International Journal of Maize & Sorghum
Formerly Revista Brasileira de Milho e Sorgo
Portal de Periódicos da Embrapa
ISSN 3086-5433

COMPETITIVE ABILITY OF SWEET SORGHUM CULTIVARS AGAINST ARROWLEAF SIDA

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ABSTRACT – Weeds infesting the sweet sorghum crop would compete for environmental resources, such as water, sunlight, and nutrients, thereby reducing the crop's productivity. The objective of this work was to evaluate the competitive ability of sweet sorghum (*Sorghum bicolor*) cultivars with the weed arrowleaf sida (*Sida rhombifolia*). The experiments were carried out in a completely randomized design, with four replications. Treatments were arranged in replacement series in proportions of 100:0, 75:25, 50:50, 25:75, and 0:100%, which were equivalent to 20:0, 15:5, 10:10, 5:15, and 0:20 plants per pot of sweet sorghum (cultivars BRS 506, BRS 509, and BRS 511), respectively. The morphophysiological variables of sweet sorghum and arrowleaf sida were determined 50 days after plant emergence. The competitive performance was analyzed using a graphical method that involved constructing diagrams based on relative productivity. The relative indices of competitiveness, clustering, and aggressiveness were also determined. Stem height and diameter were increased for all proportions in the three sweet sorghum cultivars, while leaf area and aboveground dry mass were reduced. The physiological variables were higher or close to the expected for BRS 509 and BRS 511. The competitiveness indices show that the cultivars BRS 506 and BRS 509 were more competitive than arrowleaf sida. In general, cultivars differed in their strategies for dealing with weed competition, with BRS 509 superior overall. However, further field studies are necessary to confirm the superiority of a given cultivar.

Keywords: *Sorghum bicolor, Sida rhombifolia*, weed, plant interaction.

The increase in global demand for petroleum-derived fuels and growing environmental concerns related to greenhouse gas emissions, global warming, global climate change, and other factors have directed international focus towards the production of sustainable, environmentally friendly fuels from renewable sources, such as energy crops (Appiah-Nkansah et al., 2019). Sweet sorghum has received great attention and been the subject of study over the years due to its ability to produce grains, sugar juice, and lignocellulosic biomass simultaneously.

Sweet sorghum is a viable alternative for ethanol production during the sugarcane off-season, especially in areas where sugarcane fields are being renewed or where sugarcane planting is not suitable due to climatic limitations. However, it is crucial to gather information on the cultural practices necessary for sweet sorghum cultivation to gain prominence and become economically competitive in the Brazilian biofuel scenario. Weed control is an essential component of sweet sorghum management due to the scarcity of selective herbicides registered for the crop and its slow initial growth (Silva et al., 2014; Galon et al., 2018).

Weeds can invade cultivated areas and become a significant obstacle to successful crop establishment during the initial stages of sorghum development (Bonin et al., 2018). Recent studies have shown that weed interference during the early growth stages can result in significant yield losses. Once a dense canopy is established, however, weeds are controlled and no longer pose a problem (Silva et al., 2014; Bastiani et al., 2016). In Eastern Europe, competition with broad-leaved weeds and grasses such as *Chenopodium album*, *Amaranthus retroflexus, Echinochloa crus-galli*, and *Setaria glauca* resulted in ~41% reduction in sweet sorghum biomass production (Chernelivska & Dziubenko, 2020).

However, it is important to note that weed interference levels can vary with several factors, including the traits of invasive species such as aggressiveness and competitive ability. Weed density and distribution, crop cultivar, row distance, and seeding density also play significant roles in infestation severity (Agostinetto et al., 2013, 2018; Bastiani et al., 2016; Giancotti et al., 2019).

Therefore, knowledge of sweet sorghum's capacity for interspecific competition and biomass accumulation under weed competition is crucial for adopting the most suitable weed management practices. Furthermore, sweet sorghum cultivars/lines vary in their morphological traits, growth and development rates, depending on the objective of their breeding program (Giancotti et al., 2019). Therefore, studies investigating the competitiveness of different sorghum cultivars against weeds are needed.

Cultivars with higher growth rate, leaf area, plant height, biomass production, and canopy development tend to demonstrate superior competitive ability against weeds (Bastiani et al., 2016; Galon et al., 2018, 2022). Furthermore, greater crop competitiveness may be associated with enhanced resource capture, more efficient use of environmental resources, and earlier emergence (Agostinetto et al., 2013, 2018). However, despite the recognized importance of weeds as competitors in agricultural systems, no studies have yet quantified their interference in sweet sorghum..

Experiments carried out in replacement series are widely recognized as one of the most used to compare the competitive ability of plant species (Bianchi et al., 2006; Bastiani et al., 2016; Yang et al., 2024) as they allow evaluating the effect of plant density and the proportion between species in the competitive outcome (Yang et al., 2024). Therefore, this study investigates the hypothesis that sweet sorghum cultivars have greater competitive ability than arrowleaf sida when they occur in equal proportions. Therefore, this study aimed to compare the competitive ability of sweet sorghum cultivars with arrowleaf sida.

Material and Methods

The experiments were installed in a greenhouse at the Federal University of Fronteira Sul (UFFS), Campus Erechim/RS.. The species were sown in plastic pots filled with 8 dm^{-3} of soil, classified as Red Oxisol Humic aluminoferric (Santos et al., 2018), and prior to sowing, fertility correction was carried out by following the technical recommendations for sorghum cultivation (Manual […], 2016). Chemical and physical soil characteristics were: pH_{water} = 4.8; OM = 3.5%; P = 4.0 mg dm^{-3}; K = 117.0 mg dm^{-3} Al^{3+} = 0.6 $cmol_c$ dm^{-3}; Ca^{2+} = 4.7 $cmol_c$ dm^{-3}; Mg^{2+} = 1.8 $cmol_c$ dm^{-3}; $CTC_{(t)}$ = 7.4 $cmol_c$ dm^{-3} $CTC_{(t\_pH=7)}$ = 16.5 $cmol_c$ dm^{-3}; H+Al = 9.7 $cmol_c$ dm^{-3}; SB = 6.8 $cmol_c$ dm^{-3}; V = 41 %; and clay = 60 %.

A completely randomized design was used for all experiments, with four replications. The species tested were the sweet sorghum cultivars BRS 506, BRS 509, and BRS 511, which competed with biotypes of arrowleaf sida (*Sida rhombifolia*). Preliminary experiments in additive series (monocultures) were conducted for the two species to identify the plant density at which biomass accumulation became constant and independent of further increases in density.

To achieve the proposed objectives, 1, 2, 4, 8, 16, 24, 32, 40, 48, 56, and 64 plants per pot were seeded, equivalent to 25, 49, 98, 196, 392, 587, 784, 980, 1,176, 1,372, and 1,568 plants m^{-2}. Fifty days after the emergence, the aboveground mass of sweet sorghum and arrowleaf sida was collected, packed, and placed in an oven with forced-air circulation at ~72 °C to determine aboveground dry mass (DM). A logistic regression was fit to each data set, and the inflexion point at which dry mass accumulation becomes independent of further increases in density was determined to be 20 plants per pot for all sweet sorghum cultivars and the weed, corresponding to 465 plants m^{-2} (data not shown).

