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Morphological responses of maize hybrids under competition with hairy beggarticks

Respostas morfológicas de híbridos de milho em competição com picão-preto

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ABSTRACT - The study of competitive interactions between crops and weeds can be an important tool in integrated weed management. The objective of this work was to evaluate the competitive ability of maize hybrids in the presence of hairy beggarticks, testing different proportions of plants in the associations. For maize hybrids (Dekalb 230 PRO3, Pioneer 30F53 VYH, Brevant 2B433 PW, and Syngenta 505 VIP3) and for hairy beggarticks, the final density was 20 individuals pot^{-1}, which was determined in preliminary experiments. Experiments were carried out on a substitutive series, on different combinations of the species, varying the relative proportions (100:0, 75:25, 50:50, 25:75, and 0:100%). The analysis of species competitiveness was performed using diagrams applied to the substitutive experiments and relative competitiveness indices. The maize hybrids showed less loss when reducing the morphological variables of the hairy beggarticks and demonstrated superiority in competitive ability in relation to the weed. Competition occurred between maize hybrids in the presence of hairy beggarticks, being negatively affected, regardless of the proportion of plants, causing reductions in plant height, stem diameter, leaf area, and dry mass. An average reduction of 10% and 86% of the MS of maize hybrids and weed was observed, respectively, when comparing the absence of competition with any associated densities, intraspecific competition being more harmful than interspecific. Maize hybrids and hairy beggarticks compete for the same environmental resources, with the crop being more competitive than the competitor.

Keywords: *Zea mays*. *Bidens pilosa*. Plant interaction. Interference.

RESUMO - O estudo das interações competitivas entre espécies cultivadas e não cultivadas pode ser uma ferramenta importante no manejo integrado de plantas daninhas. O objetivo deste trabalho foi avaliar a habilidade competitiva de híbridos de milho na presença do picão-preto, testando-se diferentes proporções de plantas nas associações. Tanto para os híbridos de milho (Dekalb 230 PRO3, Pioneer 30F53 VYH, Brevant 2B433 PW e Syngenta 505 VIP3) quanto para o picão-preto, a densidade final foi de 20 indivíduos vaso^{-1}, determinada em experimentos preliminares. Após foram instalados ensaios em série de substituição, nas diferentes combinações das espécies, variando-se as proporções relativas (100:0, 75:25, 50:50, 25:75 e 0:100%). A análise da competitividade das espécies foi efetuada por meio de diagramas aplicados a experimentos substitutivos e pelos índices de competitividade relativa. Os híbridos de milho apresentaram menor perda ao reduzirem as variáveis morfológicas do picão-preto e demonstraram superioridade na habilidade competitiva em relação a planta daninha. Ocorreu competição entre os híbridos de milho na presença do picão-preto, sendo afetados negativamente, independentemente da proporção de plantas, provocando reduções na estatura de plantas, diâmetro de caule, área foliar e massa seca. Observou-se redução média de 10 e 86% da MS dos híbridos de milho e da planta daninha, respectivamente ao se comparar a ausência de competição com qualquer das densidades associadas, sendo a competição intraespecífica mais prejudicial do que a interespecífica. Os híbridos de milho e o picão-preto competem pelos mesmos recursos do meio, sendo a cultura mais competitiva do que a planta daninha.

Palavras-Chave: *Zea mays*. *Bidens pilosa*. Interação entre plantas. Interferência.

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INTRODUCTION

Among the various factors responsible for the low average productivity of maize, interference caused by weeds, which compete for water, light, nutrients, and may host pests and diseases, is predominant. Weeds may also release allelopathic substances that interfere with the growth and development of the crop, reducing grain yield (FRANDOLOSO et al., 2019; GHENO et al., 2021; PIASECKI et al., 2020; FREITAS et al., 2021a) or even increasing production costs (HELVIG et al., 2020). Losses in maize grain yield caused by weeds can be greater than 80%, if no management is adopted to control these species (PIASECKI et al., 2020; HELVIG et al., 2020; FREITAS et al., 2021a,b).

Among the weeds that infest maize, the genus *Bidens* stands out with several species, including *Bidens pilosa* (hairy beggarticks) that occurs practically all over the world. In Brazil, this species is found in almost all regions, but it is concentrated in the agricultural areas of the Mid-Southern region, where it is one of the most important weeds infesting annual and perennial crops. This weed is

very aggressive because it accumulates great amounts of nutrients in its tissues, produces many seeds, and is flexible to edaphic and environmental changes, which makes it a plant with high competitive ability (SANTOS; CURY, 2011; FREITAS et al., 2021a).

Hairy beggarticks has greater efficiency in the use of water, solar radiation, and macro and micronutrients available in the soil, when compared to several agricultural crops (SANTOS; CURY, 2011; BRITO et al., 2016; FREITAS et al., 2021a). This species can release allelopathic substances capable of interfering with the growth and development of crops, which will compromise physiological and morphological characteristics of plants, in addition to being a host for insects and diseases, especially aphids, nematodes, and fungi (SANTOS; CURY, 2011; BRITO et al., 2016).

In this context, hairy beggarticks stands out as one of the weeds with the highest potential to cause damage, especially for its high competitive ability, high shading capacity (SANTOS; CURY, 2011; BRITO et al., 2016; FREITAS et al., 2021a) and also for presenting resistance to acetolactate synthase inhibitor herbicides (ALS), widely used in maize for weed control (HEAP, 2022).

In this scenario, a cultural practice complementary to herbicides, is the use of more competitive crop cultivars (AGOSTINETTO et al., 2013; FRANDOLOSO et al., 2019). The superior competitiveness of one species over another indicates that it will have a greater capacity to assimilate the resources of the ecological niche, presenting greater potential for growth and development (JHA et al., 2017; FRANDOLOSO et al., 2019; BRANDLER et al., 2021).

In crops, in general, the density of cultivated plants is usually constant, while the density of weeds varies according to the soil seed bank, and environmental and management conditions that change the level of infestation and competitiveness of species (AGOSTINETTO et al., 2013; WANDSCHEER et al., 2014; FRANDOLOSO et al., 2019; BRANDLER et al., 2021). Thus, in competition studies involving crops and weeds, there is a need to evaluate the density of plants in the competitive process, the influence of variation in the proportion between species living in community, and also the effect that different populations associated or not can cause in morphological plant traits (WANDSCHEER et al., 2014; FRANDOLOSO et al., 2019; GALON et al., 2021a).

For the study of competitive interactions between crops and weeds, experimental designs and appropriate analysis methods are required, with substitutive series experiments being the most used to clarify such relationships (WANDSCHEER et al., 2014; FORTE et al., 2017; BRANDLER et al., 2021). In these experiments, crops generally achieve greater competitive ability than weeds. In the field, the effect of the weed on the crop is mainly due to the level of infestation and not to its individual competitive ability (FRANDOLOSO et al., 2019; BRANDLER et al., 2021). However, when there is competition between individuals of the same genus and/or species, the competitive advantage of the crop may be altered, since both exploit the same ecological niche.

