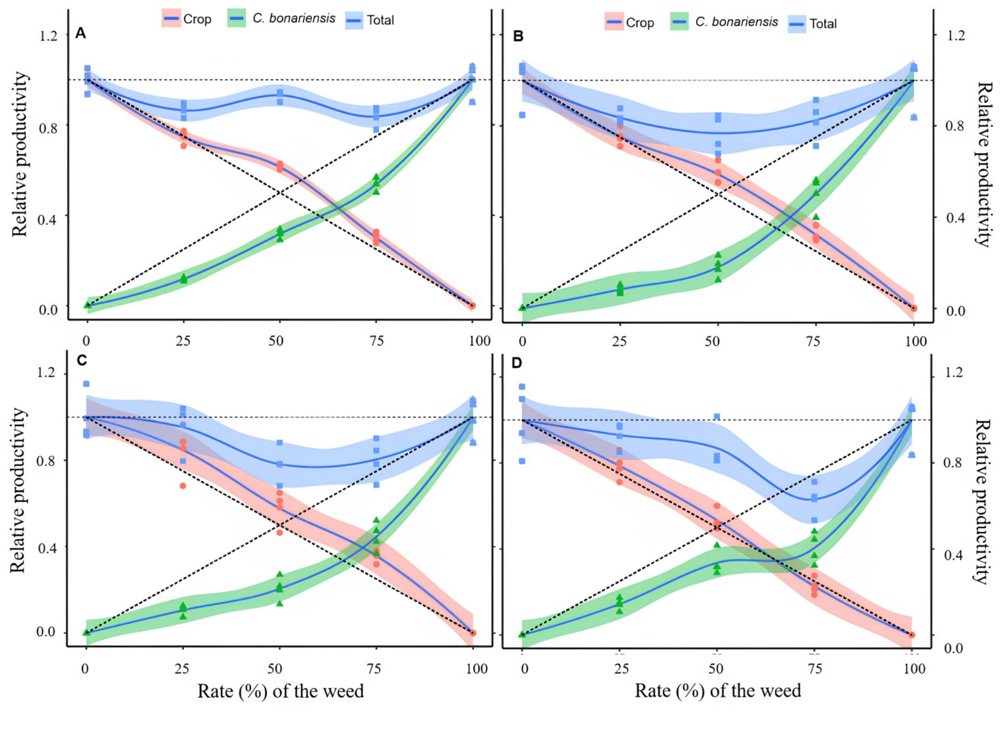

Figure 2. Relative productivity (RP) for stem diameter of the the cultivars BRS Esteio (A), IPR Urutau (B), IAC 1850 (C), and IPR Tangará (D). Bean cultivar (●), *Conyza bonariensis* (▲), and total relative productivity (TRP) of the community (■), as a function of the proportion of associated plants (beans: *C. bonariensis*). Dashed lines represent the expected values in the absence of competition, solid lines represent the values observed when the species competed in different plant proportions, and colored bands represent the standard deviation of the observations.

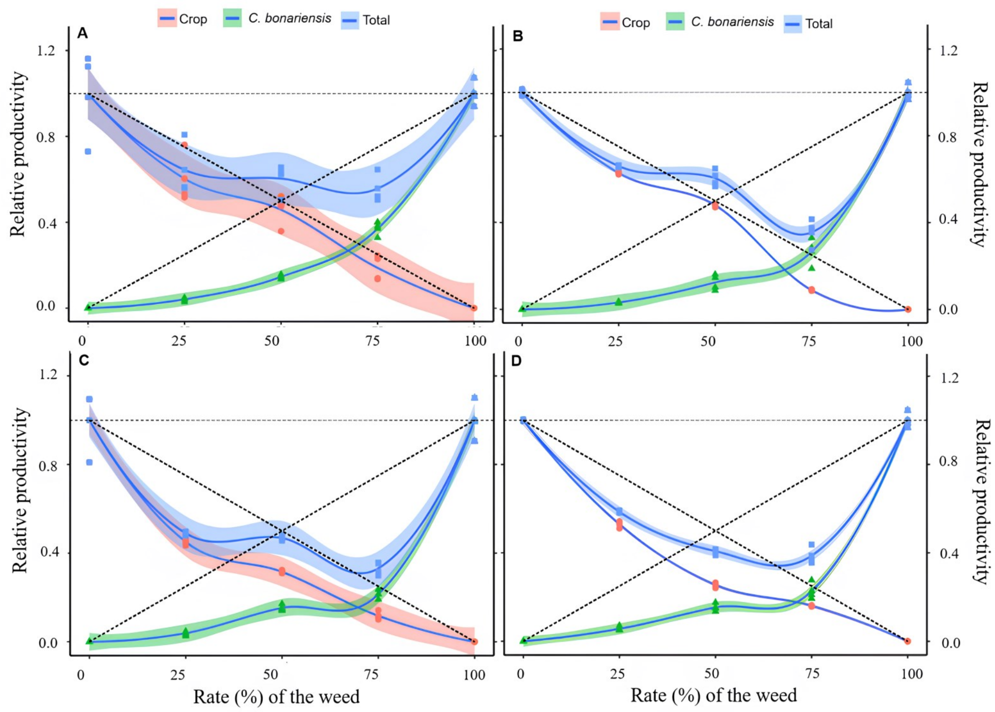

Figure 3. Relative productivity (RP) for the leaf area of the cultivars BRS Esteio (A), IPR Urutau (B), IAC 1850 (C), and IPR Tangará (D). Bean cultivar (●), *Conyza bonariensis* (▲), and total relative productivity (TRP) of the community (■), as a function of the proportion of associated plants (beans: *C. bonariensis*). Dashed lines represent the expected values in the absence of competition, solid lines represent the values observed when the species competed in different plant proportions, and colored bands represent the standard deviation of the observations.

