Universidade Federal Rural do Semi-Árido
Pró-Reitoria de Pesquisa e Pós-Graduação
https://periodicos.ufersa.edu.br/index.php/caatinga
ISSN 1983-2125 (online)

http://dx.doi.org/10.1590/1983-21252025v3811990rc

Scientific Article

Competitive ability of maize with weed species as a function of the inserted transgenic trait

Habilidade competitiva de milho com espécies de plantas daninhas em função da característica transgênica inserida

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ABSTRACT - New technologies developed to control weeds in crops have flourished in recent years. Therefore, the objective of this work was to study the competitive ability of maize hybrids 2B433 (Enlist®), Pioneer 30F53 (VYHR®), and 13K288 PWE (Enlist®) and a conventional (non-transgenic) variety with a distinct biotechnological background when competing against wild poinsettia (*Euphorbia heterophylla*) and Alexandergrass (*Urochloa plantaginea*). Crops and competitors were studied in distinct plant proportions: 20:0, 15:5, 10:10, 5:15 and 0:20 plants per pot or 100:0, 75:25, 50:50, 25:75, and 0:100% (crop:weed) in replacement series experiments. Fifty days after emergence, the leaf area and aboveground dry mass were measured. Concomitantly, the photosynthetic and carboxylation efficiency and CO_2 concentration were assessed in the leaf mesophyll. Maize hybrid 2B433 (Enlist®) showed better physiological and morphological performance compared to the conventional variety, and hybrids 13K288 PWE (Enlist®) and 30F53 (VYHR®) showed better performance when competing with wild poinsettia or Alexandergrass. The increased competitive ability seems to be due to the greater leaf area and aboveground dry mass reported for 2B433 (Enlist®). Therefore, the competitive ability presented by the hybrids was distinct, and we found no evidence that the transgenic event present in these hybrids affected their competitive ability.

Keywords: *Euphorbia heterophylla*. *Urochloa plantaginea*. *Zea mays*.

RESUMO - Novas tecnologias desenvolvidas para controlar plantas daninhas nas lavouras surgiram nos últimos anos. Diante disso objetivou-se com o trabalho estudar a habilidade competitiva dos híbridos de milho 2B433 (Enlist®), Pioneer 30F53 (VYHR®), 13K288 PWE (Enlist®) e uma variedade convencional (não transgênica), com antecedentes biotecnológicos distintos, ao competir com leiteiro (*Euphorbia heterophylla*) e papuã (*Urochloa plantaginea*). O milho e os competidores foram estudados em diferentes proporções de plantas: 20:0; 15:5; 10:10; 5:15 e 0:20 plantas vaso^{-1} ou 100:0; 75:25; 50:50; 25:75 e 0:100% (cultura: planta daninha) em experimentos de série substitutiva. Aos 50 dias após a emergência das espécies foi determinado a eficiência fotossintética e de carboxilação, a concentração de CO_2 no mesofilo foliar, além da área foliar e a massa seca da parte aérea das plantas. O milho híbrido 2B433 (Enlist®) apresentou melhor desempenho fisiológico e morfológico em relação à variedade convencional, e os híbridos 13K288 PWE (Enlist®) e 30F53 (VYHR®) quando em competição com leiteiro e papuã. O aumento da capacidade competitiva parece ser devido à maior área foliar e massa seca da parte aérea relatada para 2B433 (Enlist®). A capacidade competitiva apresentada pelos híbridos é distinta não se encontrando evidências de que o evento transgênico presente na cultura esteja afetando a habilidade competitiva.

Palavras-chave: *Euphorbia heterophylla*. *Urochloa plantaginea*. *Zea mays*.

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

Received for publication in: May 31, 2023.
Accepted in: July 12, 2024.

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INTRODUCTION

Maize (*Zea mays*) is one of the main cereals grown worldwide, being used in human food, in the formulation of feed for animal production, and as a raw material for biofuel production (ZHANG et al., 2022). Due to its socioeconomic importance, increasing investments have been made in genetic improvement in the search for higher productivity and other favorable traits (MACIEL; TUNES, 2021).

The grain yield and agronomic performance of maize can be compromised by the interference of biotic and abiotic factors. Among them, competition with weeds stands out, because when not controlled, it can lead to a decrease in productivity due to competition for resources essential for development such as water, light, and nutrients (GALON et al., 2018; FREITAS et al., 2021).

Alexandergrass (*Urochloa plantaginea*) is among the weeds most affecting the yield components and productivity of maize under competition, and the reduction in grain yield can reach more than 50% (GALON et al., 2018). In addition to Alexandergrass, wild poinsettia (*Euphorbia heterophylla*) is widely found in maize fields and has a high potential for damage due to its resistance to herbicides with different mechanisms of action (HEAP, 2024). Due to the damage caused by these weeds, control measures need to be taken, with the chemical method being the most used due to its ease, effectiveness, and low cost compared to other control methods (WESTWOOD et al., 2018).

Due to the herbicide resistance acquired by certain weeds, such as wild poinsettia, alternatives that allow the use of different herbicides are essential. The development of transgenic plants through gene insertion make it possible for the crop to survive under herbicide application, which is usually lethal for the species, and this is an advance considering the lack of recent discovery of new molecules. Thus, consolidated herbicides previously non-selective for that crop can be safely used for weed control (WESTWOOD et al., 2018). There have been 232 approvals of transgenic events in 30 countries worldwide since 1992 (ISAAA, 2024); in Brazil, maize is the crop with the most transgenic events, encompassing 72 approvals by the National Technical Commission on Biosafety (CTNBio) (ISAAA, 2024).

The first transgenic event for maize was approved in 2007, presenting a gene responsible for degradation of ammonium glufosinate, allowing its application post-emergence of maize hybrids with this technology, being called Liberty Link®. After that, new transgenic events were approved such as Roundup Ready® (RR®) in 2008, confering tolerance to glyphosate post-emergence, as well as newer technologies such as Enlist®. This technology allows the application of four different herbicides post-emergence in maize, which are: haloxyfop-methyl, 2,4-D, glyphosate, and ammonium glufosinate. These small changes in plants genetic background could pose some limitations to its development, or alternatively it could increase the response to a given stressing factors (RAYMOND; WRIGHT; BONSALL, 2011; LIU et al. 2021).