Determining competitive interactions between crops and weed species requires appropriate experimental designs and methods of analysis (BIANCHI; FLECK; LAMEGO, 2006; FRANDOLOSO et al., 2019; BRANDLER et al., 2021). Thus, the use of substitutive experiments allows obtaining results to inform the optimization of weed management strategies (BIANCHI; FLECK; LAMEGO, 2006; FRANDOLOSO et al., 2019; BRANDLER et al., 2021), and to determine whether the most important competition is intraspecific or interspecific (WANDSCHEER et al., 2014), thus enabling sustainable weed management tactics.

Research studies focusing on possible interactions between certain proportions of weeds and crops are relevant to developing management strategies, based on the possibility of defining the characteristics that confer greater competitive ability to the crop (WANDSCHEER et al., 2014; FREITAS et al., 2021a; GALON et al., 2021b). In this way, knowledge of the competitive ability of maize hybrids in relation to hairy beggarticks becomes an interesting tool for the development of new management tactics, or even the adoption of integrated weed management, being able to reduce herbicide applications for weed control over time, also helping to prevent the appearance of resistant weeds.

The hypothesis of the study is that maize hybrids present distinct competitive ability when in the presence of hairy beggarticks. Thus, the objective of this work was to compare the competitive ability of maize hybrids in the presence of hairy beggarticks in different proportions of plants in the association.

MATERIAL AND METHODS

Nine experiments were installed in a greenhouse at the Federal University of Fronteira Sul (UFFS), campus at Erechim/RS, in the 2018/19 cropping season. The experimental units consisted of plastic pots with capacity of 8 dm^3, filled with humic ferric aluminum Latosol (SANTOS et al., 2018), previously corrected and fertilized with 582 kg ha^{-1} of the formula 05-30-15 of N-P-K, according to the recommendation for maize (SILVA et al., 2016). Chemical and physical soil characteristics were: pH 5.0; OM: 2.35%; P: 2.1 mg dm^{-3}; K: 48 mg dm^{-3}; Al: 0.5 cmolc dm^{-3}; Ca: 4.5 cmolc dm^{-3}; Mg: 1.6 cmolc dm^{-3}; $CTC_{(ef)}$: 6.8 cmolc dm^{-3}; $CTC_{(pH=7.0)}$: 12.5 cmolc dm^{-3}; H+Al: 6.2 cmol dm^{-3}; SB: 6.2 cmol dm^{-3}; V: 51%; and clay: 50%.

The experimental design used was completely randomized blocks, with four replications. The tested competitors included the following maize hybrids: Dekalb 230 PRO3, Pioneer 30F53 VYH, Brevant 2B433 PW, and Syngenta NK 505 VIP3 (Table 1), which competed with hairy beggarticks (*Bidens pilosa*). The seeds used in the experiments were harvested in the summer of 2017, in the experimental area of UFFS, Campus Erechim, at the geographic coordinates 27º43'47"S; 52º17'37"W, 670 m asl.

Table 1. Genetic traits of maize hybrids used in the study.

Company	Pedigree	Type	Cycle and biotechnology
Bayer	Dekalb 230 PRO3	Simple hybrid	Short – Super Short / VT PRO3
Pioneer	Pioneer 30F53 VYH	Simple hybrid	Short / Leptra
Brevant	2B433 PW	Simple hybrid	Super Short / PowerCore
Syngenta	NK 505 VIP3	Simple hybrid	Short / VIP3

Five experiments were preliminarily installed in a greenhouse, both for maize hybrids and for hairy beggarticks, in monocultures with the objective of estimating the density of plants in which the final production of dry mass becomes constant. For this, the densities of 1, 2, 4, 8, 16, 24, 32, 40, 48, 56, and 64 plants per pot were used (equivalent to 25, 49, 98, 196, 392, 587, 784, 980, 1,176, 1,372, and 1,568 plants m^{-2}) as treatments.

Fifty days after the emergence of the species, plants of both maize and hairy beggarticks were collected to determine the aboveground dry mass (DM), which was quantified by weighing, after being dried in an oven with forced air circulation at a temperature of 65±5ºC until reaching constant mass. Through the average values of DM obtained in each test of the maize hybrids (Dekalb 230 PRO3, Pioneer 30F53 VYH, Brevant 2B433 PW, and Syngenta NK 505 VIP3) and the competitor (hairy beggarticks), the density of 20 plants per pot was obtained as the final density providing the constant final yield for the crop and the weed, which was equivalent to 463 plants m^{-2} (Figure 1).

The experiments in series of substitution consisted of five treatments formed by the relative proportions (%) of maize: hairy beggarticks of 100:0, 75:25, 50:50, 25:75, and 0:100, which was equivalent to 20:0, 15:5, 10:10, 5:15, and 0:20 plants per pot, crop versus weed. Four experiments were carried out involving the maize hybrids Dekalb 230 PRO3, Pioneer 30F53 VYH, Brevant 2B433 PW, and Syngenta NK 505 VIP3, that is, each hybrid was equivalent to an experiment, to evaluate the competitive ability of the crop against the weed, both carried out in substitutive series. In order to establish the desired densities in each treatment and obtain uniformity of the seedlings, the seeds were previously sown in trays and later transplanted into the pots.

Fifty days after emergence, plant height (EP, cm), stem diameter (DC, mm), leaf area (AF, cm^2 pot^{-1}), and aboveground dry mass (MS, g pot^{-1}) were assessed. The EP was measured with a graduated ruler from the ground level to the apex of the last fully developed leaf. The DC was estimated with the aid of a digital caliper, 5 cm above the soil surface. To quantify the AF, a portable meter model CI-203 brand Bio Science was used, performing the measurement of all the plants of each experimental unit. After determining the AF, the plants were placed in kraft paper bags and placed in an oven with forced air circulation, for drying, at a temperature of 60±5ºC, until the material reached constant mass in order to determine the DM of the species.