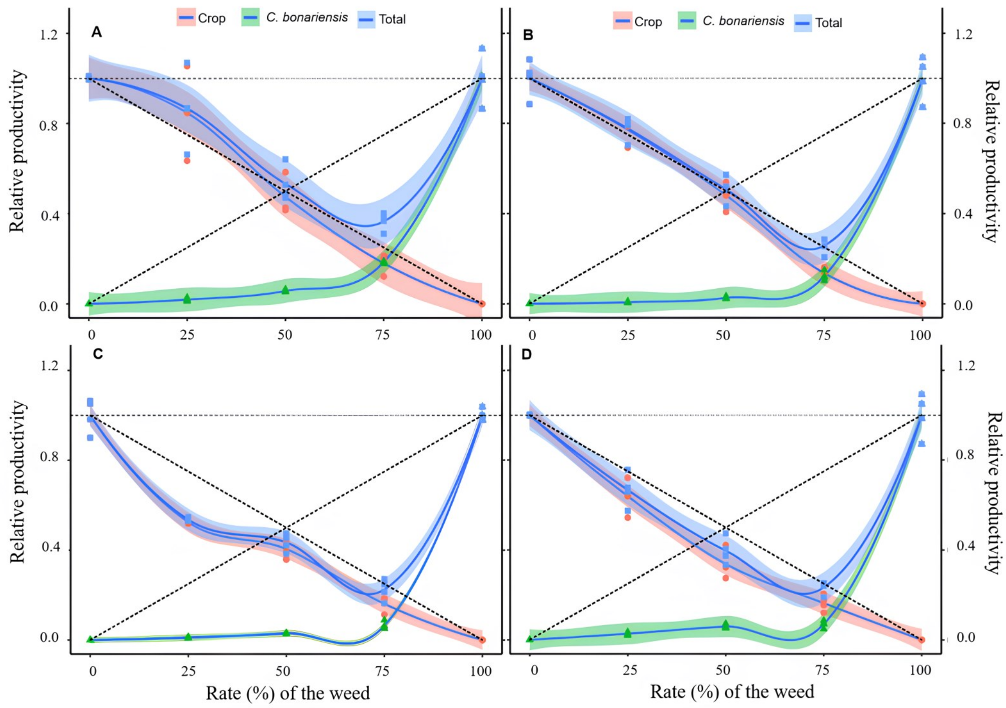

Figure 4. Relative productivity (RP) for shoot dry matter of the cultivars BRS Esteio (A), IPR Urutau (B), IAC 1850 (C), and IPR Tangará (D). Bean cultivar (●), *Conyza bonariensis* (▲), and total relative productivity (TRP) of the community (■), as a function of the proportion of associated plants (beans: *C. bonariensis*). Dashed lines represent the expected values in the absence of competition, solid lines represent the values observed when the species competed in different plant proportions, and colored bands represent the standard deviation of the observations.

Like the results presented in this paper, different bean cultivars show that this crop has a high competitive ability even in the presence of weeds such as *Bidens pilosa* (GALON et al., 2017) and alexandergrass species (GALON et al., 2022a), with the crop being less affected than the weeds. Of the four morphological variables evaluated (PH, SD, LA and DM), the RP of PH was the least affected in both species, with lines practically equal to those simulated for the crop, and concave for the weed, regardless of the bean cultivar used in the association (Figure 1), resulting in TRPs below 1, but close to the simulated lines of the RP. It should be noted that only results with differences in at least two plant proportions were considered significant (BIANCHI et al., 2006). When different plants are associated, competition for light may occur due to shading by neighboring plants, regardless of whether they are the same species or not. In response, plants tend to increase the production of auxin, the strong regulator of cell division and cell expansion, thus promoting stem elongation. This lead to etiolation to avoid shading and ensure better light uptake (WEI et al., 2023).

The analysis of the TRP lines shows that *C. bonariensis* generally increases damage to the common bean when it occurs in high densities in the association (Figures 1, 2, 3 and 4). In cropping situations, weeds generally occur at higher densities than crops, which ensures greater competitive ability for these plants (AGOSTINETTO et al., 2013). In addition, in experiments in series of substitution, the spatial distribution of the crop can contribute to increase its competitive ability, while a linear distribution in the field can impair this ability and increase the damage caused by the competing community (DUSABUMUREMYI et al., 2014).

From the morphological responses of bean cultivars with *C. bonariensis*, interspecific competition was more detrimental to both the crop and the weed. This is due to the fact that the mean values for the variables PH, SD, LA and DM were negatively affected with increasing plant density in the association (Table 1). The lowest values for these variables, especially LA and DM, indicate interspecific competition caused by competition for the same resources in the environment. Besides common bean, other crops also showed stronger interspecific competition, such as soybean and rice in the presence of *Digitaria ciliaris* (AGOSTINETTO et al., 2013), and maize infested by *Ipomoea indivisa* and *Digitaria ciliaris* (GALON et al., 2020).

In more recent work by our research group, we found that the growth, development and productivity of the bean varieties studied (IPR Uirapuru, BRS Campeiro and Predileto SCS) were lower when the plant density, leaf area and dry matter of the weed (*Urochloa plantaginea*) were higher (GALON et al. 2022c; HENZ NETO et al. 2023). This fact confirms what was observed in the present study, i.e. the greater the proportion of *C. bonariensis* in the plants or the greater the leaf area and shoot dry matter, the more negatively the bean was affected.

The morphological characteristics of the common bean, such as the rapid establishment rate and the rather soil-susceptible growth, are important parameters that can prevent losses in plant height and stem diameter in the four cultivars studied, even at lower plant densities. On the other hand, an increase in plant density in the bean cultivars lead to a reduction in the PH and SD of *C. bonariensis* (Table 1).

