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Article

Interspecific Competition Between Sweet Sorghum and Weeds

Competição Interespecífica entre Sorgo Sacarino e Plantas Daninhas

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ABSTRACT - While evidence is mounting that sweet sorghum [*Sorghum bicolor* (L.) Moench], an ethanol crop, may provide an alternative to sugarcane (*Saccharum officinarum* L.) on sugarcane lands under rehabilitation, little is known of its under production limiting factors (*e.g.*, interspecific competition with weeds). Accordingly, the aim of the present study was to identify the initial mutual interspecific competition between sweet sorghum hybrids and weeds in high infestation situations. The experiment was carried out in pots, using a 5 × 6 factorial design: (*i*) a sorghum-free control and four sweet sorghum hybrids (CVSW 81198, CVSW 80007, CVSW 80147 and XBSW 82158), besides a control without sweet-sorghum, and (*ii*) five species of weeds [*Cyperus rotundus* L., *Mucuna aterrima* (Piper and Tracy) Holland, *Brachiaria decumbens* Stapf, *Ipomoea hederifolia* L. and *Digitaria nuda* Schumach.], besides a weed-free control. *M. aterrima* was the only weed whose dry mass was not reduced by the presence of sweet sorghum. The hybrids of sweet sorghum did not suffer developmental interference from *C. rotundus*, *I. hederifolia* or *D. nuda*. On the other hand, these weeds dry mass was reduced through competition with sweet sorghum. The sweet sorghum cohabiting with *B. decumbens* or *M. aterrima* has its aboveground and leaf dry mass reduced. Sweet sorghum is a high competitive and robust plant and, even when under a high weed density, suffers little interspecific interference from certain species of the weed community.

Keywords: plant interference, *Sorghum bicolor*, *Mucuna aterrima*, plant development.

*RESUMO - Enquanto evidências indicam o sorgo sacarino [**Sorghum bicolor** (L.) Moench] como uma matéria-prima de etanol alternativa durante a entressafra da cana-de-açúcar (**Saccharum officinarum** L.), pouco se sabe sobre sua capacidade produtiva em condições adversas (sob competição com plantas daninhas, por exemplo). Portanto, o objetivo do presente estudo foi identificar a competição interespecífica mútua entre híbridos de sorgo sacarino e plantas daninhas em situações de alta infestação. O experimento foi conduzido em vasos, usando um esquema fatorial 5 x 6: (i) quatro híbridos de sorgo sacarino (CVSW 81198, CVSW 80007, CVSW 80147 e XBSW 82158), além de uma testemunha sem a presença de sorgo sacarino; e (ii) cinco espécies de plantas daninhas [(**Cyperus rotundus** L., **Mucuna aterrima** (Piper and Tracy) Holland, **Brachiaria decumbens** Stapf, **Ipomoea hederifolia** L. e **Digitaria nuda** Schumach.], além de uma testemunha sem a presença de plantas daninhas. **M. aterrima** foi a única espécie de planta daninha cuja massa seca não foi reduzida pela presença de sorgo sacarino. Os híbridos de sorgo sacarino não sofreram interferência no seu desenvolvimento com a presença de **C. rotundus, I. hederifolia** ou **D. nuda**. No entanto, tais plantas daninhas tiveram sua massa seca reduzida pela competição com sorgo sacarino.*

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*Em convivência com **B. decumbens** ou **M. aterrima**, o sorgo sacarino teve sua massa seca de parte aérea e de folhas reduzida. O sorgo sacarino mostrou-se uma planta altamente competitiva e robusta e, mesmo em alta densidade de plantas daninhas, a interferência interespecífica imposta por certas espécies destas plantas foi baixa.*

Palavras-chave: interferência entre plantas, *Sorghum bicolor, Mucuna aterrima*, desenvolvimento vegetal.

INTRODUCTION

The cultivars of sorghum [*Sorghum bicolor* (L.) Moench] termed 'sweet sorghum' have stems rich in fermentable sugars which can serve as raw material for ethanol production. Accordingly, it is seen as a promising gap filler for ethanol production between sugarcane crops, *i.e.*, when the sugarcane has yet to ripen and bears only a low sucrose concentration (Kim and Day, 2010; Purcino and Durães, 2011; Fiorini et al., 2016).