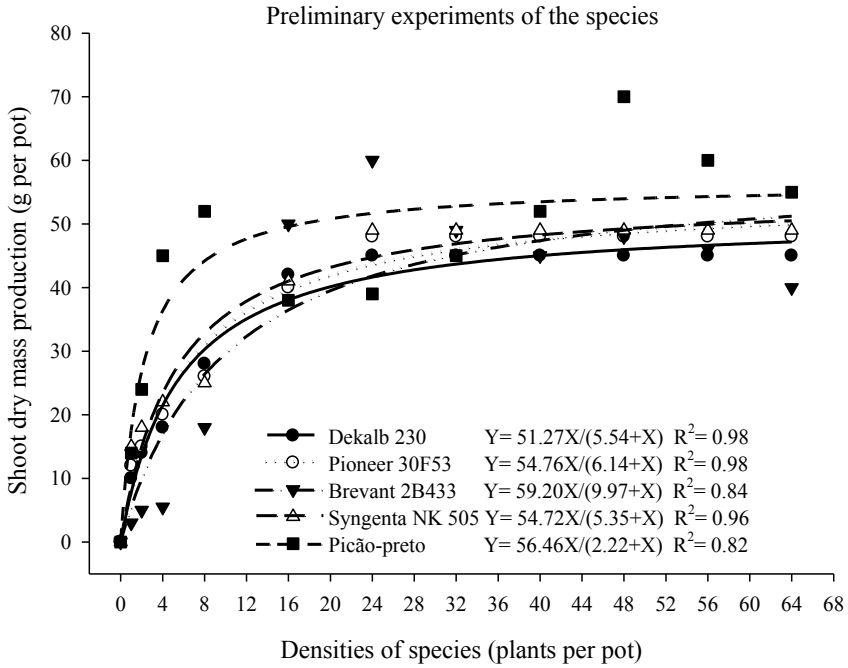

Figure 1. Constant final yield of aboveground dry mass of maize hybrids (Dekalb 230 PRO3, Pioneer 30F53 VYH, Brevant 2B433 PW e Syngenta NK 505 VIP3) and of the competitor (hairy beggarticks) as a function of plant density (plants per pot) in additive experiments.

Data were analyzed using the method of graphical analysis of variation or relative productivity (COUSENS, 1991; BIANCHI; FLECK; LAMEGO, 2006; AGOSTINETTO et al., 2013). This procedure, also known as the conventional method for substitutive experiments, consists of building a diagram based on the relative (PR) and total (PRT) yields or variations. When the PR result is a straight line, it means that the species' abilities are equivalent. If the PR results in a concave line, there was damage to the growth of one or both species. In contrast, if PR results in a convex line, there is benefit in the growth of one or both species. When the PRT is equal to unit 1 (straight line), competition for the same resources occurs; if it is greater than 1 (convex line), competition is avoided. If the PRT is less than 1 (concave line), there is mutual damage to growth (COUSENS, 1991; BIANCHI; FLECK; LAMEGO, 2006).

Indices of relative competitiveness (CR), relative clustering coefficient (K), and aggressiveness (A) of maize and hairy beggarticks were also calculated. The CR represents the comparative growth of maize hybrids (X) in relation to the competitor (Y); K indicates the relative dominance of one species over another; and A indicates which of the species is more aggressive. Thus, the CR, K, and A indices indicate which species is more competitive and their joint interpretation indicates with greater certainty the competitiveness of maize hybrids, and the weeds (COUSENS, 1991; BIANCHI; FLECK; LAMEGO, 2006). For example, hybrids of maize X are more competitive than the competitor hairy beggarticks Y when CR > 1, Kx > Ky and A > 0; on the other hand, hairy beggarticks Y is more competitive than the X maize hybrids when CR < 1, Kx < Ky and A < 0 (BIANCHI; FLECK; LAMEGO, 2006). To calculate these indices, the 50:50 proportions of the species involved in the experiment were used, that is, the densities of 10:10 plants per pot, using the equations: CR = PRx/PRy; Kx = PRx/(1-PRx); Ky = PRy/(1-PRy); A = PRx-PRy, according to Bianchi, Fleck and Lamego (2006).

The procedure of statistical analysis of the productivity or relative variation included the calculation of the differences for the values of PR (DPR) obtained in the proportions 25%, 50%, and 75% in relation to the values belonging to the hypothetical line in the respective proportions, being 0.25; 0.50, and 0.75 for PR (BIANCHI; FLECK; LAMEGO, 2006; AGOSTINETTO et al., 2013). The t-test was used to identify the relative differences of the CR, K, and A (BIANCHI; FLECK; LAMEGO, 2006). It was considered as a null hypothesis, to test the differences of A, that the means were equal to zero (Ho = 0); for the CR, the means were equal to one (Ho = 1); and for K, that the averages of the differences between Kx and Ky were equal to zero [Ho = (Kx – Ky) = 0].

The criterion for considering the observed PRT and PR curves as different 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 (GALON et al., 2015; CONCENÇO et al., 2018). The criterion for considering the PR and PRT 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, Fleck and Lamego (2006).

The results obtained for EP, DC, AF, and DM of the hybrids of maize and hairy beggarticks, expressed in average values per treatment, were submitted to analysis of variance by the F-test, for each of the experiments (Dekalb 230 PRO3, Pioneer 30F53 VYH, Dow 2B433, and Syngenta 505 VIP3 in competition with hairy beggarticks) and when this was significant, the means of the treatments were compared by Dunnett's test, considering the monocultures as controls in these comparisons. In all statistical analyses performed, $p \leq 0.05$ was adopted.

RESULTS AND DISCUSSION

The experiments in substitutive series involving the maize hybrids (Dekalb 230 PRO3, Pioneer 30F53 VYH, Brevant 2B433 PW, and Syngenta NK 505 VIP3) and hairy beggarticks indicated competition between the species, in which the productivity values obtained in the different proportions deviated from the expected line. It was observed that the association between the two species harmed more hairy beggarticks than maize (Figures 2, 3, 4, and 5), that is, the intraspecific competition was probably more harmful to maize than to the weed. There are factors that contribute to increasing the competitive capacity of species, mainly related to plant height, root dry mass, leaf traits, growth speed, among others (WANDSCHEER et al., 2014). In this case, in particular, maize plants are likely to be taller than hairy beggarticks, and thus the crop has absorbed a greater quantity and quality of light than the weeds, gaining advantage in the competition, which did not occur when maize was competing with itself. A similar result to the present study was observed by Wandscheer et al. (2014), when evaluating the competition of maize infested with Sudan grass (*Sorghum sudanense*).

The graphical results demonstrate, for the combinations of maize and hairy beggarticks (competitor), that all hybrids (Dekalb 230 PRO3, Pioneer 30F53 VYH, Brevant 2B433 PW, and Syngenta NK 505 VIP3) showed similarities in terms of competition with the weed, with significant differences occurring for the variables plant height (EP), stem diameter (DC), leaf area (AF), and shoot dry mass (DM) in the proportions of plants evaluated, since the colored lines, in general, were different from the expected or dotted lines for the PRTs and PRs (Figures 2, 3, 4, and 5). Probably the fact that all the hybrids were of the simple type, contributed to this as there was not enough genetic differentiation for them to present a pronounced distinction in behavior against hairy beggarticks. Frandoloso et al. (2019), when evaluating the competition of different simple hybrids of maize with Alexander grass (*Urochloa plantaginea*) also found similar responses to those observed in the present study.

