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Research Article

Spacing Arrangements and Environmental Factors Influence Biomass Production of Sweet *Sorghum* Cultivars Grown in Semi-arid Regions

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Abstract

Background and Objective: High biomass production of sweet sorghum [*Sorghum bicolor* (L.) Moench] may be obtained by using cultivars adapted to a determined environment and by adopting the most appropriated spacing arrangement. The aim of this study was to evaluated the effects of different spatial arrangements on the biomass productivity of two sweet sorghum varieties in the Brazilian semi-arid region. **Materials and Methods:** Two agricultural cycles (2015 and 2016) were carried out under rainfed conditions. The varieties used were BRS 506 and SF 15 and spacing between the rows (50, 60, 70 and 80 cm) and between plants (8, 12 and 16 cm) were evaluated in a randomized complete block design with four replications and a triple factorial scheme. The fresh and dry matter of the leaves, panicle and stalk were evaluated. Dry matter mass was determined by summing the mass of the dry matter of all the parts. **Results:** The values obtained with the BRS 506 variety in the first cycle were higher than those observed in the SF 15 variety. Results showed that the BRS 506 variety had the highest growth under appropriated rainfall conditions (1st cycle), while the SF 15 showed a small improvement in growth during the second cycle, which was characterized by a long and severe drought. In this context, the observed superiority for BRS 506 from one cycle to the next was 233.4%. The closer spacings between the rows and between plants provided higher average biomass due to the greater amount of material per area. **Conclusion:** The BRS 506 variety is recommended for biomass production in the semiarid at a planting density of 250,000 plants ha^{-1}.

Key words: *Sorghum bicolor* L., Moench, biomass productivity, spatial arrangements, sweet sorghum, planting density, semi-arid region

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INTRODUCTION

The sugar and alcohol industry has gained increased relevance to the economic and social development of Brazilian, which is the largest producer and world reference. In the last decade, this sector has grown approximate 65% in Brazil, with the 2017/2018 harvest estimated at a production of 647.6 million t of sugarcane and 27.8 billion L of ethanol[1]. However, the sector already shows signs of insufficiency with the increased demand generated by the growth of the automotive sector, increasing the production and sale of bi-fuel vehicles[2].

Therefore, the search for new technologies is important to increase the annual ethanol production in the country, preferably without increasing costs and planted areas[3]. Sweet sorghum (*Sorghum bicolor* (L.) Moench) may be an option in the period between the sugarcane harvesting season, specially because of its ability to germinate and growth under stressful conditions[4]. This species resembles sugarcane in the storage of sugars in the stalks, which allows the production of ethanol and the supply of sufficient bagasse to generate steam in industrial operation[5].

Sweet sorghum between sugarcane harvests benefits the sugar-energy industry, because it diminishes the downtime by supplying raw material to produce ethanol during this interval[6,7]. In addition, sweet sorghum has advantages in the high production of biomass, in the early harvest and because it uses the same industrialization process as sugarcane. These factors make it the first choice for the renewal of a cultivated area, aiming to anticipate the milling period by about 45 days[8].

For high sorghum yields, an important factor is the use of varieties adapted to the production systems and the environmental conditions found in the region, with adequate planning and management. Several factors may influence the development and production of sweet sorghum, including planting density, which can directly affect crop yield. The quantity of plants may vary depending on many factors such as the variety, the productive capacity of the soil conditions in the region and the local rainfall distribution. When defining the best arrangement of the plants in the area, the aim is to adapt the best spacing and population for each cultivar[9].

Studies have been developed to elucidate the behavior of sweet sorghum conducted at different population densities. Tang *et al.*[10] studying different planting densities, evaluated a variety of sweet sorghum (GT-3) and a variety of sorghum biomass (GN-4) in the semiarid region of China, found that with the increase in planting density (10.5 plants m^{-2}) produced a greater dry biomass yield, reaching 13.2 t ha^{-1}. On the other hand, Da Silva *et al.*[11] evaluated the BRS 511 variety in the semiarid region of Ceará, Brazil, with three different inter-row spacings (70, 80 and 90 cm) and four plant populations (80,000, 100,000, 120,000 and 140,000 plants ha^{-1}). They found the best cultivation for this variety was a plant population of less than 120,000 plants ha^{-1} and spacing between rows less than 0.80 m.

Choosing the appropriate plant arrangement is an important management practice to optimize yield of sweet sorghum. Hence, the objective of this work was to evaluate the biomass productivity of two sweet sorghum varieties as a function of spatial arrangement in the semiarid region of Ceará, Brazil.

MATERIALS AND METHODS

Location and climatic conditions: The experiment was installed at the Curu Valley Experimental Farm belonging to the Federal University of Ceará in Pentecoste, Ceará, Brazil (coordinates UTM 462620 E, 9577349 S and 48 m high) in sandy loam Planosol[12]. The experiment was carried out in two different agricultural cycles. The first one was conducted between March and July 2015, a period that includes the rainy season in the region, with manual sowing performed on March 7. The experiment was repeated in 2016, with sowing on March 18 and extending until the month of June. The region has BSw'h' climate, which is semiarid with irregular rains[13]. The meteorological data during the experiment are shown in Fig. 1.