Maize has a great competitive ability against weeds (ETHRIDGE et al., 2022; GALON et al., 2023), and the combination of cultural weed suppression with chemical control can achieve effective weed control with lower herbicide demand and production costs. Experiments based on replacement series theory have been used to precisely elucidate the interactions between crops and weeds, enabling the evaluation of both interspecific and intraspecific competition in the same experiment (BIANCHI; FLECK; LAMEGO, 2006). In this type of experiment, the total population was kept constant, while the proportion between the two species varies. This approach makes it possible to compare the productivity of associations with those from monocultures, enabling the identification of the most competitive genotype or species (COUSENS, 1991). The parameters used to measure the effects of competition generally involve plant morphological variables such as height, leaf area, and dry mass of the shoot and root.

The hypothesis of this study is that maize hybrids present distinct competitive abilities against weeds as a function of the transgenic trait they contain. Therefore, the objective of this study was to compare the competitive ability of maize hybrids with similar developmental characteristics, whose main differences were the herbicide tolerance technology used against Alexandergrass and wild poinsettia.

MATERIAL AND METHODS

Eleven treatments were evaluated in a greenhouse in a randomized block design with four replications. The experimental units consisted of plastic pots (8 dm^3), filled with soil from areas cultivated with annual crops, classified as Humic Red Alumino Ferric Latosol (SANTOS et al., 2018), previously corrected and fertilized. The chemical and physical soil properties were as follows: pH_{water} = 4.8; OM = 3.5 %; P = 4.0 mg dm^{-3}; K = 117 mg dm^{-3}; Al^{3+} = 0.6 cmol dm^{-3}; Ca^{2+} = 4.7 cmol dm^{-3}; Mg^{2+} = 1.8 cmol dm^{-3}; $CTC_{(t)}$ = 7.4 cmol dm^{-3}; $CTC_{(TpH7)}$ = 16.5 cmol dm^{-3}; H + Al = 9.7 cmol dm^{-3}; SB = 6.8 cmol dm^{-3}; V = 41%; and Clay = 60%.

The treatments were proportions of maize hybrids 2B433 (Enlist®), Pioneer 30F53 (VYHR®), and 13K288 PWE (Enlist®) and a conventional (non-transgenic) variety competing against the weeds wild poinsettia (*Euphorbia heterophylla*) or Alexandergrass (*Urochloa plantaginea*).

Five initial experiments were established, with one dedicated to each weed species or maize cultivar in monoculture. The objective was to determine the minimum plant density at which the eventual aboveground dry mass production stabilizes and becomes independent of planting density. For this, 1, 2, 4, 8, 16, 24, 32, 40, 48, 56, and 64 plants per plot were tested (equivalent to 24, 48, 96, 192, 384, 576, 768, 960, 1152, 1344, and 1536 plants m^{-2}, respectively). The final constant production of aboveground dry mass was obtained with 20 plants per pot (489 plants m^{-2}), for all maize hybrids and also for the weeds.

Six other experiments were later set up to evaluate the competitive performance of maize hybrids and a conventional (non-transgenic) variety against wild poinsettia and Alexandergrass. These experiments were conducted using replacement series, exploring various combinations of crop:weed plant proportions (20:0, 15:5, 10:10, 5:15, and 0:20 plants per pot or 100:0,; 75:25, 50:50, 25:75, and 0:100%), maintaining a constant total plant density (20 plants per pot). To achieve the intended densities in each treatment and ensure uniform seedling size, the seeds were initially planted in Styrofoam trays with compartments and later transplanted to the plots.

The variables evaluated fifty days after emergence (DAE) were leaf area (AF - cm^2 $plot^{-1}$) and aboveground dry mass (DM - g $plot^{-1}$) for all species. For AF determination, a portable leaf area meter model CI-203 (BioScence, Inc.) was used, being quantified the AF for all plants of each species, into the plot. Following the determination of the AF, plants were cut at the soil level and placed in kraft paper bags, dried into oven with forced air circulation at 60 ± 5 °C, and later weighted for DM.

Simultaneously (50 DAE), measurements of the photosynthetic rate (A - μmol CO_2 m^{-2} s^{-1}), carboxylation efficiency (EC - mol m^{-2} s^{-1}), and CO_2 concentration in leaf mesophyll (CI μmol mol^{-1}) were done in the middle third of the most recently fully expanded leaf using an infrared gas analyzer (IRGA), ADC / LCA Pro (Analytical Development Co. Ltd, Hoddesdon, UK), under natural light conditions between 08:00 and 10:00am, under clear sky, so that homogeneous environmental conditions were maintained during the analyses of plots into the same experimental block.

The data set was analyzed using the method of graphical analysis of variation, or relative productivity (COUSENS, 1991; BIANCHI; FLECK; LAMEGO, 2006). The referred procedure consists in the construction of diagrams based on the relative (PR) and total (PRT) productivities. In graphs, the black straight dashed lines (- - - -) represent the expected values for PR and PRT in each situation. The observed (experimental) values are superposed to the expected ones as solid blue lines (———), with the respective 95 % confidence intervals (95% CI) and the original observed values (dots).

The colors used to represent both the 95% CI and the original values for PRcrop, PRweed and PRT were light brown (/ ●), green (/ ▲) and blue (/ ■), respectively. In sections where the confidence intervals included the respective expected dashed line, there was no difference between expected and observed values; on the other side, in sections where the expected dashed line was out of the respective colored 95% CI, treatments were considered to differ.

When $PR_{observed} < PR_{expected}$, there was loss in the growth of the species. When $PR_{obs} > PR_{exp}$, there is a benefit for growth of the species. When $PRT_{obs} = PRT_{exp}$, there is competition for the same resources; when $PRT_{obs} > PRT_{exp}$, competition is avoided, and when $PRT_{obs} < PRT_{exp}$, there is mutual damage to growth (COUSENS, 1991).

The relative competitiveness index (CR), relative clustering coefficient (K) and aggressiveness (AG) were calculated for the 50 : 50 plant proportion of the species involved, according to the equations described by Cousens and O'Neill (1993). The CR represents the comparative growth of maize hybrids (X) in relation to wild poinsettia or Alexandergrass (Y); K indicated the clustering ability of one species over another, and A indicates which species is most aggressive in its growth. Maize cultivars (X) are more competitive than wild poinsettia and / or Alexandergrass (Y) when CR > 1, Kx > Ky and AG > 0 (BIANCHI; FLECK; LAMEGO, 2006; AGOSTINETTO et al., 2013). The joint analysis of these values indicates with greater precision the competitiveness of maize hybrids when facing weed infestation.