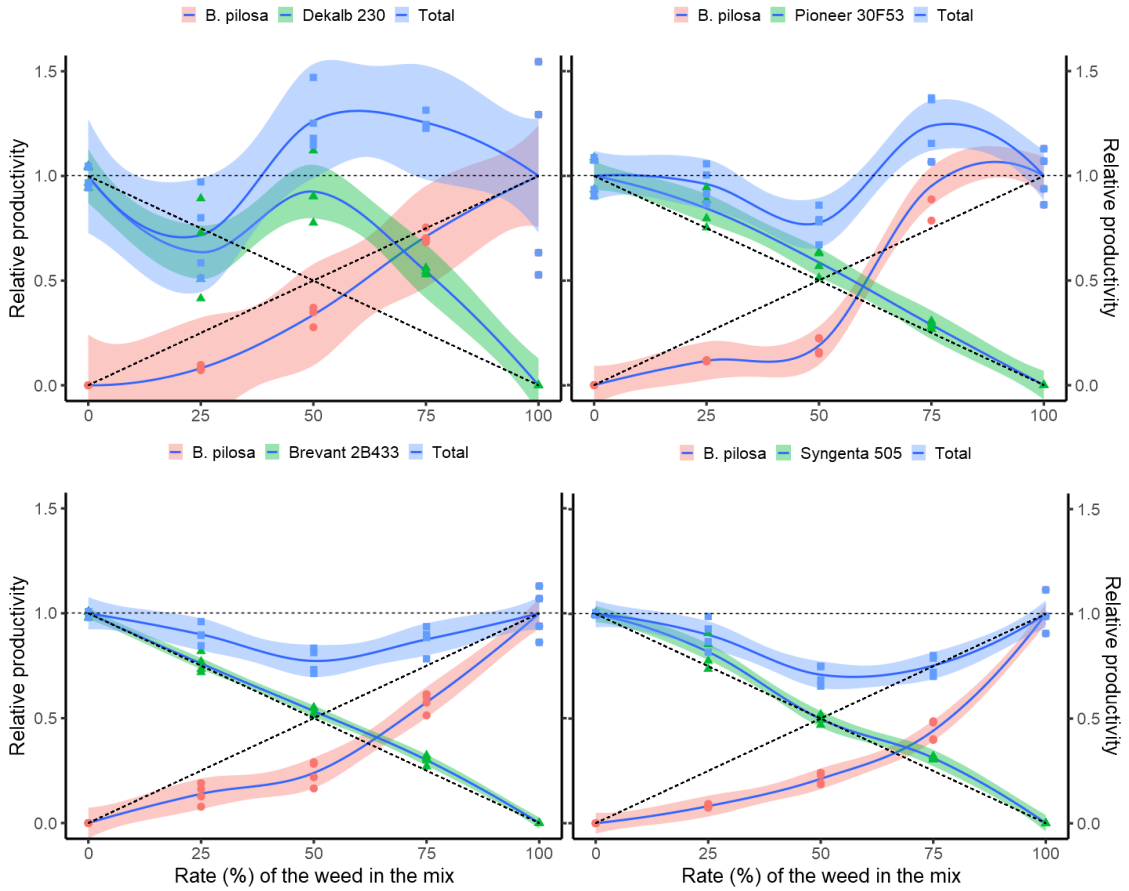

Figure 2. Relative productivity (PR) for plant height of maize hybrids Dekalb 230 PRO3, Pioner 30F53 VYH, Brevant 2B433 PW and Syngenta NK 505 VIP3 (●), hairy beggarticks (▲), and total relative productivity (PRT) of the community (■) as a function of plant proportion (maize:hairy beggarticks). Dashed lines are expected values; solid lines represent the modeled observed values; colored bands are the respective 95% confidence intervals.

For PRT, there were significant differences between the expected and estimated values in at least two plant proportions in relation to EP, DC, AF, and MS of maize hybrids, Dekalb 230 PRO3, Pioneer 30F53 VYH, Brevant 2B433 PW, and Syngenta NK 505 VIP3 when competing with hairy beggarticks, with concave lines and mean values lower than 1, in most situations in which the variables were studied (Figures 2, 3, 4, and 5). These PRT results with concave lines and values lower than 1 allows to infer that there was competition between maize and hairy beggarticks for the same environmental resources. This was also reported by Rubin et al. (2014), that the PRT was less than 1 with mutual antagonism between the species involved in the competition. Other studies have also found PRTs lower than 1 when researching the competition of maize hybrids such as DKB 240 YG in the presence of Sudan grass (WANDSCHEER et al., 2014), or Agroeste 1551 PRO 2, Morgan 300 PW, Nidera 92 PRO, and Syngenta Velox TL versus Alexander grass – *Urochloa plantaginea* (FRANDOLOSO et al., 2019) or when infested by Southern crabgrass – *Digitaria ciliaris* and morning glory – *Ipomoea indivisa* (GALON et al., 2021b).

In general, the EP, DC, and AF of maize hybrids Dekalb 230 PRO3, Pioneer 30F53 VYH, Brevant 2B433 PW, and Syngenta NK 505 VIP3 showed deviations from the observed PR lines very close to the expected straight lines and with convex lines, in most of the proportions tested (Figures 2, 3, and 4). This result indicates that the crop shows less damage than the weed from competition, since the weed presented values very far from those expected, that is, the competitor presented a concave line with damage to the growth in EP, DC, AF, and MS in practically all the proportions of plants tested (Figures 2, 3, 4, and 5). Likewise, Wandscheer and Rizzardi (2013), when studying the competition between maize and *Chloris distichophylla* observed that the hypothetical values established for the crop did not change when there was competition with the weed; the crop maintained its relative productivity equivalent to monoculture conditions. Galon et al. (2021a) when evaluating the relative competitiveness of *Euphorbia heterophylla* when infesting different maize hybrids, denoted that the competitor also presented values below the hypothetical line (concave lines), indicating that the competition was harmful to the weed.