To test the competitive ability of sorghum cultivars (BRS 506, BRS 509, and BRS 511) against arrowleaf sida, four experiments were carried out in replacement series, by alternating plant proportion of crop and weed while keeping the total density constant: 20:0; 15:5; 10:10; 5:15; and 0:20 plants per pot (crop: weed). Seeds were sown in plastic trays, and 5 days after emergence, the plants were transplanted into the final experimental units (plastic pots), thereby ensuring uniform plant spacing for each treatment.

The physiological variables were assessed in healthy, fully expanded leaves 48 days after emergence: photosynthesis rate (*A* $\mu mol_{CO2}\ m^2 s^1$), stomatal conductance (GS mol m^{-2} s^{-1}), transpiration rate (*E* mol_{H2O} m^{-2} s^{-1}), and internal CO_2 concentration (Ci µmol mol^{-1}). Carboxilation efficiency (*EC* mol_{CO2} m^{-2} s^{-1}) and water use efficiency (*WUE* $mol_{CO2}\ mol_{H2O}^{-1}$) were calculated from the $^{A}/_{Ci}$ and $^{A}/_{E}$ ratios, respectively. The measurements were performed using an infrared gas analyzer (IRGA), LCA Pro (Analytical Development Co. Ltd., Hoddesdon, UK), operating at a CO2 concentration of 400 ppm under natural light conditions.

Determination of plant height (PH), stem diameter (SD), leaf area (LA), and dry mass (DM) of sweet sorghum and arrowleaf sida was carried out 50 days after emergence, as it was the phase when both the crop and the weed were entering the reproductive stage. PH was measured with a graduated ruler from the soil level to the apex of the last fully developed leaf. SD was measured with a digital caliper at 5 cm above the soil. To quantify LA, a portable leaf area meter (BioScience, CI203) was used to measure all plants and all leaves in each experimental unit. After determining the LA, plants were placed in kraft paper bags and dried in an oven with forced-air circulation at 60 ± 5 ºC, until the material reached a constant mass to determine the DM of the species.

The data sets were analyzed by the graphical analysis of variation or relative productivity method (Bianchi et al., 2006; Cousens, 2017). This procedure, also known as the conventional method for replacement series experiments, consists of constructing a diagram based on the relative (PR) and total (PRT) productivities. When the PR result is a straight line, it means that the species' abilities are equivalent. If the PR results in a concave line, it indicates damage to the growth of one or both species. On the other hand, if the PR shows a convex line, there is a benefit in the growth of one or both species. When PRT equals 1 (straight line), competition for the same resources occurs; when PRT is greater than 1 (convex line), competition is avoided. If PRT is less than 1 (concave line), mutual damage to growth occurs (Rubin et al., 2014; Cousens, 2017).

The relative competitiveness (CR), relative clustering (K), and aggressiveness (A) coefficients were also calculated. CR represents the comparative growth of sweet sorghum cultivars (X) in relation to the competitor arrowleaf sida (Y); K indicates the relative dominance of one species over the other, and A indicates which species was the most aggressive. Thus, CR, K, and A jointly indicate which species is most competitive (Cousens, 2017). Sweet sorghum (X) cultivars were more competitive than arrowleaf sida (Y) when CR > 1, Kx > Ky, and A > 0; on the other hand, arrowleaf sida (Y) was more competitive than sweet sorghum cultivars (X) when CR < 1, Kx < Ky, and A < 0 (Hoffman & Buhler, 2002). To calculate these indices, the 50: 50 proportions were used, as follows: CR = $^{PRx}/_{PRy}$; Kx = $^{PRx}/_{(1-PRx)}$; Ky = $^{PRy}/_{(1-PRy)}$; A = Prx PRy, according to Cousens and O'Neill (1993).

The procedure for statistical analysis of productivity or relative variation included calculating differences in PR values (DPR) at the proportions 25, 50, and 75%, relative to the values along a hypothetical straight line at the same proportions (Bianchi et al., 2006). It was considered that there were differences between the treatments for PR and PRT, estimated and observed by comparing the respective standard errors of the means, adopting them as different values when the values contained in the estimated curve were not within the standard error range of the observed mean (Cumming et al., 2007; Galon et al., 2015). The "t" test was used to test the differences related to the competitiveness indices, CR, K, and A (Hoffman & Buhler, 2002). It was considered as a null hypothesis, to test the differences in A, that the means were equal to zero (Ho = 0); for CR, the means were equal to one (Ho = 1); and for K, that the average differences between Kx and Ky were equal to zero [Ho = (Kx Ky) = 0]. The criterion for considering differences in the competitiveness of the CR, K, and A was the presence of a significant difference in at least two of them (Bianchi et al., 2006).

The results for LA and DM, expressed as mean values per treatment, were analyzed by ANOVA using the F test and, if significant, the treatment means were compared using Dunnett's test, with monocultures as controls. In all statistical analyses, a significance of $p \leq 0.05$ was adopted.

Results and Discussion

Graphical analyses of competition between sweet sorghum cultivars and arrowleaf sida showed changes in physiological and morphological behavior as plant proportion changed. There were significant differences between the expected and estimated values in at least two proportions for PR in plant height (Figure 1 A, B, C) and stem diameter (Figure 1 D, E, F) of sorghum cultivars BRS 506, BRS 509, and BRS 511, when competing against arrowleaf sida.

The PR of sweet sorghum PH was very close to that expected for BRS 506 and BRS 511 (Figure 1A and 1C). The cultivar BRS 509 was not affected by competition, even with a higher weed proportion (25:75), presenting a height of 147.95 cm (Table 1). On the other hand, for this same cultivar, the highest intraspecific competition (75:25) negatively influenced PH.

The PRT of the community (Figure 1) was below 1, indicating damage to both the crop and the weed. PH plays a significant role in evaluating competitiveness, since taller plants demonstrate a greater competitive advantage in absorbing solar radiation than shorter plants (Lamego et al., 2013). It was observed that sweet sorghum was not harmed by the presence of the weed at most concentrations, possibly because its rapid growth is enabled by C4 carbon metabolism. On the other hand, arrowleaf sida had its growth strongly reduced in all proportions when competing with any sorghum cultivar (Table 1).