The physiological (A, EC and CI) and morphological (leaf area and aboveground dry mass) parameters of s maize and/or weeds, expressed in mean values per plant, were submitted to analysis of variance by the F-test. When significant, treatment means were compared by Dunnett's, considering the respective monocultures as controls. For all statistical analyzes, the probability of error was adopted as $p \leq 0.05$.

RESULTS AND DISCUSSION

Variance analysis demonstrated a significant effect of the plant proportions of plants for each maize hybrid and/or wild poinsettia and Alexandergrass for all evaluated variables.

Physiological parameters

Physiological parameters were changed based on the crop:weed ratio. The A of the conventional and 13K288 PWE (Enlist®) cultivars in competition with Alexandergrass increased when they were in a situation of greater competitiveness with the weed (25:75) compared to the control (100:0). In contrast, hybrids 30F53 (VYHR®) and 2B433 (Enlist®) showed a decrease in A as interspecific competition increased. A depends on a constant flow of CO_2 and O_2 in and out of the leaf, and this free flow is a relationship between the concentration of CO_2 and O_2 (CI) in the intercellular spaces, which depends on stomatal opening (HAWORTH et al., 2021).

The results for CI in the Enlist® 13K288 showed significance in the proportion 75:25, while the Enlist® 2B433 showed significance in the three proportions of competitiveness (25:75, 50:50 and 75: 25), the hybrid VYHR® 30F53 did not show significant differences in any proportions and the conventional variety showed significance in the 50:50 proportion only (Table 1). CI is a variable influenced by several environmental factors, such as the availability of water, light and the leaf stomatal conductance; lower CI would usually result in lower CO_2 availability in the mesophyll and potentially lower photosynthesis rates (BERTOLINO; CAINE; GRAY, 2019).

Maize hybrids in competition with wild poinsettia also presented varying results according to the variation in the crop:weed ratio (Table 1). The photosynthetic rate was significant only for hybrid 2B433 (Enlist®). However, hybrid 30F53 (VYHR®) presented higher values than the other hybrids. A is directly related to the photosynthetically active radiation and stomatal opening, thus being a good indicator of the physiological response of the crop to weed competition (FREITAS et al., 2020; FREITAS et al., 2021).

CI was significant for hybrid 30F53 (VYHR®) in the proportion 75:25 and for hybrid 2B433 (Enlist®) in the proportion 50:50, while the others did not show significance at any proportion. The highest CI was not related to the highest photosynthetic rate (Table 1) because even with a lower influx of atmospheric CO_2, maize plants maintained constant photosynthesis due to PEP-carboxylase, an enzyme that fixes atmospheric carbon efficiently even at low concentrations (BARROS et al., 2017). Furthermore, lower CI values may be a result of greater photosynthetic activity, which incorporates CO_2 through carboxylation (BARROS et al., 2017). In view of this, one can relate EC to A most accurately.

Figures 1, 2, 3 and 4 show the morphological evaluation of maize in competition with either weed. The relative productivity (PR) for leaf area (AF) for the conventional variety in competition with wild poinsettia presented values higher than expected. The curvature of the line was higher in proportions 50:50 and 75:25, indicating that interspecific competition was less harmful than intraspecific competition. For hybrids 2B433 (Enlist®) and 13K288 PWE (Enlist®), the PRs obtained were represented by convex lines, indicating that the crop benefited. Hybrid 30F53 (VYHR®) presented a PR line close to the expected one, indicating that the competition did not harm crop growth. AF is a variable that greatly influences the competitive ability of plants; the more AF, the greater the competitive ability (FRANDOLOSO et al., 2019).

The values for PRT were close to the expected values, thus avoiding competition between species. Increasing the density of *Urochloa brizantha* resulted in negative changes in water use efficiency, with direct consequences on grain productivity of the maize crop (FREITAS et al., 2021). According to the authors, physiological responses and maize productivity depend on the management of *U. brizantha* to prevent the weed from exploiting the competitive process, using management methods and cultural practices favorable to the crop to the detriment of the competitor. Similar results were observed by Frandoloso et al. (2019) in a study of competition between maize and Alexandergrass showing that a larger leaf area resulted in a greater competitive ability for the plant.

The conventional variety presented PR for AF of the crop near that expected in competition with Alexandergrass (Figure 2). Hybrid 13K88 PWE (Enlist®) presented results close to that expected, and 2B433 (Enlist®) was superior to the weed since the PR of the crop showed a convex line, reflecting a synergistic effect on the crop when in competition with Alexandergrass. For hybrid 30F53 (VYHR®), an almost straight line was reported, indicating that the crop's AF remained stable when in competition with the weed.

Comparing the PRT values, which were generally below 1, it can be inferred that even with the crop being the most aggressive, there was mutual loss for both species. Frandoloso et al. (2019) reported that when PRT < 1, there was mutual antagonism between species as they competed for the same environmental resources. In general, the results corroborate those reported by Galon et al. (2023) in a study on hybrid maize competition with beggarticks.

The PR for aboveground dry mass (DM) for the conventional cultivar in competition with wild poinsettia (Figure 2) showed a straight line, characterized by the PR obtained being close to the expected value. For hybrid 13K288 PWE (Enlist®), the PR line obtained was also straight, indicating that competition was avoided. Hybrid 2B433 (Enlist®) presented a convex line in the proportions of lower interspecific competition (75:25 and 50:50), and as competition increased, a straight line was observed, indicating that competition was avoided from then on.

Table 1. Physiological responses of maize cultivars (*Zea mays*) submitted to competition with wild poinsettia (*Euphorbia heterophylla*), in replacement series experiments, assessed 50 days after emergence.

Crop: Weed	Physiological parameter					
	Alexandergrass			Wild poinsettia		
	A	EC	Ci	A	EC	Ci
			Conventional			
100:0 (T)	5.89	0.03	247.50	2.81	0.02	270.75
75:25	6.35	0.03	267.67	3.16	0.01	239.50
50:50	4.07	0.02	305.50*	5.34	0.03*	205.50
25:75	6.01	0.02	271.38	2.84	0.01	271.00
			13K288 PWE (Enlist®)			
100:0 (T)	7.96	0.04	182.19	5.46	0.04	179.75
75:25	9.51	0.04	235.96*	6.90	0.04	165.75
50:50	11.26	0.05	197.10	6.52	0.03	188.75
25:75	10.45	0.05	170.94	4.42	0.02*	202.25
			Pioneer 30F53 (VYHR®)			
100:0 (T)	11.77	0.08	151.60	7.60	0.05	159.25
75:25	13.24	0.11	151.22	10.09	0.04	292.5*
50:50	11.19	0.08	154.02	10.69	0.06	165.50
25:75	10.30	0.07	142.50	12.84	0.05	220.25
			2B433 (Enlist®)			
100:0 (T)	12.33	0.10	123.04	12.01	0.09	127.50
75:25	14.46	0.13	146.81*	2.29*	0.02*	227.00
50:50	11.15	0.08	150.14*	9.37	0.03*	271.00*
25:75	11.89	0.09	145.71*	8.70	0.04*	237.75

*Means differ from the control (T) by Dunnett's ($p \leq 0.05$); A = Photosynthesis rate (μmol m^{-2} s^{-1}); Ci = Leaf mesophyll CO_2 concentration (μmol mol^{-1}); EC = Carboxilation efficiency (mol CO_2 m^{-2} s^{-1}).