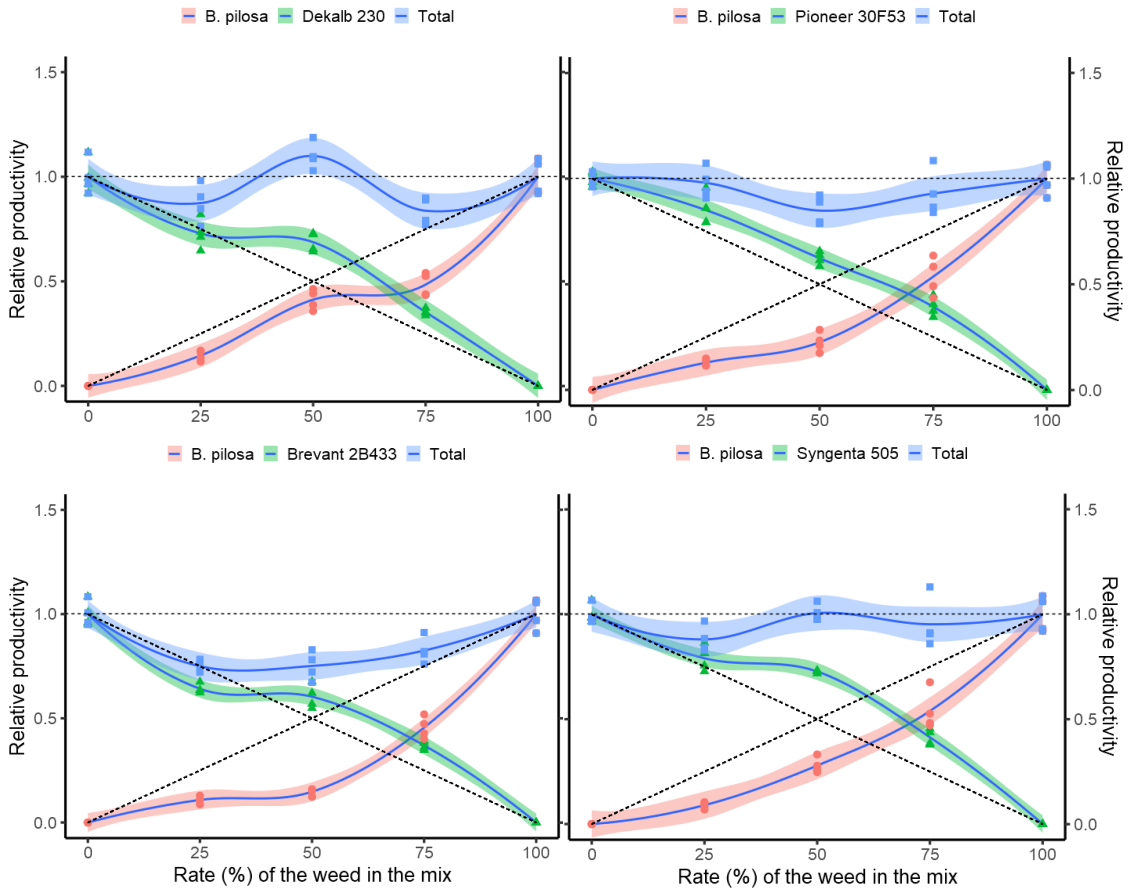

Figure 3. Relative productivity (PR) for stem diameter of maize hybrids Dekalb 230 PRO3, Pioner 30F53 VYH, Brevant 2B433 PW and Syngenta NK 505 VIP3 (●), hairy beggarticks (▲), and total relative productivity (PRT) of the community (■) as a function of plant proportion (maize:hairy beggarticks). Dashed lines are expected values; solid lines represent the modeled observed values; colored bands are the respective 95% confidence intervals.

For the DM variable, the combinations of plants demonstrate that the deviations of the PR lines in relation to the expected lines are concave for all simulations involving the hybrids Dekalb 230 and Syngenta NK 505 VIP 5, and that in at least two proportions of plants (Figure 5), both for the crop and for the weed, there was significance. The hybrids Pioneer 30F53 VYH and Brevant 2B433 PW showed convex lines for the PR up to the ratio of plants 50:50 or 10 maize plants competing with 10 plants of hairy beggarticks (Figure 5). For Pioneer 30F53 VYH in the 50:50 ratio, the same was presented for the PR concave line and the Brevant 2B433 PW hybrid from the 25:75 ratio showed the same trend as the previous hybrid. The differentiation of hybrids when in competition with weeds is due to genetic characteristics that they present such as plant architecture, development cycle, height, leaf area index, growth rate, root volume, among others that differentiate them in their competitive ability in the presence of hairy beggarticks. According to Jha et al. (2017), these crop competition attributes can potentially reduce the risk of grain yield losses due to weed interference when infesting crops, especially maize.

Regarding hairy beggarticks DM, when competing with all maize hybrids, it always presented concave PR lines and very distant from the expected lines (Figure 5), thus having a loss in growth. The same occurred with the hybrids Dekalb 230 and Syngenta NK 505 VIP 5 in all proportions of plants in the presence of the competitor (Figure 5). In this case, it can be said that hairy beggarticks showed lower competitive ability than the maize hybrids Dekalb 230 and Syngenta NK 505 VIP for all combinations of plants studied, and for Pioneer 30F53 and Brevant 2B433 from the proportions of 50:50 and 25:75 onwards, respectively. As previously explained, this fact stems from the genetic differences that exist between the hybrids (Table 2), which alters their competitive ability in the presence of weed species.

The fact that the crop and the weed showed concave lines demonstrates that there is competition for the same resources in the environment where they are inserted, causing damage to the growth of maize and also to the weed involved in the association of plants. Galon et al. (2021b) when evaluating the competition of maize hybrids Agroeste AS 1551 PRO 2, Morgan MG 300 PW, Nidera VT PRO Yeld Gard NS 92 PRO, and Syngenta Velox TL with *Digitaria* and *Ipomoea* species, also found concave lines for the crop and for weeds, which corroborates the results found in the present study.

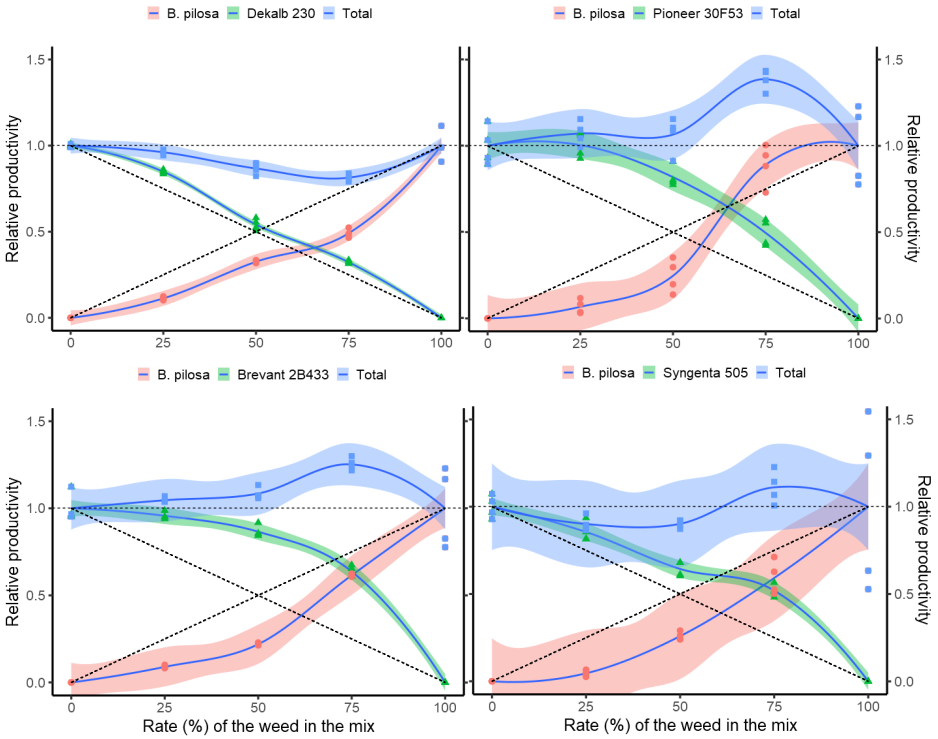

Figure 4. Relative productivity (PR) for leaf area of maize hybrids Dekalb 230 PRO3, Pioner 30F53 VYH, Brevant 2B433 PW and Syngenta NK 505 VIP3 (●), hairy beggarticks (▲), and total relative productivity (PRT) of the community (■) as a function of plant proportion (maize:hairy beggarticks). Dashed lines are expected values; solid lines represent the modeled observed values; colored bands are the respective 95% confidence intervals.