Plant materials and preparation of the experimental area: The varieties used were BRS 506, acquired from the Brazilian Agricultural Research Corporation (EMBRAPA) located in the city of Sete Lagoas, MG, Brazil and SF-15, provided by the Instituto Agronômico de Pernambuco (IPA), in Recife, PE, Brazil.

Soil preparation was performed with plowing then harrowing. According to the soil analysis (Table 1 and 2) of the experiment area and recommendations of Da Silva *et al.*[7], a fertilization was done at 30, 50 and 45 kg ha^{-1} of N, P_2O_5 and K_2O, respectively, at the time of sowing both years. The sources for each nutrient were urea, single superphosphate and potassium chloride mineral fertilizers. Twenty days after sowing, a cover fertilization was performed with 140 and 45 kg ha^{-1} of N and K_2O, respectively.

Experimental design and conduction: For the two varieties studied, the spacings between the rows of 50, 60, 70 and 80 cm and between plants of 8, 12 and 16 cm were analyzed,

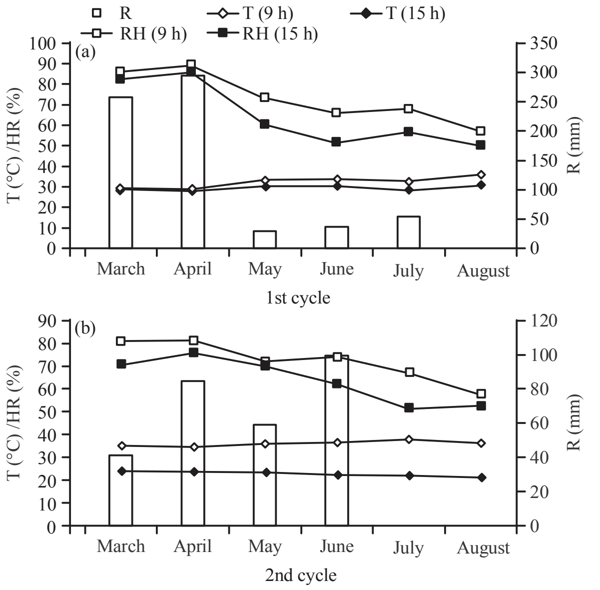

Fig. 1(a-b): Main meteorological parameters referring to the period from March to August each cultivation year of the experiment during 2015 and 2016, which were respectively the (a) First and (b) Second year of sweet sorghum growth, in Pentecoste, Ceara, Brazil

Source: FUNCEME (www.funceme.br). T: Temperature, RH: Relative humidity, R: Accumulated monthly rainfall, T (9 h) = T (09:00); T (15) = T (15:00), RH (9 h) = RH (09:00), RH (15 h) = RH (15:00)

Table 1: Physicochemical conditions of the soil at depths of 0-20 and 20-40 cm at the experimental area of vale-do-curu farm in Pentecoste, Ceará, Brazil, 2015

	CMOLC kg^{-1}							
Depth (cm)	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	$H^{+}+Al^{3+}$	Al^{3+}	S	T
0-20	5.80	1.20	0.33	0.49	1.49	0.15	7.8	9.3
20-40	5.40	1.60	0.37	0.35	1.16	0.10	7.7	8.9
	Percentage		g kg^{-1}					
	V	M	C	N	MO	P assimilated	C/N	PST
0-20	84	2	6.66	0.73	11.48	0.086	9	4
20-40	87	1	3.72	0.34	6.41	0.053	11	4
	g cm^{-3}	H_2O	DS m^{-1}	g kg^{-1}				
	D.G.	pH	CE	Sand G	Sand F	Silt	Arg.	Arg. Nat.
0-20	1.46	6.7	0.85	68	593	249	90	61
20-40	1.55	7.0	0.66	50	571	271	108	92

Source: Soil/Water Laboratory; Department of Soil Science-Federal University of Ceará, Brazil

Table 2: Physicochemical conditions of the soil at depths of 0-20 and 20-40 cm from the experimental area of vale-do-curu farm in Pentecoste, Ceará, Brazil, 2016

	CMOLC kg^{-1}							
Depth (cm)	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	$H^{+}+Al^{3+}$	Al^{3+}	S	T
0-20	5.40	2.10	0.22	0.96	0.83	0.05	8.7	9.5
20-40	4.70	3.30	0.63	0.74	0.66	0.05	9.4	10.0
	Percentage		g kg^{-1}					
	V	M	C	N	MO	P assimilated	C/N	PST
0-20	91	1	9.48	0.98	16.34	0.084	10	4
20-40	93	1	5.16	0.53	8.90	0.061	10	4
	g cm^{-3}	H_2O	DS m^{-1}	g kg^{-1}				
	D.G.	pH	CE	Sand G	Sand F	Silt	Arg.	Arg. Nat.
0-20	1.37	6.6	0.58	60	556	261	123	80
20-40	1.6	6.8	0.70	69	578	258	95	77

Source: Soil/Water Laboratory, Department of Soil Science-Federal University of Ceará, Brazil thus using different plant populations per hectare. The experiment was conducted in a randomized block design with four replications in a triple factorial scheme (two varieties, four spacings between rows and three spacings between plants). A total area of 1,248 m^2 was used, with four blocks of 312 m^2 and plots varying from 10-16 m^2 according to the treatment. Each plot consisted of four rows of 5 m, with the two central rows as the useful area of the parcel.