The PR of SD showed convex curves for all cultivars, above expectations across all crop: weed ratios (Figure 1D, E, and F). Higher

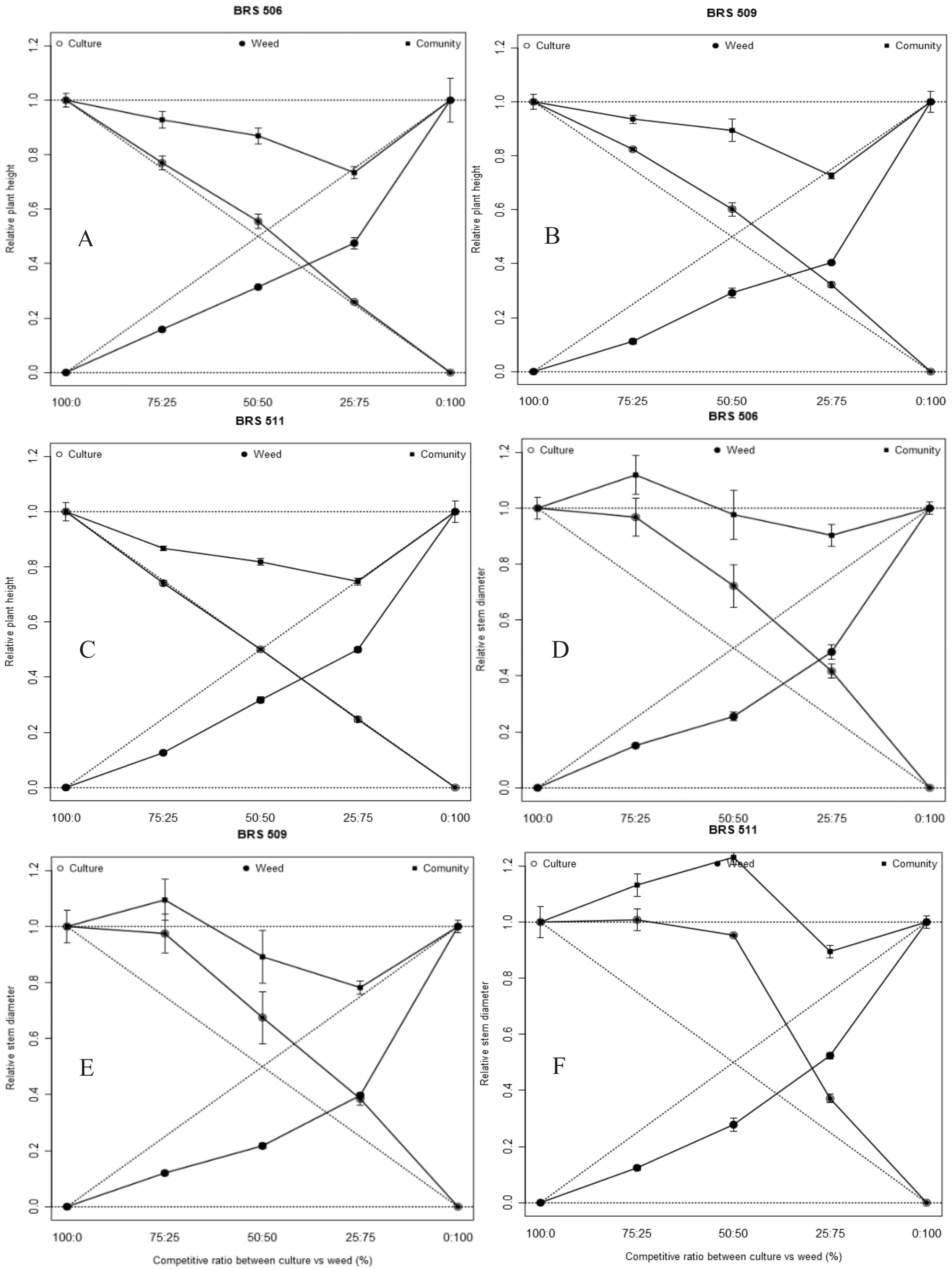

Figure 1. Relative productivity (PR) based on Plant height (A, B, C) and stem diameter (D, E, F) of sorghum cultivars and arrowleaf sida, and total relative productivity (PRT). Dashed lines indicate the expected relative productivity for each species and plant proportion. Solid lines represent the experimentally reported values. Standard errors are presented for the observed data points.

Table 1. Differences between plant proportions of sweet sorghum cultivars (BRS 506, BRS 509, and BRS 511) under competition against arrowleaf sida (*Sida rhombifolia*) aboveground morphological variables. UFFS, Erechim/RS.

Plant proportion Sorghum: Sida	**Relative variables**							
	Plant height (cm)		**Stem diameter (mm)**		**Leaf area (cm^2 pot^{-1})**		**Dry mass (g pot^{-1})**	
	BRS 506	Sida	BRS 506	Sida	BRS 506	Sida	BRS 506	Sida
0:100 ou 100:0 (T)	90.00	38.91	5.16	3.15	5546.09	1974.27	40.23	21.30
25:75 ou 75:25	92.44	24.66*	6.66*	2.04*	7357.57*	431.85*	17.14	6.22*
50:50 ou 50:50	99.98	24.41*	7.45*	1.61*	3095.87*	328.96*	22.647	2.56*
75:25 ou 25:75	93.11	24.55*	8.61*	1.90*	2937.57*	161.32	119.86*	2.19*
CV (%)	7.30	13.90	17.02	9.00	22.01	21.08	96.02	28.06
	BRS 509	Sida	BRS 509	Sida	BRS 509	Sida	BRS 509	Sida
0:100 ou 100:0 (T)	50.91	21.30	5.02	3.15	6588.86	1974.27	50.91	21.03
25:75 ou 75:25	16.78*	4.21*	6.53	1.67*	6957.13	452.35*	16.78*	4.21*
50:50 ou 50:50	71.33	3.83*	6.78	1.37*	4041.95*	247.08*	71.33	3.83*
75:25 ou 25:75	147.95*	1.30*	7.73*	1.51*	2794.62*	124.53*	147.95	1.03*
CV (%)	29.02	30.04	20.03	6.20	17.08	20.09	29.02	30.04
	BRS 511	Sida	BRS 511	Sida	BRS 511	Sida	BRS 511	Sida
0:100 ou 100:0 (T)	111.00	41.66	5.88	3.15	6806.05	1605.13	149.43	21.03
25:75 ou 75:25	109.66	27.77	7.90*	2.20*	7017.69	694.55*	38.56*	6.43*
50:50 ou 50:50	111.22	26.44	11.20*	1.75*	4767.05	386.07*	28.06*	3.85*
75:25 ou 25:75	109.66	21.07	8.73*	1.56*	3616.62*	166.05*	181.08	1.57*
CV (%)	6.00	7.06	7.60	10.40	25.05	26.03	47.00	27.09

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

values were reported for all cultivars, and, in general, the highest values were obtained in the 25: 75 ratio (Table 1). Community competition benefited both the crop and the weed equally in a 75:25 ratio, whereas in a 25:75 ratio, there was no benefit to either. This result shows that, for SD, intraspecific competition can be more harmful than interspecific competition for sorghum, which is supported by the community's PRT, which was below 1 at higher crop density. Corroborating these results, a study with four sweet sorghum hybrids reported that competition with *Cyperus rotundus*, *Brachiaria decumbens*, *Ipomoea hederifolia*, and *Digitaria nuda* did not reduce stalk diameter (Giancotti et al., 2019).