Regarding LA, it was found that there was no significant difference in the BRS Esteio cultivar, regardless of the density of *C. bonariensis* (Table 1). The maintenance of leaf area may be an intrinsic property of the cultivar when it reallocates photoassimilates to maintain gas exchange and growth in competitive situations with weeds. Other crops, such as soybean, cultivar BMX Potência RR®, also showed no change in LA in the presence of *Euphorbia heterophylla* (ULGUIM et al., 2016). On the other hand, the cultivars IPR Urutau, IAC 1850 and IPR Tangará showed lower LA values with increasing weed proportions in the associations (Table 1). The differences in competition between bean cultivars with respect to *C. bonariensis* could be related to plant establishment, as the species that establishes first has a competitive advantage. Competition between species affects the quantity and quality of production, as it alters the efficiency of use of environmental resources such as water, light and nutrients and establishes between the crop and plants of other species occurring in the same area (PITELLI, 2015; ZHOU et al., 2023). For all bean cultivars, whether black or carioca, DM production decreased with the increase of *C. bonariensis* plants in the association (Table 1). This again shows that interspecific competition was more harmful to the crop and the weed than intraspecific competition.

When analyzing the competitiveness indices, calculated at a similar proportion between the crop and the weed (50:50), it was observed that the growth of the bean cultivars (BRS Estilo, IPR Urutau IPR, IAC 1850 and IPR Tangará) was greater than the growth of *C. bonariensis* (RC > 1) in all the morphological variables evaluated (PH, SD, LA and DM) (Table 2). There was also a relative dominance of common bean over the weed as expressed by the K-index ($K_{bean} > K_{C.\ bonariensis}$), indicating that the crop was more competitive than the weed according to the aggressiveness index (positive AG). In all comparisons, there were significant differences between bean cultivars and *C. bonariensis* on at least two indices. This indicates that there is no equivalent competition for environmental resources, and that the bean cultivars proved to be more competitive than *C. bonariensis* under these conditions.

In similar work, differences between cultivars were found in relation to the competition indices. Previous studies showed that the black bean cultivar was more competitive than *Bidens pilosa* (GALON et al., 2017), and the carioca cultivar compared to *U. plantaginea* (GALON et al., 2022a). On the other hand, *Raphanus sativus* was more competitive against soybean genotypes (BIANCHI et al., 2006). Greater competitiveness of the cultivars against weeds is to be expected under similar conditions, as the greater competitive ability of weeds usually occurs at higher densities (BIANCHI et al., 2006). It is also noteworthy that in a plant community the plants that establish first have a competitive advantage, which is usually associated with traits such as height, growth rate, number of tillers, and dry matter (AGOSTINETTO et al., 2013).

Table 1. Plant height (PH), stem diameter (SD), leaf area (LA) and shoot dry matter (DM) of common bean (*Phaseolus vulgaris*) cultivars and hairy fleabane (*Conyza bonariensis*) grown in experiments in series of substitution.

Plants proportion (bean: fleabane)	PH (cm plant^{-1})		SD (mm plant^{-1})		LA (cm^{-2} pot^{-1})		DM (g pot^{-1})	
	BRS Esteio	Fleabane	BRS Esteio	fleabane	BRS Esteio	fleabane	BRS Esteio	fleabane
100:0/0:100 (C)	118.92	139.38	14.66	21.63	28968.40	12025.08	45.10	31.25
75:25/25:75	118.38	99.80*	19.16*	15.57*	23295.97	5926.08*	50.97	7.72*
50:50/50:50	145.98*	88.42*	21.12*	11.56*	26536.58	3497.81*	42.88	3.58*
25:75/75:25	142.95*	65.78*	20.47*	11.04*	21705.30	1971.29*	32.52*	2.35*
C.V (%)	5.40	7.30	13.80	15.70	23.60	9.10	18.90	17.70
	IPR Urutau	fleabane	IPR Urutau	fleabane	IPR Urutau	fleabane	IPR Urutau	fleabane
100:0/0:100 (C)	166.85	144.55	17.44	20.24	37890.20	12299.67	82.92	31.99
75:25/25:75	182.12*	97.03*	17.50	13.57*	31742.95*	4376.06*	85.23	5.23*
50:50/50:50	161.40	96.78*	20.50*	7.30*	36372.70*	3053.72*	79.79	1.67*
25:75/75:25	171.70	64.97*	22.48*	6.72*	13383.18*	1573.46*	44.82*	0.87*
C.V (%)	3.70	7.20	9.40	17.50	1.70	14.40	11.50	18.20
	IAC 1850	fleabane	IAC 1850	fleabane	IAC 1850	fleabane	IAC 1850	fleabane
100:0/0:100 (C)	159.40	146.78	17.30	18.83	49428.29	12574.26	75.86	36.93
75:25/25:75	161.02	84.92*	19.56	11.21*	29727.47*	3592.30*	53.10*	3.13*
50:50/50:50	159.50	56.70*	19.97	7.72*	31176.03*	3839.89*	61.42*	2.20*
25:75/75:25	157.50	65.80*	24.75*	7.94*	23138.90*	1940.91*	48.83*	1.59*
C.V (%)	4.70	5.60	13.00	17.6	12.70	12.10	12.10	7.30
	IPR Tangará	fleabane	IPR Tangará	fleabane	IPR Tangará	fleabane	IPR Tangará	fleabane
100:0/0:100 (C)	179.43	144.55	22.37	20.24	35452.24	12299.67	73.46	31.99
75:25/25:75	168.93	78.17*	23.45	10.91*	25028.64*	3719.11*	62.65	2.97*
50:50/50:50	174.07	99.58*	23.88	13.56*	18048.32*	3763.19*	49.63*	3.77*
25:75/75:25	184.62	82.58*	20.26	11.60*	22744.79*	2761.24*	48.03*	3.49*
C.V (%)	4.10	4.20	13.90	17.20	2.20	9.40	14.80	17.70

*Mean differs from the control (C) by Dunnett's test ($p \leq 0.05$).