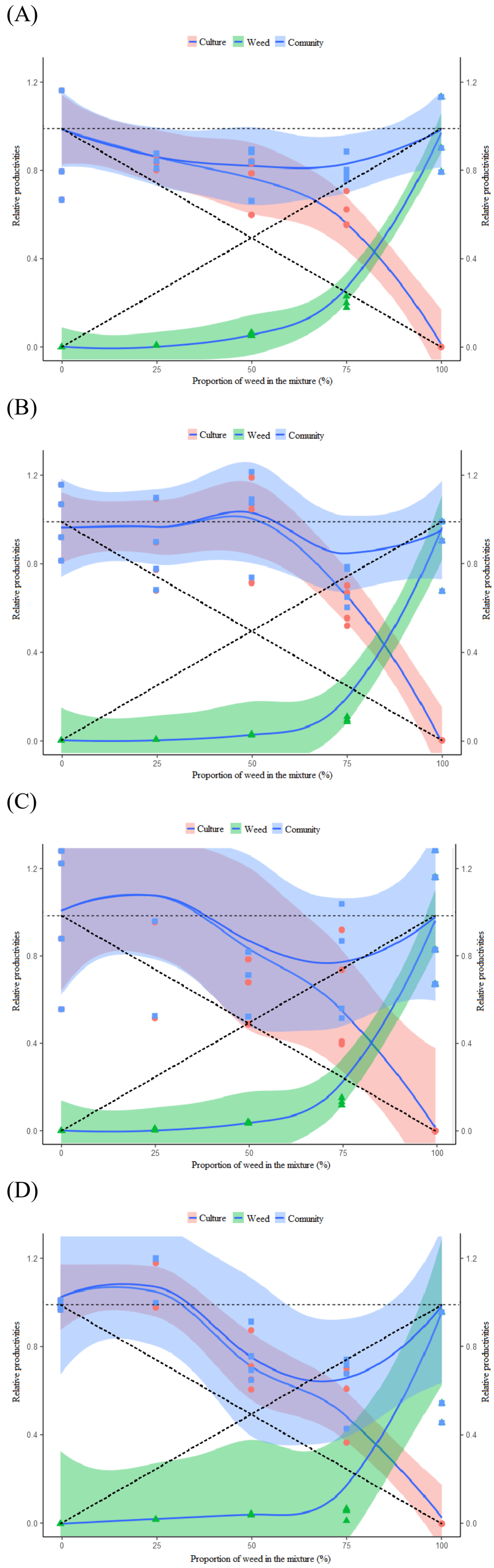


Figure 1. Relative productivity (PR) for leaf area of maize (●) and wild poinsettia (▲) plants, and total relative productivity (PRT) for the community (■) as a function of proportio of the weed in the mixture. Maize cultivars: conventional (A), 13K288 PWE (Enlist®) (B), Pioneer 30F53 (VYHR®), (C) and 2B433 (Enlist®) (D).

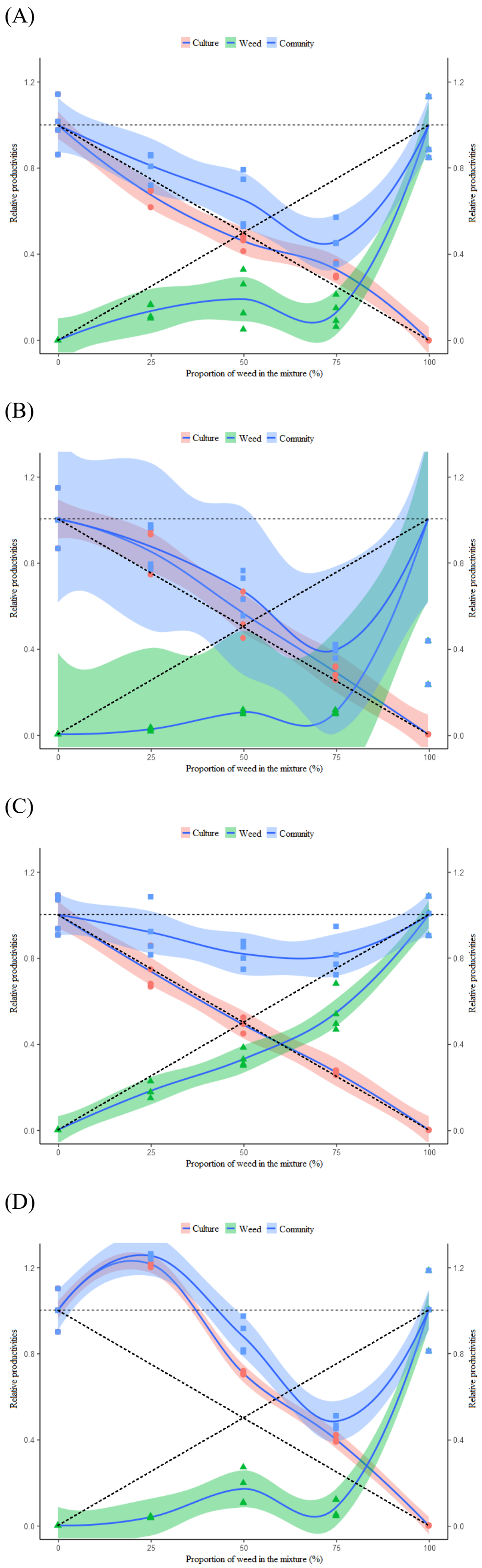


Figure 2. Relative productivity (PR) for aboveground dry mass of maize (●) and wild poinsettia (▲) plants, and total relative productivity (PRT) for the community (■) as a function of proportio of the weed in the mixture. Maize cultivars: conventional (A), 13K288 PWE (Enlist®) (B), Pioneer 30F53 (VYHR®), (C) and 2B433 (Enlist®) (D).