The PR of LA was reduced by interspecific competition for all cultivars, as a concave behavior was reported both for the crop and for the community, indicating there was harm to both competitors (Figure 2 A, B, C). Competition between sweet sorghum and Alexandergrass (*Urochloa plantaginea*) showed that the larger leaf area conferred greater competitive ability in the weed (Galon et al., 2018). In contrast, in the present study, both species were harmed by competition, resulting in a significant reduction in LA. However, the most pronounced and significant reductions in sorghum LA are observed when the weed predominates (25: 75) (Table 1). The PR of aboveground DM, as well as the LA, was reduced by interspecific competition (Figure 2D-F), particularly at higher crop density (75:25), when the estimated curve was below the expected line. In this same proportion, the greatest DM losses for the weed were also observed (Table 1). The community, represented by the coexistence of crop and weed (PRT), also suffered losses, as indicated by the concave lines and values below 1.

Conversely, studies on the competitive ability of sweet sorghum against hairy beggarticks (*Bidens pilosa*) showed a progressive reduction in aboveground DM as weed density increased (Galon et al., 2022). Other authors also noted that maize plants, which resemble sorghum, in competition with Alexandergrass and hairy beggarticks, showed a decrease in aboveground DM as weed density increased (Maciel et al., 2020). Cultivars with greater capacity to increase LA, PH, and DM have greater soil coverage and light interception by the canopy and, therefore, would perform better (Bastiani et al., 2016; Galon et al., 2022). In a competition study with soybean and Goosegrass (*Eleusine indica*), PRT decreased for soybean PH, LA, and DM, and competition hindered the growth of both species, indicating competition for the same resources (Franco et al., 2017).

It can be inferred that, in general, for PH and SD, there was no mutual decrease in species growth, due to the PR of arrowleaf sida being represented by concave lines, while the PR of sorghum by convex lines (Figure 1). This result indicates that a reduction in PRT is due to a lower contribution from the weed, resulting from the crop's increased competitiveness rather than mutual damage. Conversely, DM and LA caused mutual damage, as evidenced by the concave lines in both.

Figure 3 (A, B, and C) presents the results of

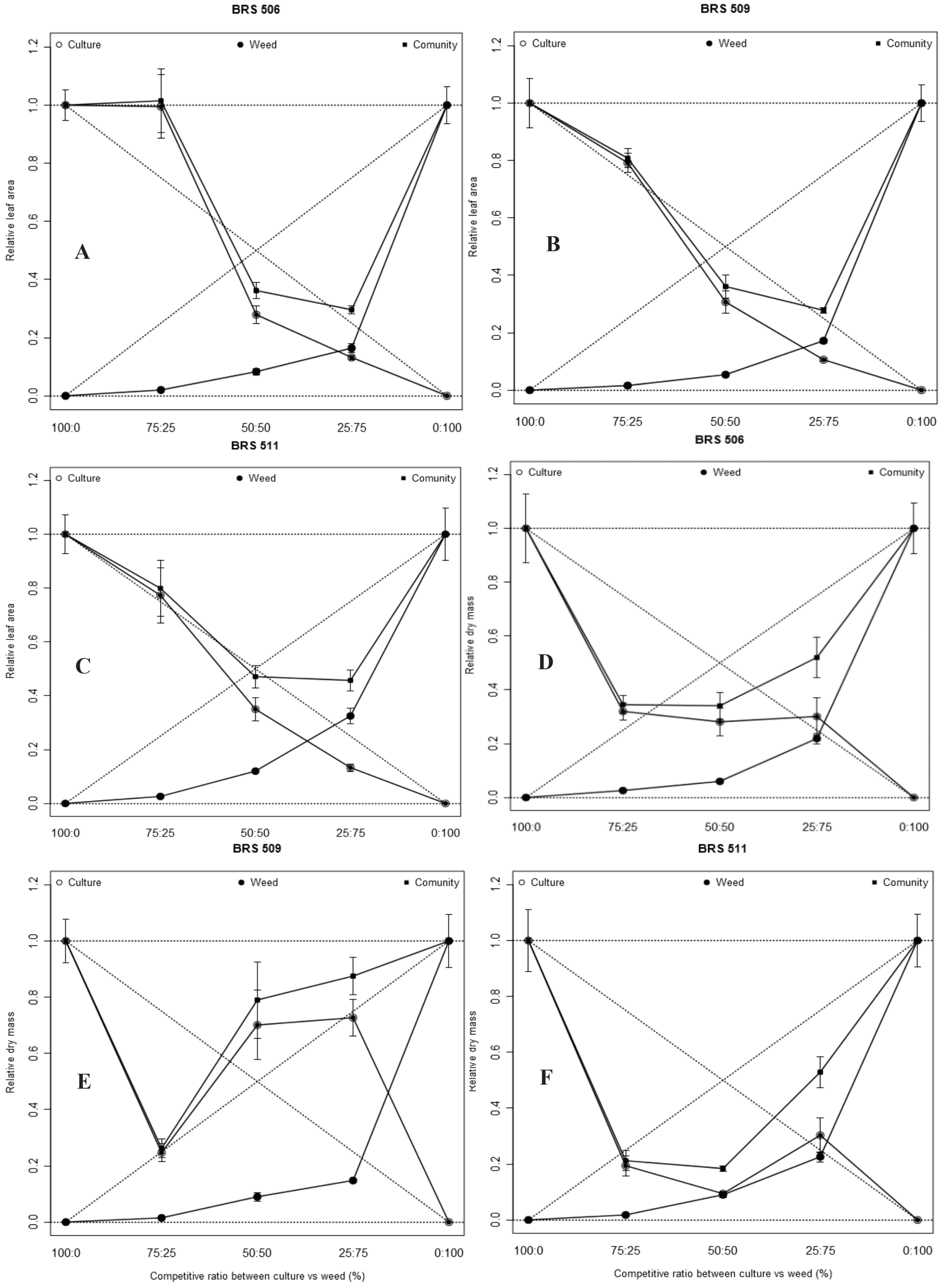

Figure 2. Relative productivity (PR) based on leaf area (A, B, C) and aboveground dry mass (D, E, F) of sorghum cultivars and arrowleaf sida, and total relative productivity (PRT). Dashed lines indicate the expected relative productivity for each species and plant proportion. Solid lines represent the experimentally reported values. Standard errors are presented for the observed data points.