Data collection and analyzed variables: The material was harvested when it reached physiological maturation, which occurred at 110 days after sowing (DAS) for the BRS 506 variety and at 130 DAS for the SF 15 variety[7]. Twelve plants were randomly collected in the rows used, then the bundles were weighed to determine the mass of total fresh matter (TFM).

Afterwards, four plants were randomly separated to determine the mass of fresh and dry matter of leaves (FLM and DLM), stalks (FSM and DSM) and panicles (FPM and DPM), which were weighed separately. The fresh matter after weighing was placed in an oven with forced air circulation until constant mass to obtain the dry matter. The mass of the total dry matter (TDM) was determined by summing the dry matter mass of the parts. The biomass data were extrapolated to tons per hectares as a function of the number of plants per hectare, respecting the spacing and sowing density used in each treatment.

Statistical analyses: The data were subjected to tests for normality and homogeneity of variances and when responding to such assumptions, a two-way analysis of variance (ANOVA) was performed using the F-test (5%). Subsequently, Tukey test (5%) was used to evaluate both varieties and plant spacing and polynomial regression was used for assessment of inter row spacing. When the data did not meet at least one of the assumptions, they were submitted to Kruskal-Wallis non-parametric test, with multiple comparisons in pairs in which p-value $\leq$0.05 and level of significance at 5%. The variables $FLM^{1,1}$, FPM^1, $FSM^{1,2}$, $DLM^{1,2}$, DSM^1 and TDM^1 were submitted to data transformation through the Boxcox system, which allowed the adjustment of data for the ANOVA.

Statistical analyzes were performed using the software Action 2.7[14] for Box-cox transformation, Bartlett test (test of variance) and Kruskal-Wallis test; Assistat 7.7 beta[15] for the normality tests and Sisvar 5.3 Build 77[16] for ANOVA with Tukey or regression.

RESULTS

Total biomass and panicle production: The data for total fresh matter in the first crop cycle (Table 3) indicated that the BRS 506 variety was excellent that year, with averages of 70.78 t ha^{-1}, while the dry matter of panicles was higher for the SF 15 variety (1.42 t ha^{-1}). In the second cropping cycle, however, no average differences were observed between any of the studied variables.

The two smaller row spacings (50 and 60 cm) favored the production of total fresh matter (TFM) in the first cycle, with an average of 80.63 and 66.11 t ha^{-1}, respectively. The fresh panicle matter also had higher averages in the spacings between 50 (0.87 t ha^{-1}) and 60 cm (0.72 t ha^{-1}), while the dry panicle matter had a value of 0.53 t ha^{-1}, both in the second crop cycle (Table 3).

The spacing between plants showed similar behavior for all the variables in Table 3, with the highest averages

Table 3: Total fresh matter ($TFM^{1,2}$), fresh panicle matter (FPM^1), dry panicle matter ($DPM^{1,2}$) of two sweet sorghum varieties submitted to different planting densities produced in a semiarid region (Pentecoste, Ceara, Brazil)

Treatments	TFM^1	TFM^2	FPM^2	DPM^1	DPM^2
Varieties					
BRS 506	70.78^a	40.22^a	0.41^a	0.77^b	0.76^a
SF-15	61.98^b	39.26^a	0.42^a	1.42^a	0.64^a
RS (cm)					
50	80.63^a	45.39^a	0.87^a	1.27^a	0.53^a
60	66.11^{ab}	42.12^{ab}	0.72^{ab}	1.05^a	0.41^{ab}
70	60.73^b	35.88^{ab}	0.63^b	1.11^a	0.37^b
80	58.05^b	35.55^b	0.57^b	0.96^a	0.35^b
PS (cm)					
8	82.16^a	48.36^a	0.90^a	1.32^a	0.55^a
12	62.59^b	38.29^b	0.66^b	1.10^{ab}	0.38^b
16	54.39^c	32.57^c	0.53^c	0.86^b	0.31^c

1: First cycle, 2: Second cycle, RS: Row spacing, PS: Plant spacing, TFM: Total fresh matter, FPM: Fresh panicle matter, DPM: Dry panicle matter. Means followed by equal letters in the columns do not differ from each other by the non-parametric Kruskal-Wallis test (K-W), with multiple comparisons in pairs when p-value $\leq$0.05, level of significance at 5%

always observed in the least space between plants (8 cm), considering the average TFM, which in the first cycle was 82.16 t ha^{-1} and in the second cycle of 48.36 t ha^{-1}, a superiority of approximately 70%. The average values observed in the 8 cm spacing for dry panicle matter in the first cycle were 1.32 t ha^{-1} and in the second cycle 0.55 t ha^{-1} (Table 3).

Biomass partitioning and plant organ growth: The parametric analysis for fresh matter of leaf (FLM^{1,2}), panicle (FPM^{1}) and stalk (FSM^{1,2}), using normalized data, showed a significant effect ($p < 0.01$) for the variation factor in isolation, for variety (V), row spacing (RS) and plant spacing (PS) (Table 4). Only the FSM, analyzed in the second cropping cycle, did not present significance for the VF variety. For dry leaf matter (DLM^{1,2}), dry stalk matter (DSM^{1,2}) and total dry matter (TDM^{1,2}), a significant difference was observed for the isolated factors of variety, row spacing and plant spacing, except for DLM^{1}, which did not show a significant effect for the variety factor (Table 4).