Table 2. Coefficients of relative competitiveness (RC), relative clustering (K) and aggressiveness (AG) of common bean (*Phaseolus vulgaris*) cultivars and hairy fleabane (*Conyza bonariensis*), in the same proportion (50:50), in relation to morphological traits, in experiments in series of substitution.

Variáveis	RC[2]	Kx[3] (feijão)	Ky (buva)	AG[4]
		Plant height (PH, cm plant^{-1})		
BRS Esteio x *C. bonariensis*	1.94 ± 0.06*	1.59 ± 0.04*	0.47 ± 0.02	0.30 ± 0.01*
IPR Urutau x *C. bonariensis*	1.45 ± 0.04*	0.94 ± 0.00*	0.50 ± 0.02	0.15 ± 0.01*
IAC 1850 x *C. bonariensis*	2.59 ± 0.07*	1.00 ± 0.02*	0.24 ± 0.01	0.31 ± 0.01*
IPR Tangará x *C. bonariensis*	1.41 ± 0.05*	0.94 ± 0.03*	0.53 ± 0.02	0.14 ± 0.02*
		Stem diameter (SD, mm plant^{-1})		
BRS Esteio x *C. bonariensis*	2.72 ± 0.21*	2.67 ± 0.30*	0.37 ± 0.02	0.45 ± 0.04*
IPR Urutau x *C. bonariensis*	3.40 ± 0.39*	1.45 ± 0.15*	0.22 ± 0.03	0.41 ± 0.02*
IAC 1850 x *C. bonariensis*	3.05 ± 0.63*	1.42 ± 0.21*	0.26 ± 0.05	0.37 ± 0.06*
IPR Tangará x *C. bonariensis*	1.61 ± 0.08*	1.16 ± 0.12*	0.51 ± 0.07*	0.20 ± 0.01*
		Leaf area (LA, cm^{-2} pot^{-1})		
BRS Esteio x *C. bonariensis*	3.17 ± 0.29*	0.87 ± 0.11*	0.17 ± 0.01*	0.31 ± 0.04*
IPR Urutau x *C. bonariensis*	4.12 ± 0.60*	0.92 ± 0.01*	0.14 ± 0.02	0.36 ± 0.02*
IAC 1850 x *C. bonariensis*	2.08 ± 0.09*	0.46 ± 0.01*	0.18 ± 0.01	0.16 ± 0.01*
IPR Tangará x *C. bonariensis*	1.68 ± 0.11*	0.34 ± 0.01*	0.18 ± 0.01	0.10 ± 0.01*
		Shoot dry matter (DM, g pot^{-1})		
BRS Esteio x *C. bonariensis*	8.36 ± 0.78*	0.94 ± 0.16*	0.06 ± 0.00	0.42 ± 0.04*
IPR Urutau x *C. bonariensis*	18.82 ± 1.53*	0.94 ± 0.1*	0.03 ± 0.00	0.46 ± 0.03*
IAC 1850 x *C. bonariensis*	13.60 ± 0.24*	0.69 ± 0.05*	0.03 ± 0.00	0.38 ± 0.02*
IPR Tangará x *C. bonariensis*	5.87 ± 0.80*	0.52 ± 0.07*	0.06 ± 0.01	0.28 ± 0.03*

*Significant difference by the *t* test ($p \leq 0.05$). Kx and Ky are the relative clustering coefficients of common bean cultivars and *C. bonariensis* competitors, respectively.

In the overall view of the data (Figures 1, 2, 3, and 4, Tables 1 and 2), a negative interaction effect between the species was found, which affected both the bean cultivars and the *C. bonariensis* plants. However, with the same proportion of plants, it can be said that the bean cultivars have a greater morphological adaptability to competition compared to *C. bonariensis*. The differences in competitive ability could therefore be due to different morphological characteristics or to the fact that *C. bonariensis* has low phenotypic plasticity and its biomass production is directly related to plant density.

Physiological characteristics

The graphical analysis of the different densities between bean and *C. bonariensis* cultivars showed that the photosynthetic rate (*A*) (Figure 5) and water use efficiency (WUE) (Figure 8) were represented in graphs with RP with convex lines, i.e. the deviations from the observed values were greater than the estimated values, which in this case favored the growth of the crop at the expense of the growth of *C. bonariensis*. For the TRPs, line values greater than 1 were observed for the photosynthetic rate of the cultivar IPR Tangará (Figure 5 D), indicating that competition was avoided, while the cultivars IAC 1850 and IPR Tangará competed with the *C. bonariensis* densities for WUE (Figure 8C and D).

Regarding stomatal conductance (g_S) (Figure 6) and transpiration € (data not shown), the similarity of the response in all crops evaluated at different densities with *C. bonariensis* could be verified with the presence of straight RP lines. According to Oliveira et al. (2005), one of the factors contributing to the variation in stomatal conductance and transpiration behavior of the plant is the change in the angle of incidence of the leaves to sunlight, which acts as a plant defense mechanism by allowing the maintenance of transpiration and temperature reduction at high temperatures.