As any other crop, sweet sorghum growth is subject to interference by weeds, whose competition under nutrient-limited conditions can cause yield losses, and which can host pests and diseases and/or have allelopathic effects (Pitelli, 1985). Weed community parameters (*e.g.*, composition of species, density and distribution) and crop parameters (*e.g.*, cultivar, row spacing, planting density) determine the level of weed interference (Pitelli, 1985). Therefore, a knowledge of interspecific competition capacity, namely the effects of weeds on sweet sorghum hybrid phenological development and biomass generation, and *vice versa*, is crucial for appropriate crop management decisions to be made for the sweet sorghum crop so as to fulfill its role as a raw material in the agroenergetic industry.

The different sorghum cultivars/lines vary in their morphological structure, growth and development, according to the objective of their breeding program. For instance, in the initial development stages, grain sorghum plants are relative small, fragile and growth slowly (Kramer and Ross, 1975). Accordingly, to prevent competitive interference from weeds, grain sorghum must be kept weed-free between 26 and 28 days after emergence (Burnside, 1977; Rodrigues et al., 2010). Feltner et al. (1973) studied the weed competition in grain sorghum and concluded that velvetleaf (*Abutilon theophrasti* Medik) was more competitive than ivy-leaved morning glory (*Ipomoea hederacea* Jacq.), although both performed significant competition and caused yield loss.

Studying forage sorghum grown under a temperate climate, Andres et al. (2009), identified Alexandergrass [*Brachiaria plantaginea* (Link) Hitchc.] and barnyardgrass [*Echinochloa crus-galli* (L.) Beauv.] as the weeds with a prevailing influence given their high infestation rate, fast grow, and capacity for shading. While many studies have investigated the growth and development of grain and forage sorghum in the presence of weeds, few have addressed interspecific competition between weeds and sweet sorghum (Giancotti et al., 2017). Given sweet sorghum's high natural resources use efficiency and robust growth of both above- and below-group portions of the plant, it can be expected that even in a physically limited environment and under high weed infestation rates, this type of sorghum would not suffer weed interference as severe as other types of sorghum.

The sorghum plant's C_4 metabolism offers high efficiency of solar radiation, resulting in a photosynthetic ranging from 30 to 100 mg dm^{-2} h^{-1} CO_2, depending on, among other factors, the plant genotype (Magalhães and Durães, 2003; Santos et al., 2015). Sweet sorghum varieties, particularly, can reach up to 3 m in plant height and produce between 40 and 60 mg ha^{-1} in biomass (Fiorini et al., 2016). Thanks to its efficient root system, high number of secondary roots and effective maintenance of its internal water content through stomatal closure sorghum is a strongly drought-resistant crop. For instance, sorghum can maintain higher water potentials compared to corn (*Zea mays* L.) (Martin et al., 1930; Sanchez-Diaz and Kramer, 1971). Sorghum crop is also reported to be very tolerant to aluminum toxicity and soil salinity, making it possible to cultivate it in areas otherwise considered infertile (Amaducci et al., 2004; Prasad et al., 2007; Vasilakologlou et al., 2011).

Besides direct competition with other plants (*i.e.*, weeds) for nutrient resources, another factor that may influence the interaction of sorghum with other plants is allelopathy, since it produces a substantial quantity of root exudates, in particular allelochemical known as sorgoleone (Santos et al., 2012).

The aim of this study was to identify the mutual initial interspecific competitiveness between sweet sorghum hybrids and weeds, in a high weed pressure environment.

MATERIALS AND METHODS

Experimental site and pots preparation

The experiment was set up in an experimental area located at -21.244474S and -48.299085W, in southeast region of Brazil. Each plot was constituted of a 7 L pot filled with a mix of ¾ of clay soil and ¼ of sand, all sieved through a 5 mm mesh. Based in a chemical analyses of the substrate, each pot received 0.2 g (377 kg ha^{-1}) of a NPK fertilizer of 4-14-8 (N - P_2O_5 - K_2O) formulation, simulating field crop requirements (Borgonovi et al., 1982). A further nitrogen fertilization was applied 30 days after emergence, using 0.1 g of urea per pot (189 kg ha^{-1}).