Considering the varieties, for the FLM and FPM (Fig. 2a and b), in the first cycle, the fresh leaf matter in the BRS 506 variety presented an average of 9.57 t ha^{-1}, while the SF 15 had an average of 6.76 t ha^{-1}, with a superiority of 41% for the BRS 506. In the second cycle, the BRS 506 produced an average of 7.01 t ha^{-1} of FLM. For the fresh panicle matter, in the first cycle, the SF 15 variety obtained the highest average at almost 1.94 t ha^{-1} (Fig. 2b).

For the both years of cultivation, the smaller spacing resulted in higher average FLM as can be observed in the Fig. 2c. In the different spacings evaluated, the highest averages were observed in the first year of cultivation. In the first cycle, the FPM data fit a linear regression ($R^2 = 0.9341$) with significant decreases due to spacing increments (Fig. 2d). For the relationship between FLM and plant spacing (Fig. 2e), the smallest spacing (8 cm) favored the highest average, presenting in the first and second cycles average values of 10.11 and 8.25 t ha^{-1}, respectively. This performance was also observed in the FPM in the first crop cycle (Fig. 2f), where the lowest plant spacing had an average of 2.01 t ha^{-1}.

Row spacing effects on biomass production: The average fresh matter of the stalk in the first cycle was higher for the BRS 506 variety, with 52.3 t ha^{-1}, while the SF 15 variety had an average of 45.4 t ha^{-1} (Fig. 3a). The smaller spacing between rows resulted in the highest average FSM, in both years of cultivation, presenting better results for the 1st cycle but with small variation among the spacings (Fig. 3c). The smallest plant spacing produced the highest averages of 60.4 t ha^{-1} in the first cycle and 36.97 t ha^{-1} in the second cycle, with a superiority of 63.4% (Fig. 3e).

For the leaf dry matter (Fig. 3b) in the second growing cycle, the SF 15 variety produced the highest average (3.21 t ha^{-1}), a superiority of 13.8% compared to BRS 506 variety.

According to Fig. 3d, DLM data fitted a linear regression for both 1st cycle ($R^2 = 0.9461$) and 2nd cycle ($R^2 = 0.9638$). This variable showed a behavior in which the smaller the row spacing, the higher its values in both analyzed. The highest averages were observed in the first cycle, showing better biomass production during that year (2015).

Data in Fig. 3f showed that in the smallest plant spacing (8 cm), the highest values were found in both the first (4.81 t ha^{-1}) and in the second cycle (4.06 t ha^{-1}).

Results for the dry stalk matter are shown in Fig. 4. In the first cycle, the BRS 506 variety presented the highest average (29.51 t ha^{-1}), while the SF 15 variety excelled in the second crop cycle, with an average of 11.02 t ha^{-1}. The observed superiority for BRS 506 from one cycle to the next was 233.4% (Fig. 4a).

Table 4: Summary of ANOVA for variable with normal and standardized data by the box-cox system: Fresh matter of leaf (FLM^{1,2}), panicle (FPM^{1}), stalk (FSM^{1,2}), dry matter of leaf (DLM^{1,2}), stalk (DSM^{1,2}) and total (TDM^{1,2}) of sweet sorghum in to different planting densities produced in the semiarid region (Pentecoste, Ceara, Brazil)

VF	DF	FLM t^{1}	FPM t^{1}	FSM t^{1}	FLM t^{2}	FSMt^{2}	DLM t^{1}	DSM^{1}	TDM^{1}	DLM t^{2}	DSM t^{2}	TDM t^{2}
MS												
Block	3	0.0077^{ns}	0.1662*	0.0581^{ns}	0.3232**	0.2858*	0.0549^{ns}	89.0628^{ns}	119.0343^{ns}	0.0555**	0.1606^{ns}	0.1471^{ns}
Variety (V)	1	2.8119**	2.0126**	0.4732**	1.2105**	0.0304^{ns}	0.1148^{ns}	2318.9855**	1883.6271**	0.1411**	1.1288**	0.8855**
Plant spacing (PS)	3	1.0345**	0.1444**	0.5201**	0.6580**	0.4243**	0.4384**	194.0284*	295.5130**	0.1642**	0.4359**	0.4524**
Row spacing (RS)	2	1.5593**	0.9438**	1.4248**	2.1003**	0.4243**	2.0847**	452.0484**	782.7754**	0.7967**	1.7123**	1.9039**
V×RS	3	0.0115^{ns}	0.0059^{ns}	0.0070^{ns}	0.0881^{ns}	0.0779^{ns}	0.0166^{ns}	11.8740^{ns}	11.5596^{ns}	0.0067^{ns}	0.1370^{ns}	0.0824^{ns}
V×PS	2	0.1675^{ns}	0.0067^{ns}	0.0084^{ns}	0.0594^{ns}	0.0299^{ns}	0.0160^{ns}	12.3896^{ns}	7.1726^{ns}	0.0115^{ns}	0.0952^{ns}	0.0536^{ns}
RS×PS	6	0.0401^{ns}	0.0499^{ns}	0.0284^{ns}	0.0601^{ns}	0.0449^{ns}	0.0339^{ns}	65.3189^{ns}	87.1897^{ns}	0.0157^{ns}	0.0832^{ns}	0.0698^{ns}
V×RS×PS	6	0.0424^{ns}	0.0101^{ns}	0.0141^{ns}	0.0757^{ns}	0.0753^{ns}	0.0238^{ns}	27.3214^{ns}	29.6176^{ns}	0.0106^{ns}	0.1307^{ns}	0.0971^{ns}
Error	69	0.0631	0.0341	0.0323	0.0669	0.0623	0.0323	50.2296	54.8012	0.0119	0.1058	0.0719
Total	95	-	-	-	-	-	-	-	-		-	-
CV	-	12.04	43.71	4.63	14.08	7.36	13.87	28.81	25.08	12.74	14.19	10.31