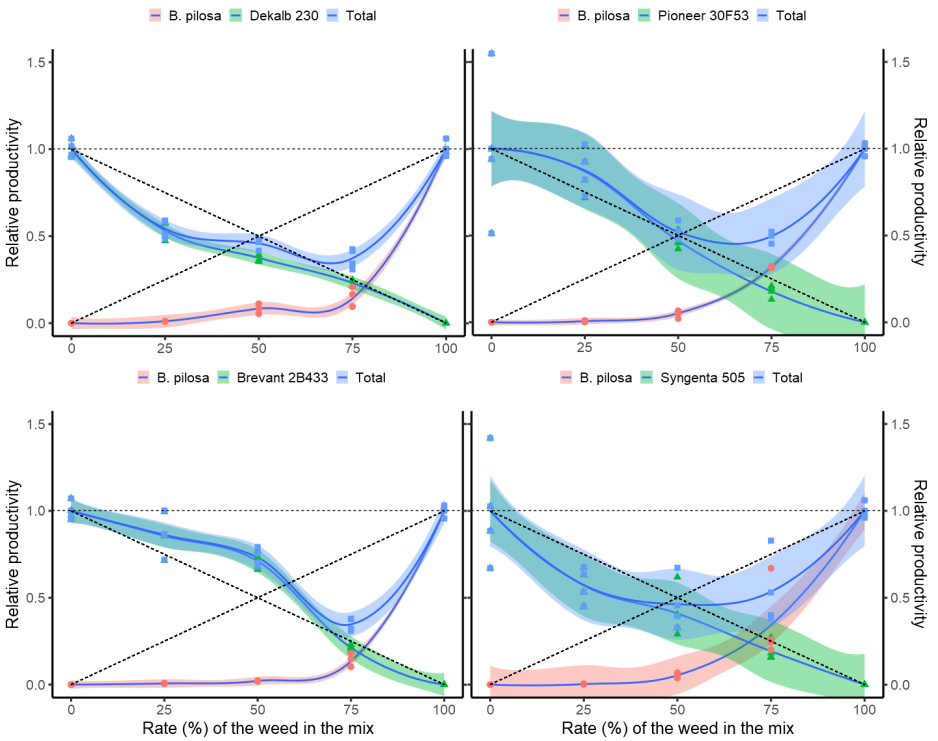

Figure 5. Relative productivity (PR) for aboveground dry mass of maize hybrids Dekalb 230 PRO3, Pioner 30F53 VYH, Brevant 2B433 PW and Syngenta NK 505 VIP3 (●), hairy beggarticks (▲), and total relative productivity (PRT) of the community (■) as a function of plant proportion (maize:hairy beggarticks). Dashed lines are expected values; solid lines represent the modeled observed values; colored bands are the respective 95% confidence intervals.

Table 2. Morphological responses of maize hybrids under competition with hairy beggarticks (*Bidens pilosa*), in terms of plant height (EP), stem diameter (DC), leaf area (AF) and aboveground dry mass (DM), in substitutive series experiments.

Plant proportion Maize: Hairy beggarticks	Plant height		Stem diameter		Leaf area		Dry mass	
	Dekalb 230 PRO3							
	Maize	Weed	Maize	Weed	Maize	Weed	Maize	Weed
100:0	81.21	81.62	10.01	6.18	3757.67	1066.18	205.44	59.56
75:25	91.88*	53.44*	11.32	3.99	3184.82	1009.96	145.61*	11.22*
50:50	87.96*	53.16*	13.76*	5.10	6956.89*	617.85 *	154.07*	9.94*
25:75	104.89*	36.81*	14.13*	3.59	8181.13*	347.95*	190.14	2.63*
C.V (%)	3.90	8.20	7.90	13.10	15.70	38.50	7.90	15.70
Plant proportion	Pioneer 30F53VYH							
	Maize	Weed	Maize	Weed	Maize	Weed	Maize	Weed
100:0	79.71	69.62	11.67	6.88	2935.50	925.32	151.97	69.72
75:25	89.75	88.35*	13.24	4.92*	3933.16*	1099.00*	176.07	29.58*
50:50	93.48*	26.31*	14.54*	3.10*	4807.52*	456.11*	142.57	7.13*
25:75	91.85	32.33*	18.36*	3.55*	5821.24*	248.20*	107.86	1.73*
C.V (%)	10.10	17.00	9.90	15.10	13.70	28.60	28.60	8.00
Plant proportion	Brevant 2B433 PW							
	Maize	Weed	Maize	Weed	Maize	Weed	Maize	Weed
100:0	92.19	69.62	11.64	6.88	3513.73	925.32	165.30	69.72
75:25	93.46	53.42*	12.96	4.17*	4483.95*	759.01	188.62	12.44*
50:50	98.44	33.27*	14.05*	2.03*	6082.74*	405.84*	235.03*	2.94*
25:75	110.75*	38.75*	17.22*	2.98*	8954.33*	330.70*	140.69	1.80*
C.V (%)	6.00	21.10	7.70	12.10	5.80	20.00	10.10	11.00
Plant proportion	Syngenta NK 505VIP3							
	Maize	Weed	Maize	Weed	Maize	Weed	Maize	Weed
100:0	83.49	81.62	10.74	6.18	3531.20	1066.18	200.41	59.56
75:25	91.12	48.08*	11.32	4.44*	4027.75	841.05	152.56	22.73*
50:50	83.04	34.64*	15.62*	3.44*	4545.10*	551.23*	164.13	6.35*
25:75	103.98*	26.62*	17.77*	2.22*	7338.76*	194.94*	153.97	0.66*
C.V (%)	6.00	11.90	7.70	15.40	7.70	46.70	33.50	54.50

*Means differ from the control (T) by Dunnett's ($p<0.05$).