Experimental design, treatments and plant cultivation

The experiment was carried out, using a 5 × 6 factorial design: (*i*) a sorghum-free control and four sweet sorghum hybrids (CVSW 81198, CVSW 80007, CVSW 80147 and XBSW 82158), in factorial combination with (*ii*) a weed-free control, and five species of weeds: nutsedge [*Cyperus rotundus* L., velvet beans [*Mucuna aterrima* (Piper and Tracy) Holland], signal grass [*Brachiaria decumbens* Stapf.], morning glory [*Ipomoea hederifolia* L.], and naked crabgrass [*Digitaria nuda* Schumach.].

The soil moisture of the plots was checked daily and manually irrigated. After emergence, for non-control treatments, plants were thinned to three sweet sorghum plants (57 plants m^{-1}) and ten weed plants per plot (189 plants m^{-1}), a density which favored the weeds and served to simulate the interspecific competition of a crop under a high weed pressure situation.

Measurements

At 28 and 45 days after emergence (DAE), the sweet sorghum plants' phenological development was evaluated by measuring the number of leaves, plant height (from ground level to the ligule of last expanded leaf) and stem diameter (0.01 m above the ground). At the 28 DAE evaluation the *in vivo* ratio of variable chlorophyll fluorescence (Fv) to maximum fluorescence (Fm), *i.e.* Fv/Fm (Handy PEA, Hansatech Instruments, Norfolk, UK) was measured, and the Falker Chlorophyll Index (FCI) (ClorofiLOG, model CFL1030, Porto Alegre, Brazil) determined. The measurement took place in the upper, middle and lower thirds of the last fully expanded leaf and averaged (Arantes et al., 2013). The Fv/Fm and the FCI evaluations were performed at daytime, between 8:00 and 10:00 AM local time.

At 45 DAE, a destructive evaluation was undertaken, with both sweet sorghum plants and the weeds cut off at ground level, separated leaves and stem, and individually dried in a forced air oven at 60 °C until constant dry weight.

Data analyses

Treatment effects were tested using analysis of variance and significant differences between means were carried out by using the Tukey test at 5% probability. Data normality were assessed prior to the analyses. Statistical analyzes were performed using SPSS Statistics (v.23; IBM SPSS, Chicago, IL.) As described in Marôco (2014) and Field (2013).

RESULTS AND DISCUSSION

The sweet sorghum and the weed species *I . hederifolia* and *D. nuda* took 5 DAS (days after sowing) to emerge, whereas *C. rotundus*, *M. aterrima* and *B. decumbens* emerged after 10 days.

The experimental factors (weed species, sweet sorghum hybrids) showed no significant interaction for the morphophysiological non-destructive parameters evaluated in sorghum plant at 28 and 45 DAE (Tables 1 and 2). The number of sweet sorghum leaves varied according to the coexisting weed species at 28 and 45 DAE. Also in both evaluations, the hybrids suffered a reduction on their number of leaves under *M. aterrima* competition (Tables 1 and 2). Among sweet sorghum hybrids, CVSW 80007 had a lower number of leaves compared to XBSW 82158 at 28 DAE.

When sweet sorghum hybrids competed with *C. rotundus* and *M. aterrima* at 28 DAE, they had grown taller than in the weed-free control (Table 1). In contrast, at 45 DAE, this difference was no longer apparent (Table 2). At 28 and 45 DAE, the sweet sorghum hybrids CVSW81198 and XBSW 82158 had the tallest plants among the four hybrids evaluated (Table 1). At 45 DAE, there was no difference in plant height between XBSW 82158 and the other cultivars (Table 2).