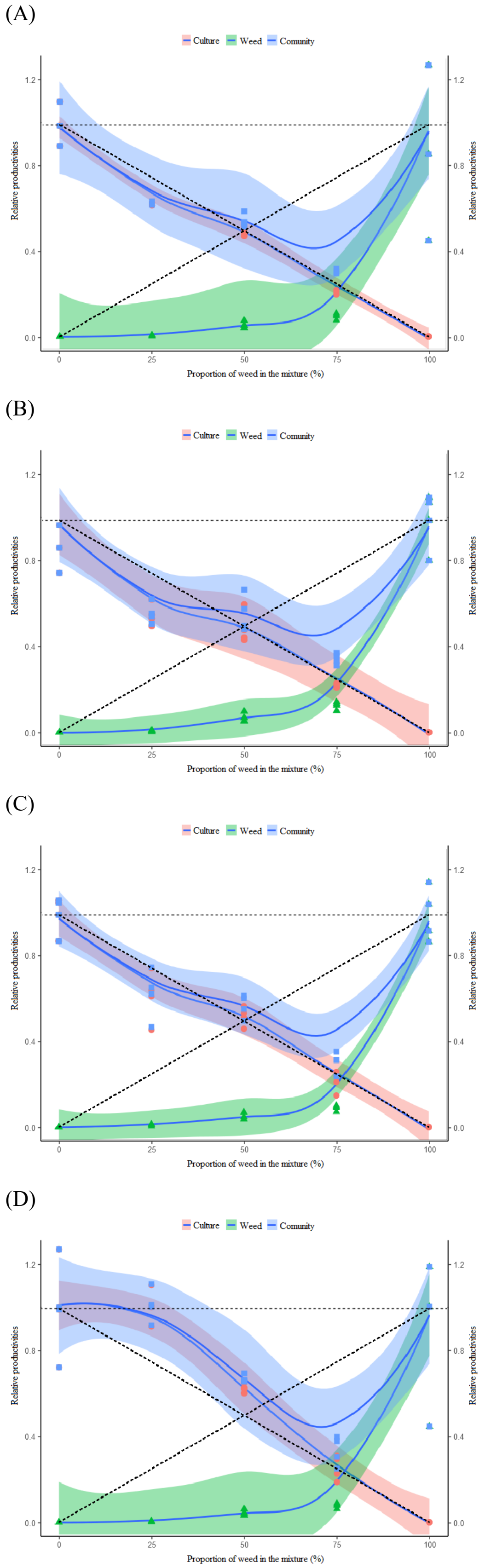
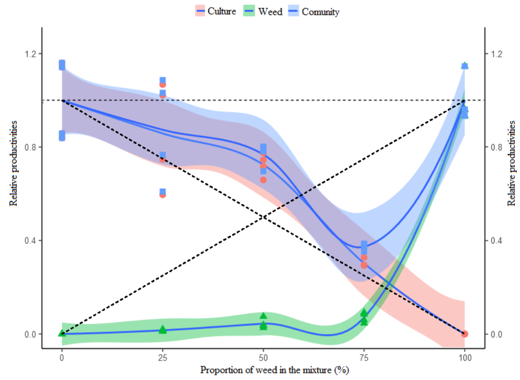
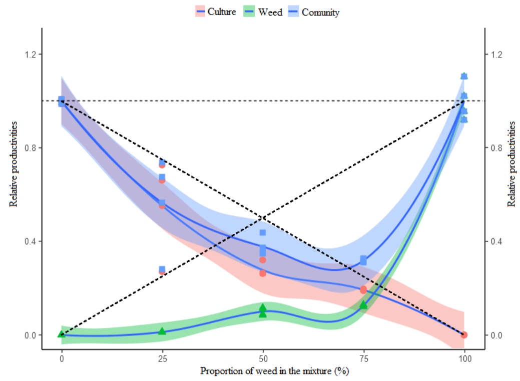


Figure 3. Relative productivity (PR) for leaf area of maize (●) and Alexandergrass (▲) plants, and total relative productivity (PRT) for the community (■) as a function of proportio of the weed in the mixture. Maize cultivars: conventional (A), 13K288 PWE (Enlist®) (B), Pioneer 30F53 (VYHR®), (C) and 2B433 (Enlist®) (D).

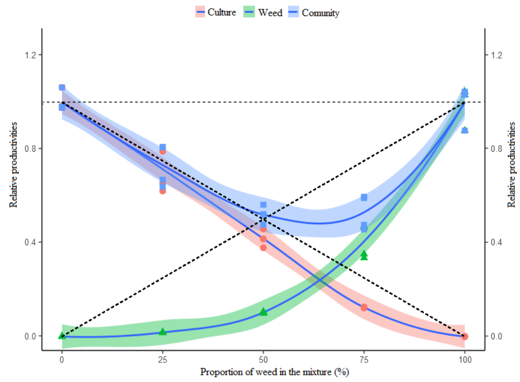
(A)



(B)



(C)



(D)

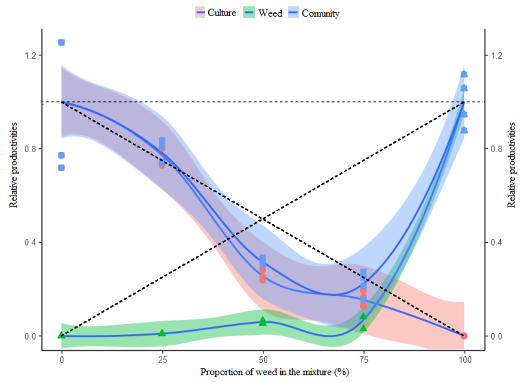


Figure 4. Relative productivity (PR) aboveground dry mass of maize (●) and Alexandergrass (▲) plants, and total relative productivity (PRT) for the community (■) as a function of proportio of the weed in the mixture. Maize cultivars: conventional (A), 13K288 PWE (Enlist®) (B), Pioneer 30F53 (VYHR®), (C) and 2B433 (Enlist®) (D).

The PRT obtained for all maize cultivars in competition with wild poinsettia was represented by concave lines below 1, indicating that the competition was harmful for both species (Figure 2). This weed's high degree of interference with crops is more related to the density and distribution with which it occurs in crops than to their individual ability to compete with crops (TANVEER et al., 2015), corroborating the results of the present study. Wandscheer, Rizzardi, and Reichert (2013) reported that interspecific competition was more important than intraspecific competition in a study of maize competition with crabgrass (*Eleusine indica*) considering maize aboveground dry mass.