VF: Variation factors, DF: Degree of freedom, MS: Mean square, CV: Coefficient of variation, ns, **,*respectively, not significant, significant at 1 and 5% probability of error by the F-test of the analysis of variance (ANOVA). t: Underwent Box Cox transformation ^{1}(cycle 1), ^{2} (cycle 2)

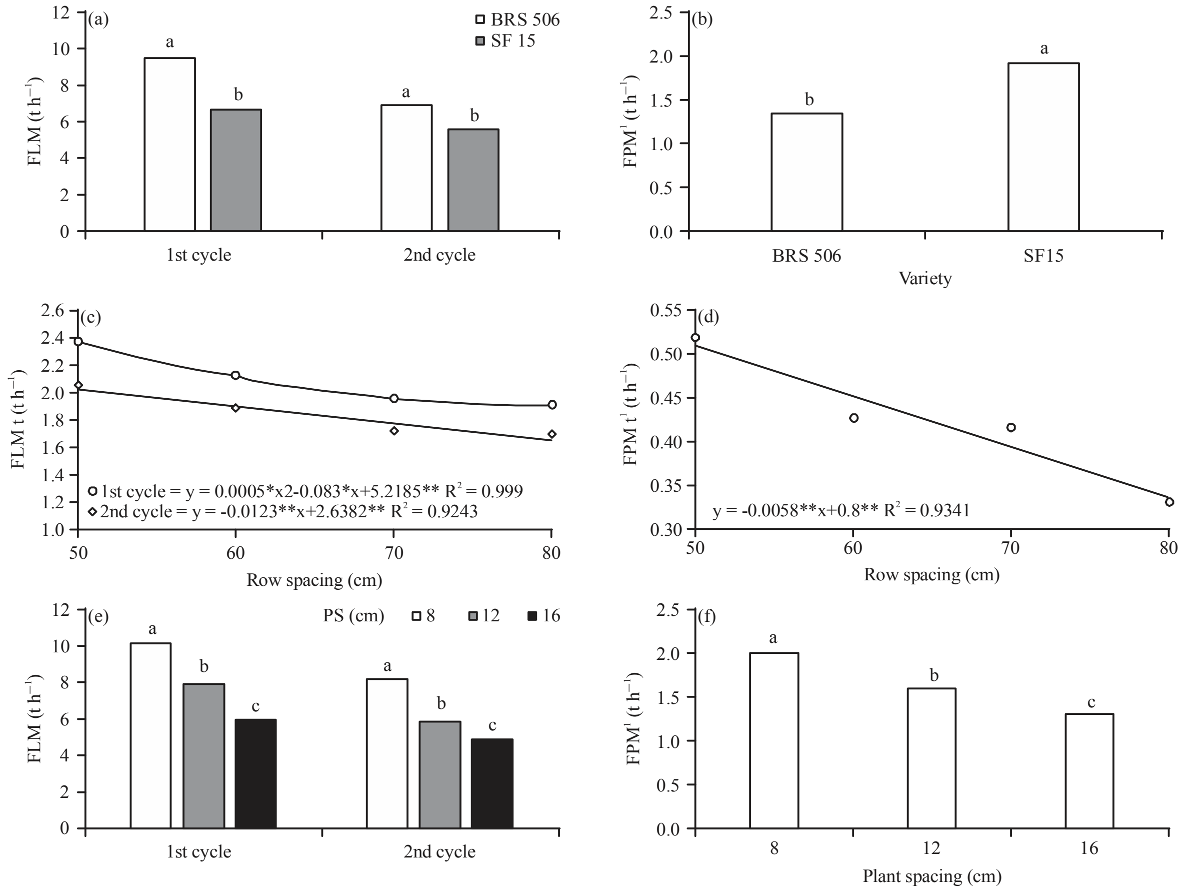

Fig. 2(a-f): Fresh leaf matter (FLM) as a function of the (a) Cycles, (c) Row and (e) Plant spacings and fresh panicle matter (FPM) as a function of the (b) Variety, (d) Row spacing and (f) Plant spacing of two sweet sorghum varieties with different planting densities in a semiarid region (Pentecoste, Ceara, Brazil)

1: First cycle; 2: Second cycle, *, **respectively, significance by the F-test when significant at the 5% level and significant at the 1% level. PS: Spacing between plants. t: Data transformation by the Box Cox system ($\lambda = 0$ (FLM^1), $\lambda = 0$ (FLM^2) and $\lambda = -0.47979798$ (FPM^1))

The smaller spacing between plants favored the production of dry stalk matter, which were represented by 8 and 12 cm in the 1st cycle, which did not differ between them and by 8 cm in the 2nd cycle, which was statistically higher than 12 cm and 16 cm spacings (Fig. 4b).