On the other hand, in *C. bonariensis*, RP with convex lines were observed for the variable Ci when it competed with the cultivars BRS Esteio, IPR Urutau and IAC 1850 (Figure 7A, B and C). For TRPs, lines with values greater than 1 for Ci were observed when the bean cultivars BRS Esteio, IPR Urutau and IAC 1850 competed with *C. bonariensis*, especially at higher weed densities (Figure 5A, B and C). The increase in internal CO_2 concentration associated with a decrease in *A* in *C. bonariensis* plants (Table 3) suggests a biochemical limitation of photosynthesis, as the CO_2 available in the substomatal chamber was not carboxylated. The biochemical limitation could be due to the degradation of the main subunit of ribulose-1,5-bisphosphate carboxylase oxygenase (RuBisCO) by the production of reactive oxygen species, or to adverse effects on the Calvin cycle, e.g. in the regeneration of ribulose-1,5-bisphosphate (MÜLLER et al., 2017; SCAFARO et al., 2023).

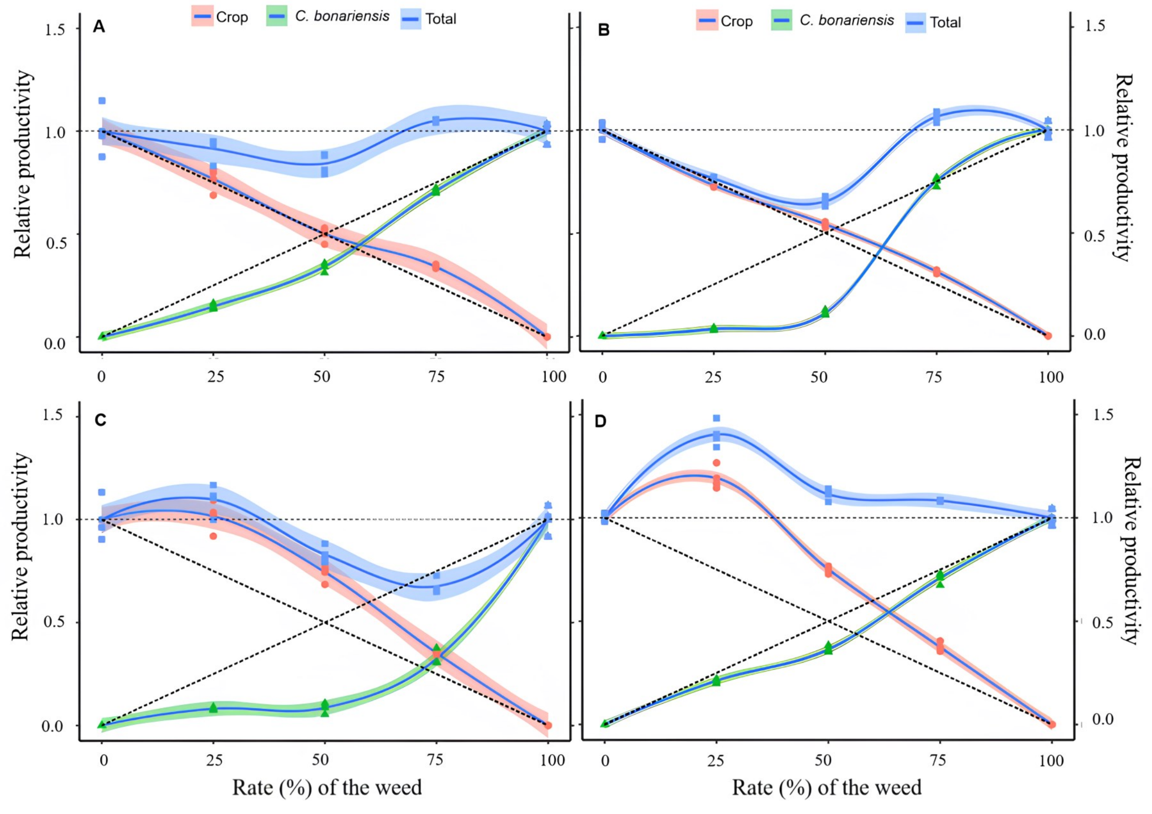

Figure 5. Relative productivity (RP) for photosynthetic rate of the cultivars BRS Esteio (A), IPR Urutau (B), IAC 1850 (C), and IPR Tangará (D). Bean cultivar (●), *Conyza bonariensis* (▲), and total relative productivity (TRP) of the community (■), as a function of the proportion of associated plants (beans: *C. bonariensis*). Dashed lines represent the expected values in the absence of competition, solid lines represent the values observed when the species competed in different plant proportions, and colored bands represent the standard deviation of the observations.