The sweet sorghum hybrids suffered reduction on their stem diameter when coexisting with a high density of *M. aterrima* at both periods evaluated (Table 1 and Table 2). The four hybrids did not differ amongst each other with regard to the parameters of stem diameter and FCI (Tables 1 and 2). The sweet sorghum chlorophyll content (FCI) and the photosystem II maximum quantum yield (Fv/Fm) were unaltered under weed competition, regardless of the weed species. Accordingly, one could conclude that weed competition did not significantly influenced the sweet sorghum's photosynthetic activity within the experimental conditions. Amongst hybrids, CVSW 81198 showed a greater Fv/Fm than CVSW 80007 (Table 1).

Mucuna aterrima grew and developed much quicker than the other weeds, accumulating four times more dry mass than *B. decumbens* at 45 DAE (Table 3). *Mucuna aterrima* was the only weed that did not have its dry mass reduced by the competition of any coexisting sweet sorghum hybrid. On the other hand, *C. rotundus* and *B. decumbens* had their dry mass reduced by all sweet sorghum hybrids. The interference provided by the hybrids CVSW 80147 and XBSW 82158 reduced the *I. hederifolia* dry mass. For *D. nuda*, the interference for that parameter occurred with the competition with CVSW 80007 hybrid (Table 3).

For the parameters of sweet sorghum total aboveground biomass, considering the sum of leaves and stem dry mass, weed species and the interaction between the two factors (hybrids and weed species) were significant (Table 4). However, the hybrid was not a significant factor.

Table 1 - Number of leaves, plant height, stem diameter, Falker Chlorophyll Index (FCI) and photosystem II maximum quantum yield (Fv/Fm) of sweet sorghum hybrids coexisting in disadvantage with weed species, 28 days after emergence

Weed species	Sweet sorghum at 28 DAE				
	Number of leaves	Plant height (cm)	Diameter stem (mm)	FCI	F_v/F_m
Cyperus rotundus	5.50 A	6.43 A	3.13 A	29.12 A	0.681 A
Mucuna aterrima	3.90 C	6.30 A	2.08 C	26.53 A	0.651 A
Brachiaria decumbens	5.29 AB	5.24 ABC	2.60 ABC	25.45 A	0.658 A
Ipomoea hederifolia	5.21 AB	5.96 AB	2.85 AB	28.33 A	0.708 A
Digitaria nuda	4.72 B	4.29 C	2.45 BC	26.06 A	0.681 A
Weed free control	4.99 AB	4.82 BC	2.95 AB	26.72 A	0.707 A
Sweet sorghum hybrids					
CVSW 81198	4.92 AB	6.25 A	2.48 A	27.55 A	0.704 A
CVSW 80007	4.74 B	4.51 B	2.51 A	27.32 A	0.652 B
CVSW 80147	4.83 AB	5.08 B	2.63 A	25.11 A	0.686 AB
XBSW 82158	5.26 A	6.18 A	2.79 A	28.16 A	0.681 AB
F (weeds)	13.217**	6.17**	5.98**	1.71^{NS}	2.04^{NS}
F (hybrids)	3.102*	9.07**	1.56^{NS}	2.31^{NS}	2.47*
F (interaction)	0.547^{NS}	1.19^{NS}	1.50^{NS}	1.10^{NS}	1.01^{NS}
CV%	12.76	25.21	23.03	15.86	9.75

Means in each column followed by the same letter are not significantly different (Tukey's test, $P = 0.05$); ** $P < 0.01$ * $P < 0.05$; ^{NS} Not significant.

Table 2 - Number of leaves, plant height and stem diameter of sweet sorghum hybrids coexisting in disadvantage with weed species, 45 days after emergence

Weed species	Sweet sorghum at 45 DAE		
	Number of leaves	Plant height (cm)	Diameter stem (mm)
Cyperus rotundus	5.10 A	8.87 A	4.34 A
Mucuna aterrima	3.58 B	7.77 A	2.53 B
Brachiaria decumbens	5.20 A	7.31 A	3.70 A
Ipomoea hederifolia	5.58 A	8.75 A	4.22 A
Digitaria nuda	5.28 A	6.80 A	3.60 AB
Weed free control	5.85 A	7.51 A	3.67 A
Sweet sorghum hybrids			
CVSW 81198	5.01 A	9.07 A	3.74 A
CVSW 80007	4.95 A	6.81 B	3.47 A
CVSW 80147	5.07 A	7.15 B	3.76 A
XBSW 82158	5.36 A	8.32 AB	3.73 A
F (weeds)	15.17**	1.96^{NS}	5.52**
F (hybrids)	1.20^{NS}	4.82**	0.39^{NS}
F (interaction)	1.00^{NS}	0.69^{NS}	0.57^{NS}
CV%	15.95	29.83	29.73