Graph of the regression equation for the dry stalk matter as a function of the row spacing in the first and second cycle are given in Fig. 4c and d. The lowest spacing produced the highest averages, showing that the values were negatively affected by the spacing increases in both the first cycle (Fig. 4c) and the second cycle (Fig. 4d), resulting in a simple linear regression model with coefficients of determination of 0.791 and 0.8497, respectively.

As Fig. 4 also provided the values for total dry matter. Just as with the DSM, the BRS 506 produced the highest average in the first year of cultivation, with an average of 33.95 t ha^{-1}. In the second cycle, SF 15 presented the highest average with 14.71 t ha^{-1} (Fig. 4e).

Figure 4f illustrates that in the first cycle, no significant difference occurred between the average TDM in the spacing of 8 and 12 cm between the plants, being respectively 34.27 and 29.88 t ha^{-1}. However, in the second cycle, the smaller spacing favored the production of total dry matter, with an average of 12.55 t ha^{-1}.

The smaller spacing between the rows provided the highest values of the average TDM in the first and second cycles. As can be seen in Fig. 4g and 4h, as the spacing increased, the volume of TDM decreased, resulting in similar linear regression models negatively affected by higher spacings in the first cycle ($R^2 = 0.8164$) and in the second cycle ($R^2 = 0.8938$).

DISCUSSION

In this study it was observed that during the first year there was a cumulative precipitation of 652.6 mm and

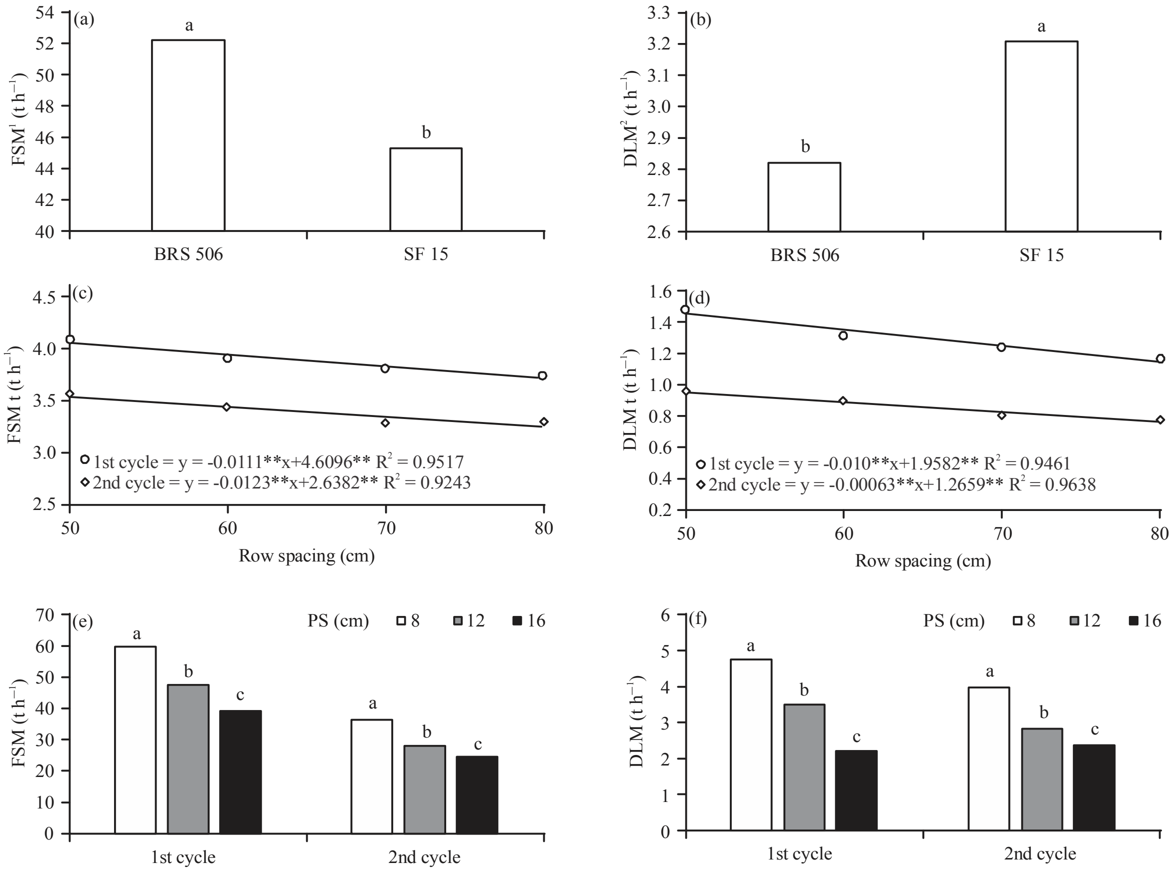

Fig. 3(a-f): Fresh stalk matter (FSM) and dry leaf matter (DLM) as a function of the (a and b): Varieties, (c and d) Row, (e and f) and Plant spacings of two sweet sorghum varieties submitted to different planting densities in a semiarid region (Pentecoste, Ceara, Brazil)