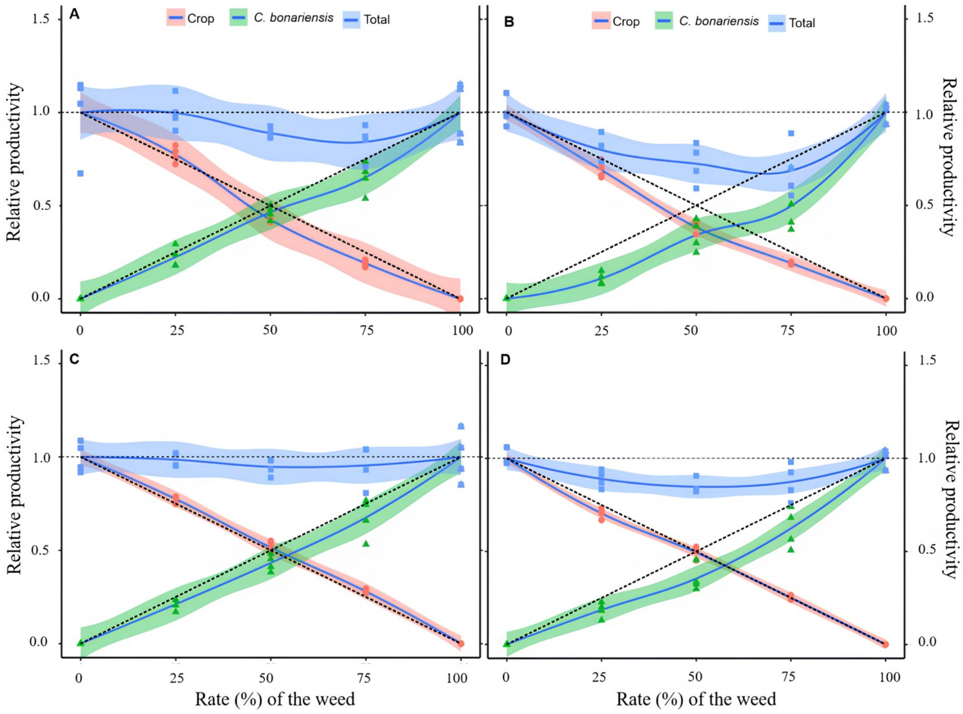

Figure 6. Relative productivity (RP) for stomatal conductance of the cultivars BRS Esteio (A), IPR Urutau (B), IAC 1850 (C), and IPR Tangará (D). Bean cultivar (●), *Conyza bonariensis* (▲), and total relative productivity (TRP) of the community (■), as a function of the proportion of associated plants (beans: *C. bonariensis*). Dashed lines represent the expected values in the absence of competition, solid lines represent the values observed when the species competed in different plant proportions, and colored bands represent the standard deviation of the observations.

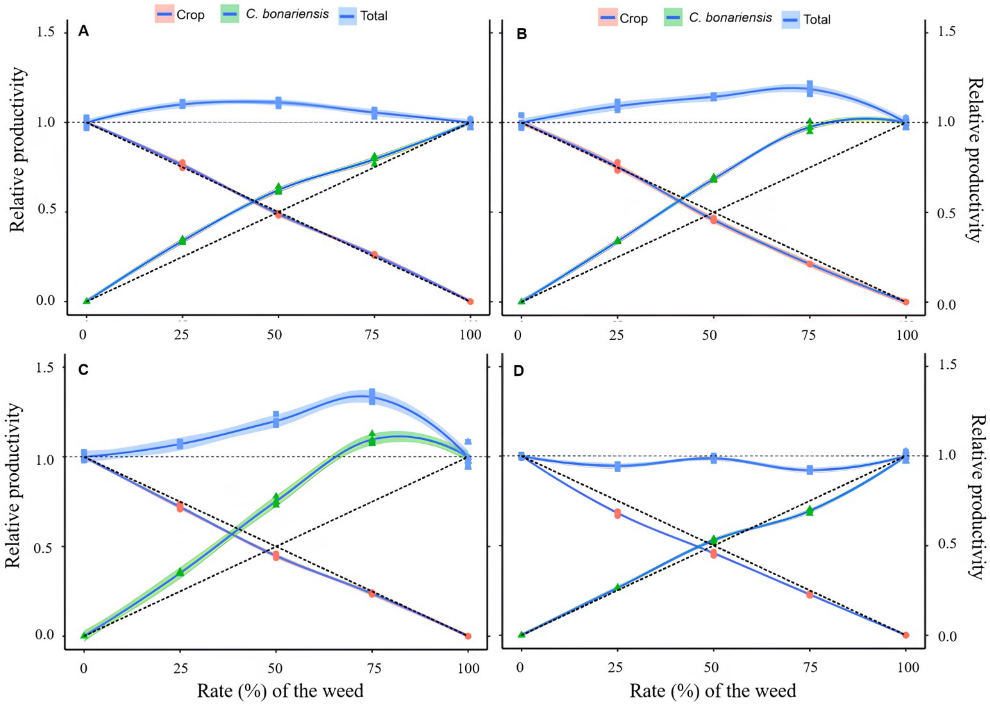

Figure 7. Relative productivity (RP) for the internal CO_2 concentration of the cultivars BRS Esteio (A), IPR Urutau (B), IAC 1850 (C), and IPR Tangará (D). Bean cultivar (●), *Conyza bonariensis* (▲), and total relative productivity (TRP) of the community (■), as a function of the proportion of associated plants (beans: *C. bonariensis*). Dashed lines represent the expected values in the absence of competition, solid lines represent the values observed when the species competed in different plant proportions, and colored bands represent the standard deviation of the observations.

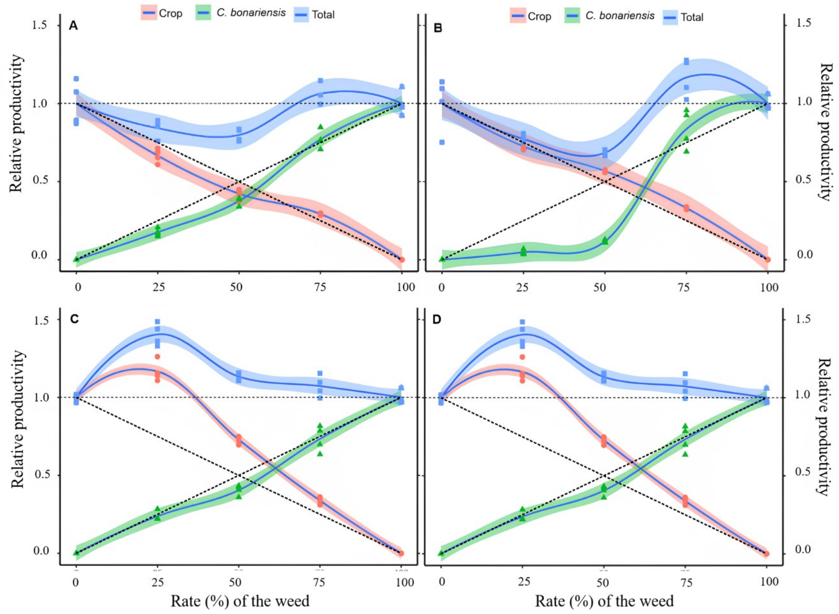

Figure 8. Relative productivity (RP) for water use efficiency of the cultivars BRS Esteio (A), IPR Urutau (B), IAC 1850 (C), and IPR Tangará (D). Bean cultivar (●), *Conyza bonariensis* (▲), and total relative productivity (TRP) of the community (■), as a function of the proportion of associated plants (beans: *C. bonariensis*). Dashed lines represent the expected values in the absence of competition, solid lines represent the values observed when the species competed in different plant proportions, and colored bands represent the standard deviation of the observations.