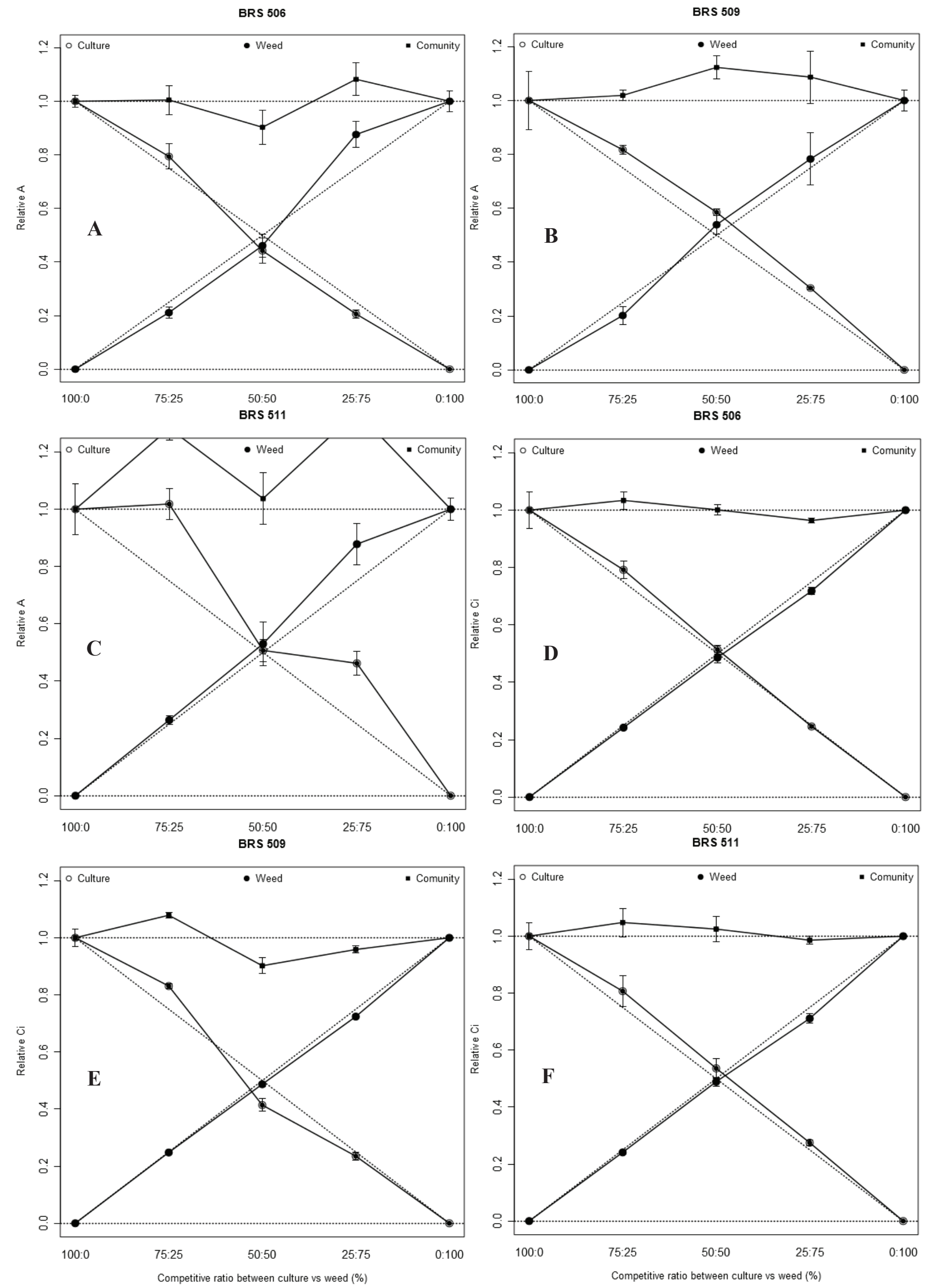

Figure 3. Relative productivity (PR) based on photosynthesis rate (A, B, C) and internal CO_2 concentration (D, E, F) of sorghum cultivars and arrowleaf sida, and total relative productivity (PRT). Dashed lines indicate the expected relative productivity for each species and plant proportion. Solid lines represent the experimentally reported values. Standard errors are presented for the observed data points.

Table 2. Differences between plant proportions of sweet sorghum cultivars (BRS 506, BRS 509, and BRS 511) under competition against arrowleaf sida (*Sida rhombifolia*) for physiological parameters associated with photosynthesis and transpiration. UFFS, Erechim/RS.

Plant proportion Sorghum: Arrowleaf sida	Relative variables					
	Photosynthesis rate		**Internal CO_2 concentration**		**Transpiration rate**	
	BRS 506	Sida	BRS 506	Sida	BRS 506	Sida
0:100 ou 100:0 (T)	3.67	3.11	248.00	386.00	1.45	2.42
25:75 ou 75:25	3.88	3.64	262.00	369.50	1.47	1.94*
50:50 ou 50:50	3.25	2.87	255,00	375.50	1.29	1.73*
75:25 ou 25:75	3.03	2.63	244.00	373.00	1.62	1.61*
CV (%)	15.70	15.90	9.30	4.70	18.10	14.00
	BRS 509	Sida	BRS 509	Sida	BRS 509	Sida
0:100 ou 100:0 (T)	3.90	3.11	242.25	386.00	1.11	2.42
25:75 ou 75:25	4.25	3.25	268.33	372.50	1.64*	2.48
50:50 ou 50:50	4.56	3.35	200.67*	376.25	1.41	2.42
75:25 ou 25:75	4.74*	2.51	227.75	383.33	1,24	2.00
CV (%)	11.50	22.90	9.20	2.60	19.50	38.00
	BRS 511	Sida	BRS 511	Sida	BRS 511	Sida
0:100 ou 100:0 (T)	3.63	3.11	224.75	386.00	1.29	2.42
25:75 ou 75:25	4.93	3.64	241.75	366.00	1.75*	2.12
50:50 ou 50:50	3.69	3.30	241.00	377.75	1.23	1.89
75:25 ou 25:75	6.71*	3.29	247.33	371.75	1.76*	1.96
CV (%)	18.40	20.30	12.50	5.20	13.40	17.00
Plant proportion	**Carboxilation efficiency**		**Stomatal conductance**		**Water use efficiency**	
Sorghum: Arrowleaf sida	BRS 506	Sida	BRS 506	Sida	BRS 506	Sida
0:100 ou 100:0 (T)	0.02	0.01	0.05	0.23	2.66	1.29
25:75 ou 75:25	0.01	0.01	0.05	0.13*	2.64	1.55
50:50 ou 50:50	0.01	0.01	0.05	0.15*	2.50	1.45
75:25 ou 25:75	0.01	0.01	0.04	0.12*	1.67*	1.51
CV (%)	20.70	18.60	22.70	10.90	20.80	22.70
	BRS 509	Sida	BRS 509	Sida	BRS 509	Sida
0:100 ou 100:0 (T)	0.02	0.1	0.04	0.23	3.53	1.31
25:75 ou 75:25	0.02	0.01	0.06*	0.19	2.60	1.40
50:50 ou 50:50	0.02*	0.01	0.05	0.13*	3.32	0.99
75:25 ou 25:75	0.02*	0.01	0.05	0.15*	3.94	1.31
CV (%)	14.30	21.10	14.90	17.70	21.00	17.60
	BRS 511	Sida	BRS 511	Sida	BRS 511	Sida
0:100 ou 100:0 (T)	0.02	0.01	0.04	0.23	2.85	1.29
25:75 ou 75:25	0.02	0.01	0.06*	0.15*	2.87	1.55
50:50 ou 50:50	0.02	0.01	0.04	0.15*	2.99	1.45
75:25 ou 25:75	0.03*	0.01	0.007*	0.16	3.79	1.30
CV (%)	24.30	22.90	16.40	25.20	17.70	24.50

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

the PR of photosynthesis rate (A). There was an increase in A of BRS 509 and BRS 511 in the proportion of 25: 75, represented by the convex curve. Meanwhile, BRS 506 was not affected, indicating that competition was avoided in this case. It can be inferred that intraspecific competition was more harmful than interspecific competition. This result is reported in Table 2, where only the 25: 75 ratio showed statistical significance due to the increase in A. The weed did not show a statistical difference when the crop: weed ratio was changed (Table 2). Different from what was observed, for maize, 45 days after planting, there was a reduction in photosynthetic rate in the presence of Alexandergrass and weedy sorghum (*Sorghum arundinaceum*). At the same time, for the weeds, reductions in photosynthesis and transpiration rates were observed due to increased density and interspecific competition with maize (Barros et al., 2017).