2: Second cycle, *,**respectively, significance by the F test with the significance level of 5% and significance level at 1%. PS: Spacing between plants. t: Data transformation by the Box Cox system ($\lambda = 0$ (DSM^2), $\lambda = 0$ (DLM^1), $\lambda = -0.47979798$ (DLM^2))

temperatures between 27.5 and 36°C. While in the second year, we measured 284.8 mm of accumulated precipitation during the experiment, with temperatures between 21.3 and 38.1°C (Fig. 1). Current data, therefore, confirmed that changes currently observed related to the world climatic conditions may cause impacts in biomes, biodiversity and agriculture. Evidence of this climatic issue was observed during the experiment, resulting in considerable differences in rainfall between the first and second year of growth. Hence, drought may be considered the most important limiting factor for crop production[17,18].

In these two situations, the present study showed the behavior of the varieties. The first year had the recommended amount of rain for an adequate crop. However, the second year received precipitation below what the literature recommends as ideal, which is between 375 and 625 mm for the sweet sorghum crop[19]. This verifies with work developed by Albuquerque *et al.*[9] with sorghum at 50 and 70 cm spacings between rows, in northern Minas Gerais. They found that a precipitation above 500 mm during the crop cycle was required for satisfactory production.

Considering the average biomass yield of the experiments individually for each year of cultivation, in the first year, the BRS 506 variety presented the best results, with a superiority of 14.2% total fresh matter in relation to the SF 15 variety (Table 3) and fresh stalk matter of 15.2% (Fig. 3a). For Pereira-Filho *et al.*[20], fresh matter is a very important feature to consider in sweet sorghum and reflects directly on the volume of the broth. The national average total biomass productivity for sweet sorghum[21] is 50 t ha^{-1} and the average values obtained in this experiment, conducted in the dry season in the caatinga of Ceará, in the first cycle for BRS 506 was 70.78 t ha^{-1} and therefore quite satisfactory.

Lower values were observed in works developed in two regions of northeastern Mexico, conducted under an irrigated regime by Williams-Alanis *et al.*[22]. They evaluated the