In general, the maize hybrids showed higher relative growth than the weed hairy beggarticks in all the proportions of plants evaluated for the variables EP, DC, AF, and DM. This demonstrates that the crop has a higher PR than the weed, however there was little contribution to PRT (Figures 2, 3, 4, and 5). An explanation that maize showed greater relative growth compared to the hairy beggarticks and expressed greater competitiveness may be related to the density of plants that competed with the crop, since weeds have greater competitive ability when present in crops at high densities – thus acting as a community, and not as individuals (AGOSTINETTO et al., 2013; FORTE et al., 2017; FRANDOLOSO et al., 2019).

The results demonstrate increases in the PRT of the combinations as greater the proportions of plants competing with each other, a significant situation for all the variables studied (Figures 2, 3, 4, and 5). This behavior shows that the species are competitive and that one does not contribute more than expected to the total productivity of the other. As they belonged to different botanical families, it was expected that the maize hybrids and the weed would explore different ecological niches and not compete for the same environmental resources. Thus, they would not present a distinction in terms of competitiveness, as such differences were verified in a study that used related species, such as maize x Sudan grass (WANDSCHEER et al., 2014). However, some research has found differences in plant competition between different families, such as *Digitaria* x soybean (AGOSTINETTO et al., 2013) and soybean x hairy beggarticks (FORTE et al., 2017). Galon et al. (2021b) when working with maize hybrids infested with *Digitaria* and *Ipomoea* species, reported that the PRT of the community was also harmed, demonstrating that

both weeds and the crop present losses when in competition.

The relative growth of maize hybrids Dekalb 230 PRO3, Pioneer 30F53 VYH, Brevant 2B433 PW, and Syngenta NK 505 VIP presented, in general, different values in the same proportion of plants in competition, for all variables (Figures 2, 3, 4, and 5). This is due to the fact that the maize hybrids have different characteristics in terms of height and development cycle, thus differentiating their competition against hairy beggarticks, that is, they presented different behavior in the presence of the weed, as already explained. These results allow us to infer that there is a marked effect of maize genetic characteristics against hairy beggarticks and that the ability of maize hybrids to interfere with the weed is different. Jha et al. (2017) describe that there is differentiation in the competitive ability according to the type of maize hybrid involved in the competition.

Regarding the morphological variables EP, DC, and AF of maize plants, Dekalb 230 PRO3, Pioneer 30F53 VYH, Brevant 2B433 PW, and Syngenta NK 505 VIP, they increased in competition with hairy beggarticks for all combinations, independently of the proportion of plants in the association (Table 2). It was observed that the higher the proportion of the competitor in the association with maize hybrids, the smaller the damage to the variables (EP, DC, and AF) of the crop. The maize hybrids Dekalb 230 PRO3, Pioneer 30F53 VYH, Brevant 2B433 PW, and Syngenta NK 505 VIP showed lower values for DM in accordance with the increase in the density of the competitor, that is, in the absence of hairy beggarticks (100:0) the highest values were reported.

It can be said that maize altered the partition of photoassimilates between the organs of the plant, that is, the cultivated plant invested in variables that could give it greater competitive ability, to the detriment of others. According to Pierik and Ballaré (2021), a plant when in shade normally allocates a greater amount of resources to the stem, which allows it to reach greater stature and advantage in competition for light with its neighbors. Plants, when deprived of any factors necessary for their growth, tend to change their distribution pattern of photoassimilates and, as a consequence, their morphophysiological characteristics (SANTOS; CURY, 2011; FREITAS et al., 2021a), as happened in the present study, where there was a greater accumulation of DM when maize plants were free from interspecific competition (100:0), with intraspecific competition being more harmful to the crop. In studies of competition between maize and pigweed (*Amaranthus retroflexus* L.) plants, maize was the best competitor, and for the cultivated plant, intraspecific competition was more important than interspecific. The opposite was verified for pigweed, where interspecific competition was the most harmful (CHRISTOFFOLETI; VICTORIA FILHO, 1996), which corroborates the results found in the present study.

Regarding hairy beggarticks, there was a reduction in the variables (EP, DC, AF, and DM), when in the same or smaller proportion of plants, compared to maize hybrids (Table 2). Studies show that damage to the growth of crops and weeds can occur when they are in competition in a given community (FORTE et al., 2017; FRANDOLOSO et al., 2019; FREITAS et al., 2021b). The lowest values of dry mass accumulation demonstrate high interspecific competition, in which the species compete for the same resources in the environment, according to studies that evaluated the interference of turnip (BIANCHI; FLECK; LAMEGO, 2006) and of *Brassica napus* (FORTE et al., 2017) in soybean cultivars. In the present work, the crop was well distributed, which increases its competitive ability, while the distribution in lines, generally used in the field, increases the damage caused by the weed community (BIANCHI; FLECK; LAMEGO, 2006; WANDSCHEER et al. , 2014).

The results demonstrate for all the variables studied that the highest averages per plant of the crop, or even of hairy beggarticks, were obtained when they were in lower densities in the associations in all combinations, except for maize DM which showed higher averages in the absence of competition (Table 2). As previously explained, the higher DM averages in the absence of competition are due to the relocation of photoassimilates that occurred for maize plants.

It was observed that the values of EP, DC, and AF of maize hybrids in the proportions of each mixture (25%, 50%, and 75%) with those obtained in monoculture (100%), that the intraspecific competition involving the species in the association (maize x hairy beggarticks) were more expressive with the highest averages per plant for the crop when it was presented at higher densities (Table 2). On the other hand, for hairy beggarticks, interspecific competition proved to be more harmful to the growth of the weed, with lower averages per plant when it competed with the highest proportions of plants of maize hybrids, for all variables. This fact was also reported by Christoffoleti and Victoria Filho (1996) when studying maize competition with pigweed. Rizzardi and Wandscheer (2014) observed that the species that demonstrate greater competitiveness suffer more from intraspecific competition than from interspecific competition, as plants with greater competitive capacity are usually harmed due to lack of space or environmental resources.

Competition affects production quantitatively and qualitatively, as it modifies the efficiency of use of environmental resources, such as water, light, CO_2, and nutrients (BIANCHI; FLECK; LAMEGO, 2006), establishing itself between the crop and plants of other species present in a plant community. The plants that establish themselves first in a certain environment are benefited in the process of competition, or even in function of differentiated characteristics such as greater height, leaf area index, fresh or dry mass production, root system, among others, which demonstrates greater competitive ability in a plant community (WANDSCHEER et al., 2014; FORTE et al., 2017) or even with different forms of management and cultivation practices adopted (BRITO et al., 2016; FREITAS et al., 2021b).