In contrast, the PR of internal CO2 concentration (CI) remained very close to what was expected for all sorghum cultivars, and in all plant proportions (Figure 3D, E, and F). Only for BRS 509 there was a significant reduction in CI for the 50:50 ratio, while for arrowleaf sida, the values were near the expected (Table 2).

The photosynthetic rate is influenced by the continuous flow of CO_2 and O_2 into and out of stomata. This movement is related to CI and O_2 dynamics in the intercellular spaces, which are dependent on stomatal opening. The signals that control the fluxes of CO_2 and water into the plant mesophyll are carefully coordinated, enabling plants to precisely adjust the demand for carbon and the need to regulate water loss (Bertolino et al., 2019). In this case, sorghum cultivars maintained CI and increased A in some of the plant proportions. Sorghum is a plant with C4 Carbon metabolism that uses PEP-carboxylase to fix atmospheric carbon more quickly, even at lower CO2 concentrations (Freitas et al., 2020), thereby providing the most efficient control of stomatal opening.

Figure 4 (A, B, and C) shows the results of transpiration rate (E) and stomatal conductance (Gs) (D, E, and F). The E for cultivar BRS 506 was close to expected, while BRS 509 and BRS 511 performed better for a 75:25 ratio (Table 2). The weed was harmed, especially when competing with BRS 506, as crop density increased (Table 2). The PR for E was similar to those reported for Gs for the three cultivars. BRS 506 remained close to expectations, and BRS 509 and BRS 511 had increased E under competition. These results are directly related to Gs, indicating that increased stomatal opening affected sorghum transpiration rates. Plants acquire the ability to regulate transpiration as an ecological advantage, and this benefit influences water use efficiency, optimizing gas exchange (Torres et al., 2012; Zenes et al., 2020).

When there is a significant availability of water in the soil or atmosphere, the turgor pressure in the guard cells increases, resulting in greater opening of stomatal pores and increased conductance, potentially increasing the photosynthesis rate (Bertolino et al., 2019). Furthermore, it is assumed that there is a direct relationship between A and E, so that increased

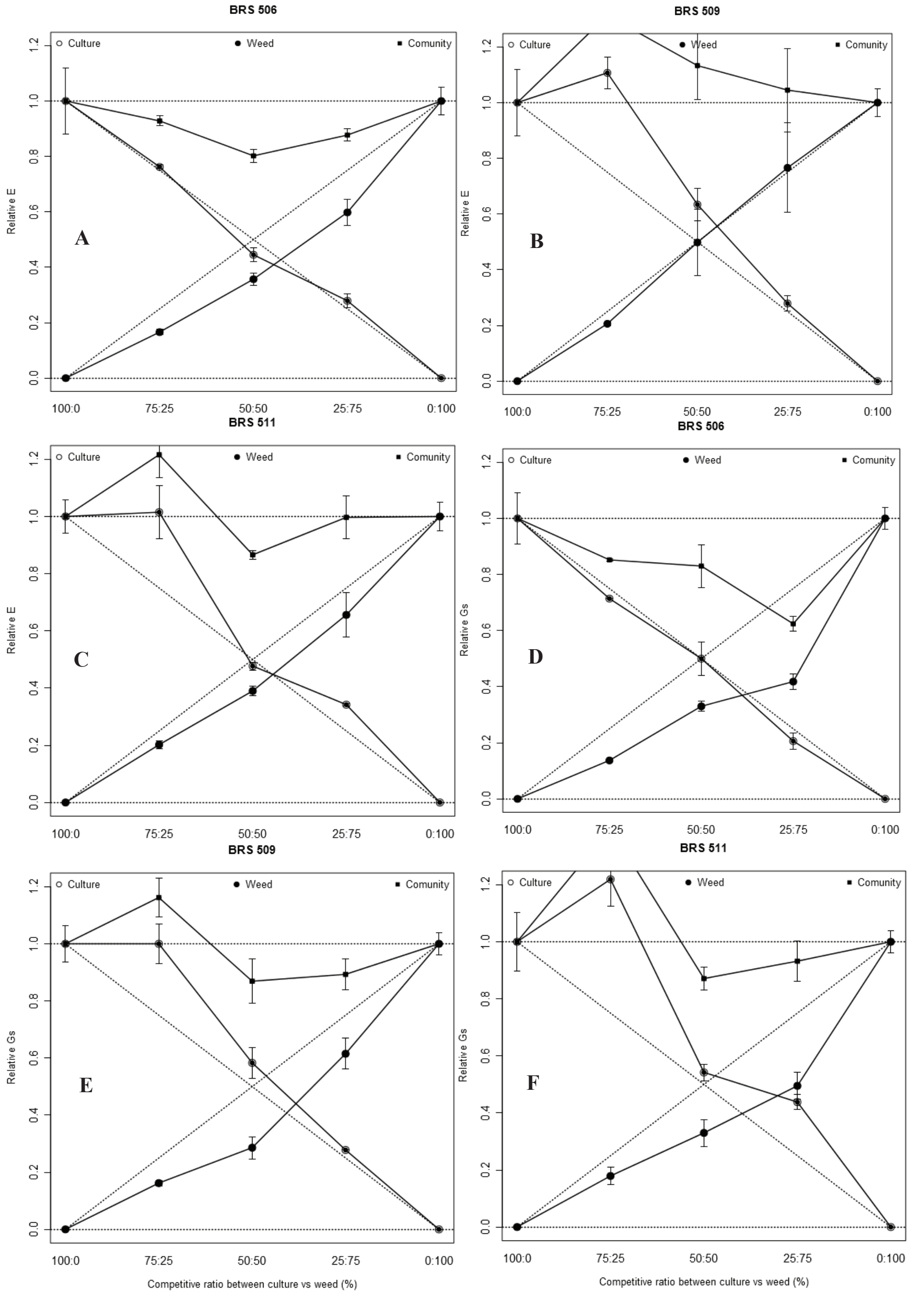

Figure 4. Relative productivity (PR) based on transpiration rate (A, B, C) and stomatal conductance (D, E, F) of sorghum cultivars and arrowleaf sida, and total relative productivity (PRT). Dashed lines indicate the expected relative productivity for each species and plant proportion. Solid lines represent the experimentally reported values. Standard errors are presented for the observed data points.

competition between plants can affect water availability, leading to stomatal closure and reduced transpiration rates. Consequently, carbon assimilation rates decrease (Zenes et al., 2020). Therefore, despite there being an increase in A and Gs, there was no increase in DM or LA, showing losses for sweet sorghum under competition with arrowleaf sida.