Table 3. Photosynthetic rate (*A*), stomatal conductance (g_S), transpiration rate (*E*), internal CO_2 concentration (Ci), and water use efficiency (WUE) of the common bean (*Phaseolus vulgaris*) cultivars (BRS Esteio, IPR Urutau, IAC 1850 and IPR Tangará) and hairy fleabane (*Conyza bonariensis*) grown in series of substitution experiments.

Plants proportion bean: fleabane or fleabane: bean	*A* (µmol m^{-2} s^{-1})		g_S (mol m^{-2} s^{-1})		*E* (mol m^{-2} s^{-1})		Ci (µmol m^{-2} s^{-1})		WUE (mol mol^{-1})	
	Esteio	fleabane	Esteio	fleabane	Esteio	fleabane	Esteio	fleabane	Esteio	fleabane
100:0	11.59	16.29	1.20	0.42	2.83	3.89	387.00	260.33	4.13	4.20
75:25	11.86	15.41	1.24	0.36	3.23*	3.58	393.32	276.00*	3.67	4.31
50:50	11.61	11.12*	1.02	0.39	3.33*	3.52	378.25	324.25*	3.49*	3.16*
25:75	15.79*	9.58*	0.92*	0.37	3.27*	3.27*	403.25*	352.67*	4.83*	2.96*
C.V (%)	8.00	5.60	14.70	18.30	5.50	8.20	20.00	2.80	9.60	9.90
	Urutau	fleabane	Urutau	fleabane	Urutau	fleabane	Urutau	fleabane	Urutau	fleabane
100:0	16.99	18.15	0.72	0.38	3.81	3.85	322.50	251.04	4.22	4.71
75:25	16.56	18.22	0.67	0.26*	4.00*	3.52	324.00	326.44*	4.08	5.26
50:50	18.43*	4.01*	0.55*	0.26*	3.86	3.64	295.50*	344.33*	4.78	1.10*
25:75	21.20*	2.42*	0.55*	0.16*	3.80	2.66*	273.00*	339.78*	5.57*	0.89*
C.V (%)	2.80	5.20	7.20	23.60	3.10	14.90	2.60	2.00	9.00	16.10
	IAC	fleabane	IAC	fleabane	IAC	fleabane	IAC	fleabane	IAC	fleabane
100:0	8.06	19.75	0.77	0.35	3.12	3.83	405.67	241.75	2.90	4.71
75:25	10.92*	8.54*	0.80	0.32	3.17	3.62	389.50*	353.44*	4.50*	4.61
50:50	12.00*	3.38*	0.79	0.30	3.20	3.54	363.33*	363.70*	4.22*	3.81*
25:75	11.34*	6.40*	0.86*	0.30	3.34*	3.47	384.33*	340.00*	3.92*	4.48
C.V (%)	7.00	10.90	6.10	15.30	2.30	7.90	2.30	10.90	5.50	10.90
	IPR	fleabane	IPR	fleabane	IPR	fleabane	IPR	fleabane	IPR	fleabane
100:0	9.83	18.15	0.83	0.38	3.40	3.85	375.56	251.04	2.90	4.71
75:25	15.64*	17.17	0.78	0.32	3.48	3.75	341.33*	232.37*	4.50*	4.61
50:50	14.77*	13.19*	0.82	0.27*	3.50	3.48	343.50*	266.07*	4.22*	3.81*
25:75	14.71*	15.38*	0.83	0.29*	3.76*	3.46	340.75*	264.67*	3.92*	4.48
C.V (%)	4.80	4.40	5.20	17.90	2.40	9.40	2.00	1.90	5.50	10.90

*Mean differs from the control (C) by Dunnett's test ($p \leq 0.05$).

When analyzing the physiological traits of the bean cultivars, an increase in *A*, g_S, *E*, and WUE was generally observed in the cultivars BRS Esteio, IPR Urutau, IAC 1850 and IPR Tangará in coexistence with *C. bonariensis* in all plant proportions compared to the crop monoculture (Table 3). On the other hand, there was a decrease in physiological variables for the weed. Competition can limit the availability of resources between species, e.g. the water availability, leading to a reduction in stomatal conductance and a limitation of photosynthesis in the species with the lowest competitive ability (GALON et al., 2022b).

All variables related to gas exchange were included in the analysis of the competitiveness indices as they are stable in relative productivity (RP and TRP). The competition indices related to the physiological variables showed that all bean cultivars BRS Esteio, IPR Urutau, IAC 1850 and IPR Tangará had a RC > 1.0, $K_{bean} > K_{C. bonariensis}$ and positive AG for variables *A* and WUE (Table 4). For Ci, the bean cultivars had RC < 1.0, $K_{bean} < K_{C. bonariensis}$ and negative AG. The cultivar BRS Esteio showed superiority in competition for the three indices when competing with *C. bonariensis* for *E*, while the other cultivars showed no significant effect when competing with the weed for this variable. For g_S, there was no significant effect considering the competitiveness indices for the crop and the competitor.