Aboveground mass is important, as the higher the DM, the greater the competitive ability of the weed (GALON et al., 2018). The PR of the conventional variety indicated it as more competitive than Alexandergrass, mainly in the 50:50 ratio (Figure 3). Hybrids 13K288 PWE (Enlist®), 30F53 (VYHR®), and 2B433 (Enlist®), in general, presented a concave PR, indicating that they could be less competitive than the conventional variety under certain conditions, in competition with Alexandergrass (Figure 4). Maize plants in competition with goosegrass (WANDSCHEER; RIZZARDI; REICHERT, 2013) and beggarticks (GALON et al., 2023) showed a decrease in aboveground dry mass as weed density increased.

The PRT obtained was below 1, represented by the concave blue line, for all cultivars, indicating that there was damage to the plants involved, affecting growth and development (Figure 4). The results verified in the present research, with differences in the competitive ability between maize cultivars, corroborate those obtained by Bianchi, Fleck and Lamego (2006) and Galon et al. (2023). The greater relative growth of Alexandergrass compared to maize may be related to the fact that although both belong to the same family (Poaceae), weeds are usually more aggressive than crops (FREITAS et al., 2020).

Morphological parameters

The results showed that as the proportion of the competitor (either wild poinsettia or alexandergrass) increased, maize was forced to respond by increasing its leaf area while trying to overcome the competition. This behavior, however, occurred at the cost of reduction in most of the other morphological parameters (Table 2). However, weeds were most affected under greater interspecific competition. Galon et al. (2023) reported results similar to those found in the present study when evaluating the competitive ability of maize hybrids in competition with the *Bidens pilosa*.

Table 2. Morphological variables of maize (*Zea mays*) genotypes submitted to competition with wild poinsettia (*Euphorbia heterophylla*) or Alexandergrass (*Urochloa plantaginea*), in terms of morphological parameters in substitutive series experiments assessed 50 dias after emergence.

Crop:weed	Morphological variables							
	LA		DW		LA		DW	
	Maize	Wild poinsettia	Maize	Wild poinsettia	Maize	Alexandergrass	Maize	Alexandergrass
Conventional								
100:0 (T)	3411.13	885.28	233.64	18.79	4311.37	633.74	182.45	98.30
75:25	3874.18	234.81*	194.95*	2.20*	3888.38	108.96*	208.76	9.25*
50:50	5655.24*	98.77*	230.52	1.43*	3978.08	242.52*	264.27*	8.67*
25:75	7962.69*	28.02*	200.17*	0.39*	5672.06*	343.81*	220.91	6.21*
C.V (%)	11.29	24.94	5.22	32.58	11.20	36.00	17.10	20.10
13K288 PWE (Enlist®)								
100:0 (T)	2670.53	1884.92	166.92	12.19	4416.99	1912.04	216.88	153.51
75:25	3093.19	242.00*	142.60	2.06*	5000.88	260.72*	159.79*	25.59*
50:50	5942.09*	98.77*	189.74	1.68*	4973.82	392.63*	120.38*	30.75*
25:75	6266.93*	28.02*	173.06	0.39*	5102.68	177.53*	167.08	7.71*
C.V (%)	13.84	50.90	11.29	21.42	15.10	121.70	20.10	13.90
Pioneer 30F53 (VYHR®)								
100:0 (T)	4520.22	1472.745	212.73	17.08	5271.05	377.87	227.86	153.76
75:25	7296.44	234.81*	182.28*	2.06*	5178.91	274.25*	217.02	83.24*
50:50	5215.79	98.77*	221.39	1.68*	5156.80	248.49*	190.35*	31.64*
25:75	9870.11*	40.36*	195.31	0.87*	5654.14	274.16*	113.31*	10.63*
C.V (%)	34.47	28.27	6.06	20.62	9.30	15.20	9.70	15.50
2B433 (Enlist®)								
100:0 (T)	2887.42	1519.89	129.28	23.30	3902.94	696.50*	247.60	136.52
75:25	4848.85*	110.75*	159.69*	2.06*	6320.61*	78.20*	255.13	12.53*
50:50	3835.75*	110.50*	148.70	1.68*	5520.82*	237.05*	126.82*	16.27*
25:75	7770.17*	104.38*	131.95	0.39*	6238.78*	107.65*	152.80*	5.37*
C.V (%)	6.67	86.40	9.37	20.60	4.10	31.80	23.30	20.50

*Means differ from the control (T) by Dunnett's ($p \leq 0.05$); LA = Leaf area (cm^{-2} $vaso^{-1}$) e DW= Dry weight (g pot^{-1}).

Significant differences were report to the LA of maize in competition to the wild poinsettia. Maize 30F53 (VYHR®) showed the highest LA values, proving to be a potential competitor against wild poinsettia compared to the other cultivars. It can be inferred that the degree of competition between maize and the weed is influenced by the LA, that is, the more LA assigned to the crop, the more competitive it tends to be. Weed control in situations of increased crop density is generally attributed to crop shading over weeds (MHLANGA; CHAUHAN; THIERFELDER, 2016), and this is directly related to the greater LA found in maize.

DW was reduced in conventional maize and 30F53 (VYHR®) when intraspecific competition was higher with wild poinsettia. Therefore, intraspecific competition was more harmful than interspecific competition. The aboveground dry weight of sweet sorghum did not differ when subjected to increasing periods of weed control or no weed control (GIANCOTTI et al., 2017). This sweet sorghum hybrid showed high tolerance to weeds, even in a situation of density disadvantage (GIANCOTTI et al., 2019), showing that a crop morphophysiologically similar to maize showed results similar to those found in the present study.

The results observed for Alexandergrass were similar to those for wild poinsettia, with the most harmful intraspecific competition for maize. The AL of conventional maize and 2B433 (Enlist®) in competition with Alexandergrass was reduced at a 25:75 ratio. DW showed an increase in the 50:50 ratio for conventional maize. However, for the other genotypes, there were reductions for this variable in this proportion. Maize DW was reduced when it was in different periods of competition with Alexandergrass, and with weed control, avoiding competition, DW increased (GALON et al., 2018). Therefore, the negative effects of intraspecific competition outweighed the greater presence of weeds.