The PR for carboxylation efficiency (EC) presented in Figure 5 (A, B, and C) showed results near or superior to those expected for the three sorghum cultivars. BRS 509 and BRS 511 showed higher values in the 25:75 ratio, indicating that, for EC, intraspecific competition was more damaging than interspecific competition. The PR for water use efficiency (WUE) generally showed results close to those expected for the cultivars. However, a 75:25 ratio was observed for BRS 509; no statistical significance was reported (Table 2). Only BRS 506 showed a reduction in PRWUE in the 25: 75 ratio. For both EC and WUE, arrowleaf sida performed near the expected, without statistical differences in any of the proportions.

WUE is intrinsically linked to the dynamic process of stomatal opening and closure. This biological attribute occurs because, while plants absorb CO2, water is lost through transpiration at rates determined by the potential gradient between the inner and outer sides of the leaf cuticle (Concenço et al., 2009). Generally, species with C4-carbon metabolism, such as sorghum, tend to exhibit higher WUE. Therefore, crops that are more efficient in water use usually accumulate higher DM per gram of water transpired than C3 species (Torres et al., 2012). Thus, WUE is a trait inherent to the species, helping minimize water losses by competition.

Corroborating some of our results, a study of soybean competition with wild poinsettia (*Euphorbia heterophylla*) found no changes in the crop's photosynthetic parameters, whereas the weed showed reductions in these parameters due to competition (Ulguim et al., 2017)

Assuming that sweet sorghum is more competitive than arrowleaf sida when CR > 1, Kcrop > Kweed and A > 0 (Hoffman & Buhler, 2002) and adopting such a criterion to prove its competitive superiority and the occurrence of differences in at least two of these indices (Bianchi et al., 2006), SD and LA were superior for the crop, compared to the weed (Table 3). DM presented Kcrop > Kweed for BRS 506 and BRS 509, but the difference was not significant for BRS 511. PH of the crop tended to be superior compared to the weed, even with A = 0 for BRS 509 and BRS 511. In general, the sweet sorghum BRS 506, BRS 509, and BRS 511 were more competitive than arrowleaf sida. As reported in the present study, different sweet sorghum cultivars competing with hairy beggarticks were more competitive than the weed, especially for leaf area (LA) and aboveground dry mass (DM) (Galon et al., 2022).

Sweet sorghum showed greater competitiveness than arrowleaf sida for physiological parameters (Table 3). In this case, the competitiveness coefficients indicated that BRS 509 was the most competitive for CI, E, Gs, and WUE, with CR > 1, Kcrop > Kweed,

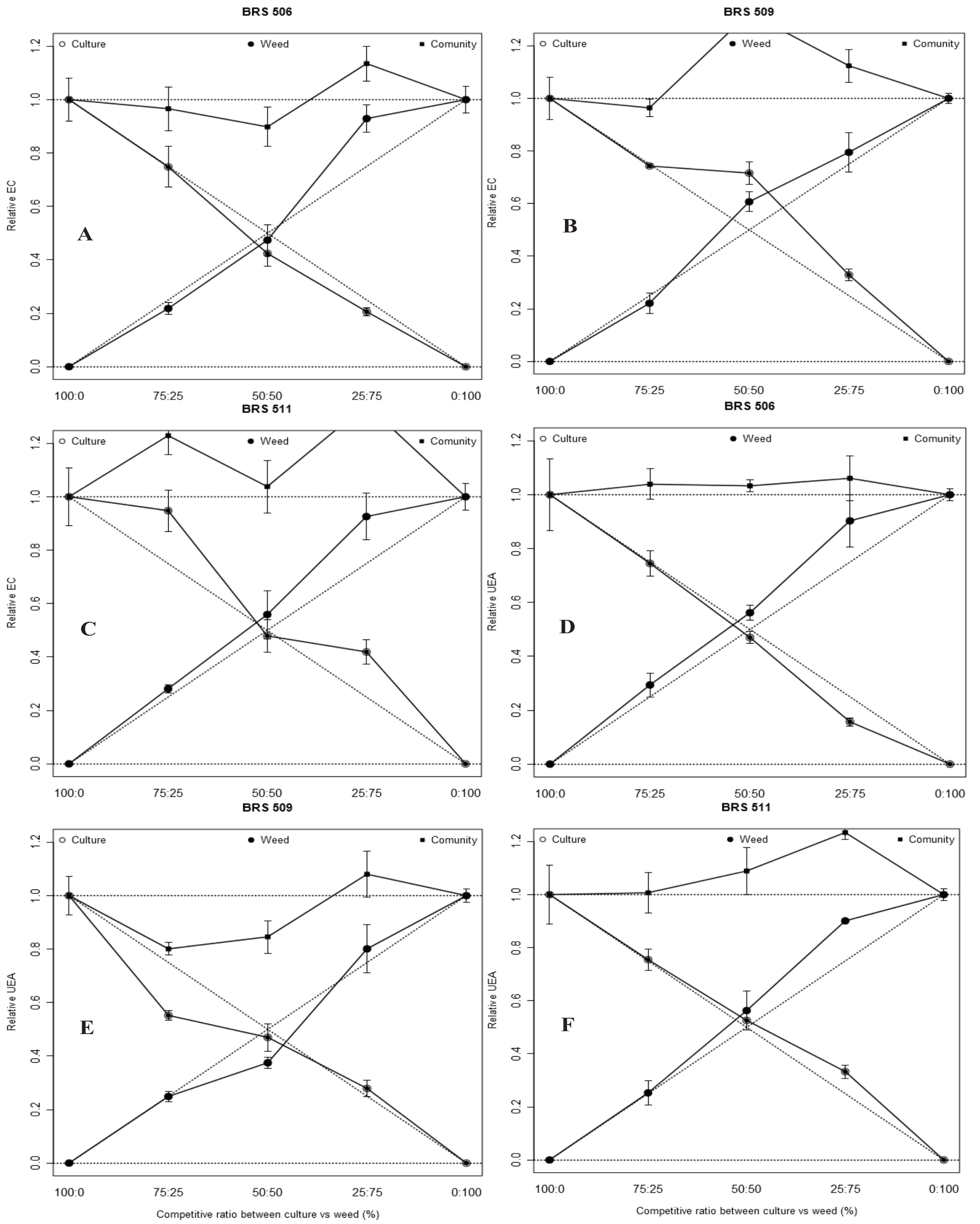

Figure 5. Relative productivity (PR) based on carboxilation efficiency (A, B, C) and water use efficiency (D, E, F) of sorghum cultivars and arrowleaf sida, and total relative productivity (PRT). Dashed lines indicate the expected relative productivity for each species and plant proportion. Solid lines represent the experimentally reported values. Standard errors are presented for the observed data points.

Table 3. Competitiveness coefficients based on morphological and physiological variables between sweet sorghum cultivars (BRS 506, BRS 509, and BRS 511) under competition against arrowleaf sida (*Sida rhombifolia*) at equal plant proportions (50:50), in terms of relative competitiveness (CR), relative clustering coefficient (K), and aggressiveness (A). UFFS, Erechim/RS.