Means in each column followed by the same letter are not significantly different (Tukey's test, $P = 0.05$); ** $P < 0.01$; ^{NS} Not significant.

Table 3 - Weed dry mass per plot, after coexisting in advantage with sweet sorghum hybrids, 45 days after emergence

Sweet sorghum hybrids	Weed dry mass m^{-2} (g)				
	Cyperus rotundus	*Mucuna aterrima*	*Brachiaria decumbens*	*Ipomoea hederifolia*	*Digitaria nuda*
Control without sorghum	65.8 A	275.5 A	73.8 A	25.7 A	42.1 A
CVSW 81198	43.2 B	248.5 A	31.9 B	17.7 AB	23.0 AB
CVSW 80007	39.4 B	229.6 A	38.9 B	17.2 AB	15.3 B
CVSW 80147	45.7 B	264.3 A	30.6 B	12.5 B	23.4 AB
XBSW 82158	35.3 B	240.4 A	34.3 B	14.5 B	22.3 AB
F	18.06**	2.27^{NS}	6.48**	5.64**	3.56**
CV%	12.09	9.71	33.88	24.17	40.40

Means in each column followed by the same letter are not significantly different (Tukey's test, $P = 0.05$); ** $P < 0.01$; ^{NS} Not significant.

Among the five weed species tested, *C. rotundus*, *I. hederifolia* and *D. nuda* did not reduced the aboveground dry biomass of sorghum, nor that of its leaves or stem individually, through competition (Table 4). *Mucuna aterrima* competition reduced sweet sorghum dry biomass accumulation in both leaves and stem. For sweet sorghum aboveground and leaf dry mass, *B. decumbens* competition also caused losses, although not as pronounced as *M. aterrima* (Table 4).

Studying the weed community presence in sorghum, Silva et al. (2014) described its negative effect on plant height and stem diameter, citing a reduction of approximately 9% and 25%, respectively, compared to a weed-free control. In the present study, at 28 DAE, *D. nuda* competition caused reduction in sweet sorghum height; however, in the presence of *M. aterrima* and *C. rotundus*, weeds that had more dry biomass accumulation, provided conditions for sorghum to grow excessively tall, causing plant etiolation. At 28 and 45 DAE, the only weed that reduced the sweet sorghum stem diameter was *M. aterrima*, with 45 and 42% reduction respectively, compared to the weed-free control. Therefore, sorghum stems also had their dry mass reduced (48%).

Two weeds of same photosynthetic cycle (C_4) as sorghum showed different competitive behaviors. Despite the fact that *C. rotundus* accumulated more dry mass than *B. decumbens*, it did not reduce sweet sorghum dry biomass as much as *B. decumbens*. *B. decumbens* is an aggressive perennial plant exclusively of tropical habitat, which was at full vegetative development

Table 4 - Dry mass per plot of portions of sweet sorghum hybrids (aboveground as a whole, leaves and stem) coexisting in disadvantage with weed species, 45 days after emergence

Weed	Sweet sorghum dry mass m^{-2} (g)		
	Aboveground	Leaves	Stem
Cyperus rotundus	40.75 A	26.42 A	14.34 A
Mucuna aterrima	12.26 C	5.28 C	6.98 B
Brachiaria decumbens	26.23 B	16.23 B	10.19 AB
Ipomoea hederifolia	41.51 A	26.98 A	14.53 A
Digitaria nuda	32.26 AB	20.75 AB	11.32 AB
Weed free control	36.79 A	23.21 A	13.40 A
Sorghum hybrid			
CVSW 81198	30.00 A	19.06 A	10.94 A
CVSW 80007	30.57 A	19.25 A	11.32 A
CVSW 80147	34.53 A	21.70 A	12.64 A
XBSW 82158	31.51 A	19.25 A	12.26 A
F (weeds)	19.41**	27.34**	7.41**
F (hybrids)	0.97^{NS}	1.04^{NS}	0.90^{NS}
F (interaction)	2.37**	2.21*	2.67**
CV%	31.68	31.31	36.73