Table 4. Coefficients of relative competitiveness (RC), relative clustering (K) and aggressiveness (AG) of common bean (*Phaseolus vulgaris*) cultivars and hairy fleabane (*Conyza bonariensis*), in the same proportion (50:50), in relation to physiological characteristics, in a series of substitution experiments.

	RC[2]	Kx[3] (feijão)	Ky (buva)	AG[4]
		Photosynthetic rate (*A*, µmol m^{-2} s^{-1})		
BRS Esteio x *C. bonariensis*	1.47 ± 0.06*	1.01 ± 0.07*	0.52 ± 0.02	0.16 ± 0.02*
IPR Urutau x *C. bonariensis*	4.95 ± 0.25*	1.19 ± 0.03*	0.12 ± 0.01	0.43 ± 0.01*
IAC 1850 x *C. bonariensis*	9.38 ± 1.69*	3.00 ± 0.32*	0.09 ± 0.01*	0.66 ± 0.03*
IPR Tangará x *C. bonariensis*	2.07 ± 0.04*	3.03 ± 0.13*	0.57 ± 0.02	0.39 ± 0.01*
		Stomatal conductance ($g_{S,}$ mol m^{-2} s^{-1})		
BRS Esteio x *C. bonariensis*	0.92 ± 0.05	0.74 ± 0.02	0.87 ± 0.06	-0.04 ± 0.02
IPR Urutau x *C. bonariensis*	1.16 ± 0.11	0.62 ± 0.03	0.54 ± 0.10	0.04 ± 0.03
IAC 1850 x *C. bonariensis*	1.20 ± 0.09	1.07± 0.07*	0.77 ± 0.07	0.08 ± 0.031
IPR Tangará x *C. bonariensis*	1.44 ± 0.16	0.98 ± 0.06*	0.56 ± 0.09	0.14 ± 0.05
		Transpiration rate (*E*, mol m^{-2} s^{-1})		
BRS Esteio x *C. bonariensis*	1.30 ± 0.03*	1.43 ± 0.02*	0.83 ± 0.02	1.14± 0.01*
IPR Urutau x *C. bonariensis*	1.08 ± 0.06	1.02 ± 0.03	0.92 ± 0.11	0.03 ± 0.03
IAC 1850 x *C. bonariensis*	1.11 ± 0.04	1.05 ± 0.04*	0.87 ± 0.04	0.05 ± 0.02
IPR Tangará x *C. bonariensis*	1.15 ± 0.06	1.06 ± 0.02*	0.83 ± 0.07	0.06 ± 0.02
		Internal CO_2 concentration (Ci, µmol m^{-2} s^{-1})		
BRS Esteio x *C. bonariensis*	0.79 ± 0.01*	0.96 ± 0.01*	1.65 ± 0.05	-0.13 ± 0.01*
IPR Urutau x *C. bonariensis*	0.67 ± 0.01*	0.85 ± 0.01*	2.18 ± 0.04	-0.23 ± 0.01*
IAC 1850 x *C. bonariensis*	0.60± 0.01*	0.81 ± 0.02*	3.06± 0.18	-0.30 ± 0.01*
IPR Tangará x *C. bonariensis*	0.86 ± 0.01*	0.84 ± 0.02*	1.13± 0.02	-0.07 ± 0.01*
		Water use efficiency (WUE, mol mol^{-1})		
BRS Esteio x *C. bonariensis*	1.13 ± 0.06	0.74 ± 0.05	0.61 ± 0.03	0.05 ± 0.02
IPR Urutau x *C. bonariensis*	4.87 ± 0.16*	1.31 ± 0.02*	0.13 ± 0.01	0.45 ± 0.00*
IAC 1850 x *C. bonariensis*	1.81 ± 0.10*	2.71 ± 0.16*	0.68 ± 0.04	0.32 ± 0.03*
IPR Tangará x *C. bonariensis*	1.81 ± 0.10*	2.71 ± 0.16*	0.68 ± 0.04	0.32 ± 0.02*

*Significant difference by the *t* test ($p \leq 0.05$). Kx and Ky are the relative clustering coefficients of common bean cultivars and competitor *C. bonariensis*, respectively.

Recently, when analyzing the three competitiveness indices (RC, K and AG) in relation to the physiological variables, our research group also found a greater competitive ability of sweet sorghum in the presence of *Bidens pilosa* (GALON et al., 2022b). In general, the most competitive species have a greater ability to assimilate the resources available in the environment, increasing the potential for development and growth and consequently causing damage to the competitor, as lower amounts of resources are available (AGOSTINETTO et al., 2013).

The analysis of the graphical data (Figures 5, 6, 7 and 8), the physiological variables (Table 3) and the physiological competitiveness indices (Table 4) shows that the bean cultivars BRS Esteio, IPR Urutau, IAC 1850 and IPR Tangará have better physiological performance compared to *C. bonariensis*, especially considering *A* and WUE.

In this way, it is important to understand the competitiveness of *C. bonariensis* against common bean cultivars so that appropriate weed control methods can be applied, often reducing or even avoiding the use of herbicides and ensuring healthier and more sustainable agriculture.

CONCLUSION

The bean cultivars BRS Esteio, IPR Urutau, IAC 1850 and IPR Tangará competed when infested with *C. bonariensis* regardless of the proportion of plants in the association, which affected plant growth and development. Interspecific competition caused greater damage to plant height, leaf area and shoot dry matter than intraspecific competition. Bean cultivars and *C. bonariensis* competed for the same environmental resources. Considering photosynthetic rate and water use efficiency, bean cultivars were equally more competitive than *C. bonariensis*. In a similar proportion, the bean cultivars were more competitive than *C. bonariensis*.

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