Competitiveness indices

Maize hybrids were more competitive than weeds when considering the coefficients threshold defined by Bianchi, Fleck and Lamego (2006) and Agostinetto et al. (2013): CR > 1, Kx > Ky, and AG > 0. In addition, significant differences in at least two competitive indices is required to demonstrate competitive superiority (BIANCHI; FLECK; LAMEGO, 2006). The competitiveness indices indicate the greater competitive ability of maize compared to Alexandergrass, due to CR being greater than 1 for leaf area and aboveground dry mass (Table 3).

Table 3. Competitiveness indexes between maize (*Zea mays*) cultivars, under competition with either Alexandergrass (*Urochloa plantaginea*) or wild poinsettia (*Euphorbia heterophylla*) at equal proportions (50:50) in replacement series experiments, 50 days after emergence.

Variety x Weed[1]	CR[2]	K_{maize}[3] (maize)	K_{weed}	AG[4]
		Leaf area		
Conventional x Alex.	3.992 ± 1.842*	0.861 ± 0.054*	0.260 ± 0.099	0.270±0.061*
Enlist 13K288 x Alex.	5.567 ± 0.697*	1.383 ± 0.273*	0.115 ± 0.006	0.460±0.054*
30F53 VYHR x Alex.	1.498 ± 0.075*	0.963 ± 0.058*	0.494 ± 0.044	0.160±0.020*
Enlist 2B433 x Alex.	4.875 ± 1.039*	2.418 ± 0.045*	0.214 ±0.061	0.537 ± 0.04*
		Aboveground dry mass		
Conventional x Alex.	19.002 ± 3.956*	2.711 ± 0.319*	0.047 ± 0.012	0.680±0.029*
Enlist 13K288 x Alex.	2.802 ± 0.163*	0.386 ± 0.029*	0.112 ± 0.010	0.177±0.011*
30F53 VYHR x Alex.	4.058 ± 0.130*	0.721 ± 0.049*	0.115 ± 0.002	0.315±0.015*
Enlist 2B433 x Alex.	4.360 ± 0.365*	0.345 ± 0.016*	0.063 ± 0.004	0.197±0.011*
		Leaf area		
Conventional x W. Poin.	14.117 ±1.615*	4.098 ±0.939*	0.059 ±0.003	0.717 ±0.06*
Enlist 13K288 x W. Poin.	38.96 ±4.471*	0.897±0.468	0.027±0.002	0.988±0.103*
30F53 VYHR x W. Poin.	22.275±3.874*	0.914±1.576	0.039±0.002	0.81±0.195*
Enlist 2B433 x W. Poin.	16.882 ±1.76*	3.428±1.413	0.045±0.001	0.676±0.06*
		Aboveground dry mass		
Conventional x W. Poin.	9.89±1.198 *	0.975±0.034 *	0.056±0.009	0.441±0.004*
Enlist 13K288 x W. Poin.	7.519±0.884 *	1.009±0.174 *	0.074±0.012	0.424±0.037*
30F53 VYHR x W. Poin.	11.193±1.244 *	1.106±0.096 *	0.052±0.008	0.473±0.19*
Enlist 2B433 x W. Poin.	15.703±2.125 *	1.619±0.075 *	0.045±0.007	0.585±0.015*

[1] Assessment of the indicated parameter at the defined variable at density 50 : 50, compared to the respective controls by Dunnett's ($p \leq 0.05$); [2] Significant when differed from "1" by the t-test; [3] difference between K_{crop} and K_{weed}, at the same competitive level (50 : 50), compared by the t-test with Welch criteria; [4] Significant when it difered from "0" by the t-test. * significant difference ($p \leq 0.05$). Conventional: maize variety; Alex. = Alexandergrass (*Urochloa plantaginea*); W. Point = wild poinsettia (*Euphorbia heterophylla*).

The clustering coefficients (K) indicate the relative dominance of maize over Alexandergrass ($K_{crop} > K_{weed}$). The positive aggressiveness coefficient (AG) indicates that maize was more competitive for the conventional cultivar and hybrids 13K288 PWE (Enlist®) and 30F53 (VYHR®) (Table 3). The greater competitive ability of maize compared to Alexandergrass was also observed by Frandoloso et al. (2019). However, Galon et al. (2018) reported sweet sorghum to be less competitive than Alexandergrass. This result may be related to the fact that plants with greater growth capacity generally have greater competitive abilities due to their greater resource use efficiency (RAHMANI; ALIABDI, 2022). This crop may also have a greater competitive ability than the weed in individual terms, as the weed may build greater competitiveness due to its plant density (AGOSTINETTO et al., 2013; FRANDOLOSO et al., 2019).

Maize also showed greater competitiveness in DM when competed with wild poinsettia for all cultivars, as indicated by CR > 1, $K_{crop} > K_{weed}$, and AG > 0. For AF, hybrid 13K288 PWE (Enlist®) presented $K_{crop} < K_{weed}$ but CR > 1 and A > 0 (Table 3). Maize in competition with Alessandergrass (FRANDOLOSO et al., 2019) and black beggarticks (GALON et al., 2023) was less competitive than the weed for leaf area and DM, with CR> 1, $K_{crop} > K_{weed}$, and AG > 0. The same authors reported that the probable causes of this are the cultivar characteristics, such as a certain growth habit, early cycle, short plants, and lower leaf area index, among other aspects. Wild poinsettia can also exert allelopathic effects on maize and other crops, such as wheat and peas, reducing growth, delaying germination, and decreasing chlorophyll content (TANVEER et al., 2015).

Interspecific competition is generally less harmful to plants than intraspecific competition (YUAN; LI; VAN KLEUNEN, 2022). The same results were found by several authors in similar studies, with different species of agronomic interest in competition with weeds (AGOSTINETTO et al., 2013; GALON et al., 2018; FREITAS et al., 2021). In addition, there are several reports in the literature demonstrating that the competitive ability is different according to the cultivar, for crops such as soybean, rice and maize, when competing against weed species (AGOSTINETTO et al., 2013; GALON et al., 2018; PAZZINI et al., 2022).

In a competitive environment, according to the plant density, maize tends to become more effective in gas exchange, maximizing the use of available resources (ZHANG et al., 2022). The hybrid that showed the greatest effectiveness in the use of available resources was 2B433 (Enlist®). The physiological characteristics that contributed to the greater relative growth of this maize cultivar under competition with wild poinsettia were photosynthetic rate and carboxylation efficiency, which directly contributed to the increase in leaf area and aboveground dry mass. This effect is linked to its efficient metabolism in the assimilation of CO_2 (C4 carbon metabolism), which makes maize one of the most efficient plants in energy storage in nature (FREITAS et al., 2021; ZHANG et al., 2024).