Treatment	CR	Kx (crop)	Ky (weed)	A
	Plant height			
BRS 506 x arrowleaf sida	1.77 (±0.08)*	1.27 (±0.14)*	0.46 (±0.01)	0.24 (±0.03)*
BRS 509 x arrowleaf sida	5.42 (±0.70)*	0.11 (±0.02)*	0.46 (±0.002)	0.13 (±0.02)
BRS 511 x arrowleaf sida	1.95 (±0.06)*	0.959 (±0.5)*	0.43 (±0.04)	0.24 (±0.01)
	Stem diameter			
BRS 506 x arrowleaf sida	2.13 (±0.13)*	4.09 (±7.21)	0.53 (±0.02)	0.34 (±0.04)*
BRS 509 x arrowleaf sida	2.70 (±0.13)*	5.09 (±3.74)	0.40 (±0.01)	0.41 (±0.04)*
BRS 511 x arrowleaf sida	2.73 (±0.22)*	7.60 (±11.60)	0.42 (±0.03)	0.42 (±0.03)*
	Leaf area			
BRS 506 x arrowleaf sida	16.23 (±1.62)*	15.37 (±16.86)	0.06 (±0.04)	0.62 (±0.07)*
BRS 509 x arrowleaf sida	16.86 (±1.23)*	1.40 (±0.28)*	0.05 (±0.02)	0.49 (±0.02)*
BRS 511 x arrowleaf sida	10.04 (±0.92)*	4.04 (±5.13)	0.08 (±0.08)	0.46 (±0.06)*
	Aboveground dry mass			
BRS 506 x arrowleaf sida	4.14 (±0.32)*	0.16 (±0.02)*	0.08 (±0.05)	0.16 (±0.02)*
BRS 509 x arrowleaf sida	5.43 (±0.70)*	0.11 (±0.02)*	0.05 (±0.02)	0.13 (±0.02)*
BRS 511 x arrowleaf sida	3.58 (±0.72)*	0.08 (±0.02)	0.05 (±0.04)	0.09 (±0.02)*
	Photosynthesis rate (μmol m^{-2} s^{-1})			
BRS 506 x arrowleaf sida	1.28 (±0.11)	1.78 (±0.75)	0.81(±0.10)	0.10 (±0.04)
BRS 509 x arrowleaf sida	1.46 (±0.24)	1.53 (±0.16)*	0.77(±0.19)	0.14 (±0.07)
BRS 511 x arrowleaf sida	1.30 (±0.14)	8.54 (±5.05)	1.08(±0.07)	0.15 (±0.06)
	Internat CO_2 concentration (μmol mol^{-1})			
BRS 506 x arrowleaf sida	1.09 (±0.03)	1.37 (±0.223)	0.95 (±0.01)	0.04 (±0.01)
BRS 509 x arrowleaf sida	1.11 (±0.002)*	1.65 (±0.09)*	0.99 (±0.002)	0.05 (±0.00)*
BRS 511 x arrowleaf sida	1.12 (±0.09)	1.88 (±0.65)	0.95 (±0.03)	0.05 (±0.04)
	Transpiration rate (E - mol H_2O m^{-2} s^{-1})			
BRS 506 x arrowleaf sida	1.54 (±0.08)*	1.07 (±0.04)*	0.60 (±0.04)	0.17 (0.01)*
BRS 509 x arrowleaf sida	1.80 (±0.13)*	1.23 (±4.29)	0.77 (±0.02)	0.32 (±0.04)*
BRS 511 x arrowleaf sida	1.73 (±0.26)	8.32 (±6.94)	0.76 (±0.06)	0.27 (±0.08)*
	Carboxilation efficiency (EC - mol CO_2 m^{-2} s^{-1})			
BRS 506 x arrowleaf sida	1.16 (±0.13)	2.46 (±1.74)	0.84 (±0.01)	0.06 (±0.06)
BRS 509 x arrowleaf sida	1.21 (±0.20)	0.96 (±0.03)	0.88 (±0.20)	0.05 (±0.08)
BRS 511 x arrowleaf sida	1.14 (±0.13)	9.07 (±9.25)	1.17 (±0.09)	0.07 (±0.07)
	Stomatal conductance (GS - mol m^{-1} s^{-1})			
BRS 506 x arrowleaf sida	1.74 (±0.07)*	0.83(±0.00)*	0.47(±0.02)	0.20(±0.01)*
BRS 509 x arrowleaf sida	2.08 (±0.20)*	0.32(±0.18)	0.53(±0.04)	0.34(±0.05)*
BRS 511 x arrowleaf sida	2.49 (±0.50)	0.20(±1.60)	0.66(±0.13)	0.45(±0.06)*
	Water use efficiency (EUA - mol CO_2 mol H_2O_{-1})			
BRS 506 x arrowleaf sida	0.91 (±0.16)	1.16 (±0,34)	1.30 (±0.27)	0.09 (±0.10)
BRS 509 x arrowleaf sida	0.75 (±0.06)*	0.41 (±0,02)*	1.00 (±0.10)	0.13 (±0.04)
BRS 511 x arrowleaf sida	1.08 (±0.16)	1.18 (±0,32)	1.06 (±0.25)	0.00 (±0.08)

* Significant difference by the T-test ($p \leq 0.05$). Values in parenthesis represent the standard error of the mean. Kx and Ky are the clustering coefficients of the crop and weed, respectively.

and A > 0. For BRS 506, superiority was also reported for E and Gs. BRS 511 did not change physiological parameters as competition levels increased.

Galon et al. (2022) also reported that the sweet sorghum cultivar BRS 509 was more competitive than BRS 506 and BRS 511 against hairy beggarticks. In the literature, cases are frequently described in which competitive capacity varies among cultivars, as, for example, in crops such as wheat, corn, soybeans, and rice, when they compete with different weed species (Agostinetto et al., 2013, 2018; Lamego et al., 2013; Bastiani et al., 2016; Maciel et al., 2020).

The morphological and physiological responses of sweet sorghum to competition with arrowleaf sida are complex and influenced by inherent species traits, such as metabolism and genetic background. Therefore, research on the competitive ability of distinct sweet sorghum cultivars against weeds is relevant, especially because this information can be applied to integrated weed management in sorghum fields.

Sweet sorghum BRS 509 shows the most stable physiological and morphological behavior under competition, surpassing BRS 506 and BRS 511. This attribute is also confirmed by the competitive coefficients under controlled conditions. However, this study needs to be extended to field conditions to determine whether this behavior is maintained under production edaphoclimatic conditions.

Conclusions

Sweet sorghum BRS 509 shows the most stable physiological and morphological behavior under competition, surpassing BRS 506 and BRS 511. This result is also confirmed by the competitive coefficients under controlled conditions. This study should be extended to field conditions to determine whether this behavior is maintained under production edaphoclimatic conditions.

Acknowledgment

To CNPq, FAPERGS, UFFS, and FINEP for the financial support, research, and grants.

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