Means in each column followed by the same letter are not significantly different (Tukey's test, $P = 0.05$); ** $P < 0.01$; ^{NS} Not significant.

at 45 DAE, unlike *C. rotundus*, that already had flowered by that time. Andres et al., (2009) corroborate these results in a study where a weed community reduced the grain production of forage sorghum. That weed community was composed mainly by *Brachiaria plantaginea* (Link) Hitchc., plant of same genus of *B. decumbens*.

In a field trial, Favero et al., (2001) demonstrated the high potential of weed suppression by *M. aterrima* due its extremely quick initial growth, thereby overlying the soil in an effective way. Akobundu and Polku, (1984) showed that, in nineteen weeks, *Mucuna pruriens* (L.) DC. fully covered an area infested with *Imperata brasiliensis* Trin. Their results highlighted the competitive potential of *Mucuna* spp., its fast growth and area dominance capability, which supports the robust dry mass accumulation by *M. aterrima* found in the present study.

Besides the competitive traits mentioned regarding *M. aterrima*, the interference capability of this weed have been also related to its allelopathic potential. According to Lorenzi (1984), *M. aterrima* has a strong and persistent inhibitory effect upon *C. rotundus* and *Bidens pilosa* L. At 120 days after *M. aterrima* emergence, Medeiros (1989) did not found presence of any other species in an experimental field, and attributed this phenomenon to allelopathic effects.

The slow development of sorghum during the first growth stages makes the crop more susceptible to weed competition, particularly if the weeds exhibit a fast germination and emergence, taking up nutrient sources first (Passini et al., 1986). However, in our study, the weeds *M. aterrima* and *B. decumbens* needed more time to emerge, comparing to sweet sorghum; even though they were the most competitive of the studied weed species. *M. aegyptia* is reported to develop small dry mass and macronutrient accumulation initially, only intensifying it after 49 DAE (Martins et al., 2010). Overall, most weeds studied in this study did not interfere in the morphophysiological development of sweet sorghum.

Sweet sorghum suffered no competition by *I. hederifolia*, for any of the growth and development parameters evaluated. These results differ from those of Feltner et al. (1973) in grain sorghum, who found that *Ipomoea* spp. a density of 2 plants m^{-1}, significantly competed with the crop, reducing its yield by approximately 18%.

In a study carried out under field conditions, the hybrid of sweet sorghum CVSW 80007 did not have its yield reduced by a weed community (mainly composed by *C. rotundus* and *Alternanthera tenella* Colla), even in a crop grown without any weed control (Giancotti et al., 2017). In the present study, that hybrid of sweet sorghum also showed high weed tolerance, even in a situation of population disadvantage. Both experiments supports the potential of CVSW 80007 as a crop in historically weedy areas or as a source material in breeding programs aimed for new weed tolerant cultivars. It is important to emphasize that not only competition capacity is important to tolerate weeds but also allelopathy. Correia et al., (2005) demonstrated sorghum allelopathy in controlled conditions where leaf extract of grain sorghum hybrids XBG 00478 and DKB 860 and a stem extract of the SARA hybrid inhibited the root growth of soybean.

Sweet sorghum showed competitive superiority over *C. rotundus*, *I. hederifolia* and *D. nuda*, even in a situation of population disadvantage. In that condition, *B. decumbens* and the sweet sorghum hybrids suffered mutual interspecific competition, both were affected by their coexistence. *Mucuna aterrima* showed greater competitiveness than the sweet sorghum hybrids, under the population density studied. Therefore, the hybrids of sweet sorghum showed themselves to be very competitive and robust, even under an environment of high weed density, they can still not suffer competition by certain plants.

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