In summary, when maize competed with Alexandergrass, the results for physiological parameters showed that hybrid 30F53 (VYHR®) was more effective, as it presented a higher A and EC. However, under competition with wild poinsettia, hybrid 2B433 (Enlist®) was metabolically superior in biomass conversion. This study showed morphological and physiological data supporting the hypothesis that hybrid maize is more competitive than conventional varieties against weeds. This information is beneficial for producers to increase the effectiveness of integrated weed management and to maintain and reduce costs with weed control by opting for more competitive maize hybrids.

CONCLUSIONS

Maize hybrid 2B433 (Enlist®) showed better physiological and morphological performance in relation to the conventional variety, and hybrids 13K288 PWE (Enlist®) and 30F53 (VYHR®) had better performance when competing with wild poinsettia or Alexandergrass. The increased competitive ability seems to be due to the greater leaf area and aboveground dry mass reported for 2B433 (Enlist®). Therefore, the competitive ability presented by the hybrids was distinct, and we found no evidence that the transgenic event present in these hybrids affected their competitive ability.

ACKNOWLEDGEMENTS

To CNPq, FAPERGS, UFFS and FINEP, for the financial support for this research and for the Scientific Initiation and Postgraduate grants.

REFERENCES

AGOSTINETTO, D. Habilidade competitiva relativa de milhã em convivência com arroz irrigado e soja. **Pesquisa Agropecuária Brasileira**, 48: 1315-1322, 2013.

BARROS, R. E. et al. Physiological response of maize and weeds in coexistence, **Planta Daninha**, 35: e017158134, 2017.

BERTOLINO, L. T.; CAINE, R. S.; GRAY, J. E. Impact of stomatal density and morphology on water-use efficiency in a changing world. **Frontier in Plant Science**, 225: 1-11, 2019.

BIANCHI, M.A.; FLECK, N.G.; LAMEGO, F.P. Proporção entre plantas de soja e plantas competidoras e as relações de interferência mútua. **Ciência Rural**, 36: 1380-1387, 2006.

COUSENS, R. Aspects of the design and interpretation of competition (interference) experiments. **Weed Technology**, 5: 664-673, 1991.

COUSENS, R.; O'NEILL, M. Density dependence of replacement series experiments. **Oikos**, 66: 347-352, 1993.

ETHRIDGE, S. R. et al. Crop physiological considerations for combining variable-density planting to optimize seed costs and weed suppression. **Weed Science**, 70: 687-697, 2022.

FRANDOLOSO, F. et al. Competition of maize hybrids with alexandergrass (*'Urochloa plantaginea'*). **Australian Journal of Crop Science**, 13: 1447-1455, 2019.

FREITAS, D. M. et al. Gaseous exchanges of maize and weeds under competition and water regimes. **Revista Brasileira de Engenharia Agrícola e Ambiental**, 24: 465-473, 2020.

FREITAS, M. A. M. et al. Physiological characteristics of corn intercropped with different arrangements of palisade grass plants. **Advances in Weed Science**, 39: e021230847, 2021.

GALON, L. et al. Interference Periods of weeds infesting maize crop. **Journal of Agricultural Science**, 10: 197-205, 2018.

GALON, L. et al. Morphological responses of maize hybrids under competition with hairy beggarticks, **Revista Caatinga**, 36: 41-52, 2023.

GIANCOTTI, P. R. F. et al. Weed community interference and phytosociological studies in a sweet sorghum crop. **Planta Daninha**, 35: e017154150, 2017.

GIANCOTTI, P. R. F. et al. Interspecific competition between sweet *Sorghum* and weeds. **Planta Daninha**, 37: e019209325, 2019.

HAWORTH, M. et al. Integrating stomatal physiology and morphology: evolution of stomatal control and development of future crops. **Oecologia**, 197: 867-883, 2021.

HEAP, I. **International survey of herbicide resistant weeds**. Disponível em: http://weedscience.org. Acesso em: 17 mai. 2024.

ISAAA - International Service for the Acquisition of Agri-biotech Applications. **GM Crop Events approved in Brazil**. 2024. Disponível em: https://www.isaaa.org/gmapprovaldatabase/approvedeventsin/default.asp?CountryID=BR. Acesso em: 10 jul. 2024.

LIU, D. et al. Overexpression of an agave phosphoenolpyruvate carboxylase improves plant growth and stress tolerance. **Cells**, 10: 1-20, 2021.

MACIEL, L. M., TUNES, L. V. M. A importância do controle de qualidade nas sementes de milho. **Brazilian Journal of Development**, 7: 49934-49938, 2021.

MHLANGA, B.; CHAUHAN, B. S.; THIERFELDER, C. Weed management in maize using crop competition: A review. **Crop protection**, 88: 28-36, 2016.

PAZZINI, E. P. et al. Competitive ability of soybean cultivars with Ipomoea indivisa. **Revista de Ciencias Agroveterinarias**, 21: 216-228, 2022.

RAHMANI, A. M.; ALIABDI, I. Plant competition optimization: A novel metaheuristic algorithm. **Expert Systems**, 39: e12956, 2022.

RAYMOND, B., WRIGHT, D. J.; BONSALL, M. B. Effects of host plant and genetic background on the fitness costs of resistance to *Bacillus thuringiensis*. **Heredity**, 106: 281-288, 2011.

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

TANVEER, A. et al. Yield losses in chickpea with varying densities of dragon spurge (*Euphorbia dracunculoides*). **Weed Science**, 63: 522-528, 2015.

WANDSCHEER, A. C. D.; RIZZARDI, M.A.; REICHERT, M. Competitive ability of maize in coexistence with goosegrass. **Planta Daninha**, 31: 281-289, 2013.

WESTWOOD, J.H. et al. Weed management in 2050: Perspectives on the future of weed science. **Weed Science**, 66: 275-285, 2018.

YUAN, L.; LI, J.; VAN KLEUNEN, M. Competition induces negative conspecific allelopathic effects on seedling recruitment. **Annals of Botany**, 130: 917-926, 2022.

ZHANG, G. et al. Optimizing planting density to increase maize yield and water use efficiency and economic return in the arid region of northwest China. **Agriculture**, 12: 1322, 2022.

ZHANG, Q. et al. Regulatory NADH dehydrogenase-like complex optimizes C4 photosynthetic carbon flow and cellular redox in maize. **New Phytologist**, 241: 82-101, 2024.