The growth of the maize hybrids Dekalb 230 PRO3, Pioneer 30F53 VYH, Brevant 2B433 PW, and Syngenta NK 505 VIP surpassed that of hairy beggarticks, as indicated by the CR index (greater than 1) for all the variables studied

(Table 3). A relative dominance of maize over the weed expressed was also observed by the K indices (K_{maize} > $K_{hairy\ beggarticks}$) and that the crop is more competitive than the weed according to the aggressiveness index (A > 0). In all comparisons, significant differences were found in at least two proportions of plants tested, following the proposal by Bianchi, Fleck and Lamego (2006). This demonstrates that both species are not equivalent in terms of competition for environmental resources, with maize being more competitive than hairy beggarticks. Maize when competing with Alexander grass (FRANDOLOSO et al., 2019), *Digitaria* or *Ipomoea* species (GALON et al., 2021b) stood out in the competition, showing greater efficiency in capturing the environmental resources and consequently higher relative growth. When sowing crops in association with weeds, with variation in the proportion of plants, cultivated plants usually have an advantage in relative productivity, thus demonstrating that intraspecific competition exceeds interspecific (WANDSCHEER et al., 2014).

Table 3. Competitiveness indices between maize hybrids and hairy beggarticks (*Bidens pilosa*), in equivalent plant proportions (50:50), expressed as relative competitiveness (CR), clustering coefficient (K) and aggressiveness (A), estimated in substitutive series experiments.

Hybrid	CR	Kx (maize)	Ky (weed)	A
		Stem diameter (DC)		
Dekalb 230	1.686 ± 0.124*	2.253 ± 0.238*	0.711 ± 0.071	0.275 ± 0.034*
Pioneer 30F53	2.839 ± 0.261*	1.667 ± 0.108*	0.295 ± 0.039	0.398 ± 0.020*
Brevant 2B433	4.110 ± 0.185*	1.565 ± 0.194*	0.173 ± 0.011	0.456 ± 0.024*
Syngenta 505	2.642 ± 0.160*	2.670 ± 0.042*	0.389 ± 0.037	0.449 ± 0.018*
		Plant height (ES)		
Dekalb 230	2.786 ± 0.277*	3.194 ± 4.372^{ns}	0.512 ± 0.044	0.589 ± 0.076*
Pioneer 30F53	3.200 ± 0.354*	1.452 ± 0.165*	0.235 ± 0.030	0.397 ± 0.031*
Dow 2B433	2.356 ± 0.340*	1.148 ± 0.043*	0.320 ± 0.050	0.295 ± 0.032*
Syngenta 505	2.364 ± 0.110*	0.992 ± 0.043*	0.271 ± 0.022	0.285 ± 0.007*
		Leaf area (AF)		
Dekalb 230	1.664 ± 0.058*	1.190 ± 0.080*	0.483 ± 0.009	0.216 ±0.018*
Pioneer 30F53	3.785 ± 0.794*	5.293 ± 1.545*	0.344 ± 0.087	0.572 ±0.061*
Dow 2B433	3.951 ± 0.115*	6.985 ± 1.395*	0.281 ± 0.006	0.646 ±0.019*
Syngenta 505	2.514 ± 0.184*	1.835 ± 0.167*	0.350 ± 0.022	0.385 ±0.032*
		Aboveground dry mass (DM)		
Dekalb 230	4.810 ± 0.740*	0.601 ± 0.025*	0.092 ± 0.014	0.292 ±0.017*
Pioneer 30F53	11.433 ± 3.649	0.895 ± 0.088*	0.054 ± 0.012	0.418 ±0.027*
Dow 2B433	33.887 ± 1.203*	2.543 ± 0.321*	0.022 ± 0.001	0.690± 0.024*
Syngenta 505	7.881 ± 1.378*	0.798 ± 0.281	0.056 ± 0.007	0.356 ± 0.073

*Significan difference according to the t-test ($p<0.05$).

Using the three indices to define competitiveness, it was found that maize is more competitive than sudan grass (WANDSCHEER et al., 2014), Alexander grass (FRANDOLOSO et al., 2019), and morning glory (GALON et al., 2021b). In this way, it was found that there is differentiation, in relation to the three evaluated indices (CR, K, and A) when the maize hybrids Dekalb 230 PRO3, Pioneer 30F53 VYH, Brevant 2B433 PW, and Syngenta NK 505 VIP competed with hairy beggarticks at the same time regarding EP, DC, AF, and DM (Table 3).

In most situations, the cultivated plant showed greater competitive ability than hairy beggarticks in isolation, this is due to the fact that the effect of the weeds is not due to their greater individual competition, but mainly due to the combined effect of their density (WANDSCHEER et al., 2014). However, in some studies, crops showed less competitive ability than weeds, such as soybeans when infested by turnip (BIANCHI; FLECK; LAMEGO, 2006) and other weed species (FORTE et al., 2017). It is also worth noting that in a plant community there is a benefit in the competition for resources for those that establish themselves first, or for intrinsic characteristics of each cultivar in terms of competitive ability (height, growth rate, number of branches, leaf area, dry mass, among others) and in this way smaller amounts of resources will be available in the environment, which causes increased damage to the competitor or the crop (AGOSTINETTO et al., 2013; FREITAS et al., 2021b).

Interpreting the graphical analyses of the relative

variables and their significance together in relation to the equivalent values (Figures 2, 3, 4, and 5), the morphological variables (Table 2), and the competitiveness indices (Table 3), in general, it may be concluded that there is a negative interaction effect between species, with maize hybrids (Dekalb 230 PRO3, Pioneer 30F53 VYH, Brevant 2B433 PW, and Syngenta NK 505 VIP) as well as the weed hairy beggarticks, being negatively affected. The maize hybrids demonstrate greater competitive ability than hairy beggarticks in all proportions of associated plants. This is due to the high competitive capacity and greater efficiency in the search for environmental resources, in this way maize ends up by suppressing the weed in the search for these resources (WANDSCHEER et al., 2014). Thus, the differences in terms of competitiveness of the evaluated species may be due to the fact that they exploit the same resources from the environment, such as water, light, and nutrients.

The knowledge of the interactions that occur between crops and weeds in community becomes important for the adoption of a more rational management in respect to agroecosystems. In this way, it is possible to achieve a lower use of herbicides, reduced environmental contamination, and greater economic return to the farmer.

CONCLUSIONS

There is competition between the maize hybrids Dekalb 230 PRO3, Pioneer 30F53 VYH, Brevant 2B433 PW, and Syngenta NK 505 VIP in the presence of hairy beggarticks, being negatively affected, regardless of the proportion of plants with reductions in plant height, stem diameter, leaf area, and aboveground dry mass.

Intraspecific competition causes greater damage to the growth of maize hybrids than interspecific competition with hairy beggarticks. The maize hybrids Dekalb 230 PRO3, Pioneer 30F53 VYH, Brevant 2B433 PW, and Syngenta NK 505 VIP and the hairy beggarticks compete for the same environmental resources. The maize hybrids Dekalb 230 PRO3, Pioneer 30F53 VYH, Brevant 2B433 PW, and Syngenta NK 505 VIP are more competitive than hairy beggarticks.

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