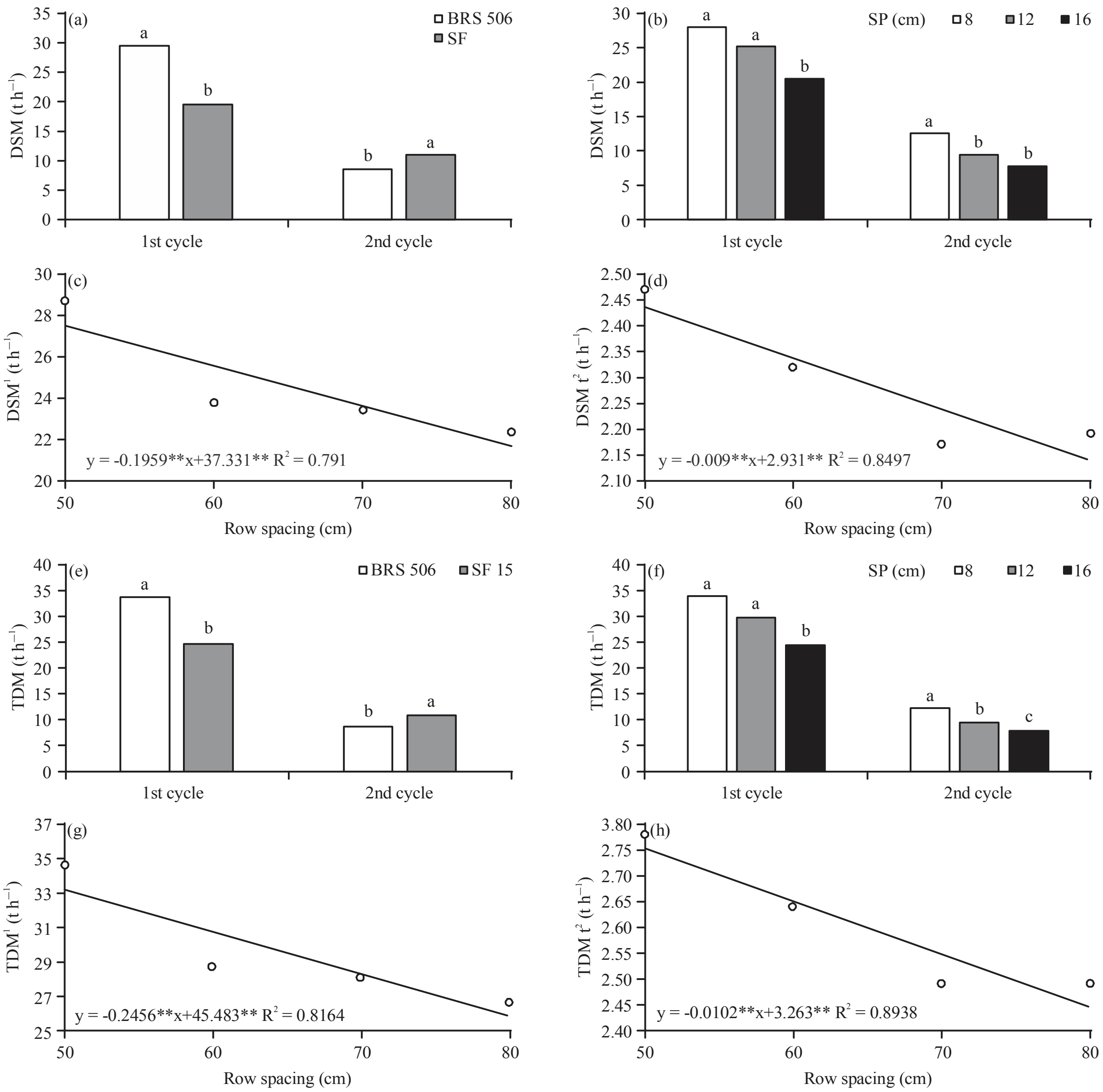

Fig. 4(a-h): Dry stalk matter (DSM) as a function of the (a) Cycles, (b) Plant and row spacings during the (c) First and (d) Second cycle and total dry matter (TDM) as a function of the (e) Cycles, (f) Plant and row spacings during the (g) First and (h) Second cycle of two sweet sorghum varieties at different planting densities in the semiarid region (Pentecoste, Ceara, Brazil)

1: First cycle; 2: Second cycle, *,**respectively, significance by the F test with the significance level of 5% and significance level at 1%. SP: Spacing between plants. t: Data transformation by the Box Cox system ($\lambda = 0$ (DSM^2), $\lambda = 0$ (DLM^1), $\lambda = -0.47979798$ (DLM^2))

agronomic characteristics of different genotypes of sweet sorghum and obtained average fresh biomass weight of 44.37 t ha^{-1} and fresh stalk weight of 35.43 t ha^{-1}.

In the second cropping cycle, the SF 15 variety was more tolerant to the adverse conditions of the study region, but the best averages obtained by it were below the national average. For the dry stalk matter of SF 15, an average of 11.02 t ha^{-1} was observed, whereas in the conditions of the first cycle the same variety had a superiority of 78.6% (Fig. 4a).

This superiority of SF 15 in relation to BRS 506, under climatic conditions of the second cycle, can be justified because it is a variety developed by the Instituto Agronômico de Pernambuco (IPA) to be planted in the semiarid conditions found in northeastern Brazil. Dutra *et al.*[23] evaluated the biomass and ethanol production of the SF 15 variety in the semiarid region, reporting that cultivars SF 15 and BR 506 seem to be very promising as an energy crop in semiarid regions.

Defining an ideal arrangement of plants in the edaphoclimatic conditions faced in semiarid region is extremely important[9]. Mekdad and Rady[24], evaluated five varieties of sweet sorghum in dry environments in southeastern Egypt, found that under the studied conditions the Brandes variety stood out from the others and should be cultivated at the highest plant density rate (166,000 plant ha^{-1}).

In the present experiment, the smaller spacing between the rows favored the biomass production in both years of cultivation. However, in the climatic conditions of the first year, the average values for all variables were higher. Pereira-Filho *et al.*[20], evaluated different cultivars of sweet sorghum and sowing densities, verified that the increased sowing density provided higher green mass yield, which corroborate with the results of this test. It is worth mentioning that the observed values of total fresh matter were 80.62 t ha^{-1} in the first cycle and 45.39 t ha^{-1} in the second cycle (Table 3), with a superiority of 77.64%.

In the conditions of the second cycle, with a precipitation of 284.8 mm (Fig. 1), 16.12 t ha^{-1} of total dry matter was observed at 50 cm spacing (Fig. 4h). Tang *et al.*[10], evaluated sweet sorghum at different planting densities in a semiarid region of China, with an average precipitation of 348.3 mm they obtained the highest dry biomass yields (10.5 plants m^2) with 11.9 t ha^{-1}.

Plants with greater leaves or greater weight are presumed to have greater photosynthetic rate and consequently better performance in relation to the transport of photoassimilates[7]. The smallest spacings produced the greatest fresh averages (Fig. 2c) and consequently the highest average FSM (Fig. 3c) and TDM (Fig. 4g and h). For sweet sorghum, in a tropical climate region of India with a dry season, Sahu, Nandeha[25] observed better performance in the smallest spacing used (50×15 cm), obtaining an average green biomass of 25.77 t ha^{-1}, values lower than those reported in this experiment.

The higher averages observed in the first year of cultivation of this experiment probably occurred due to the better climatic conditions, mainly the amount of rain during the experiment period, resulting in well-developed plants, with more gains in quantitative and qualitative variables. This behavior confirmed that sorghum biomass production may be affected by abiotic stress, such as water or salt stress[26].

CONCLUSION

Current results suggested the sweet sorghum BRS 506 variety for biomass production in semiarid regions. In addition, the plant density had a pronounced effect on crop yield at 50×8 cm spacing, allowing for higher biomass yields.

SIGNIFICANCE STATEMENT

This study discover the use of high-density planting in sweet sorghum can be beneficial for this crop biomass production. Our manuscript presents new findings regarding two new sweet sorghum cultivars grown under peculiar spacing arrangements and environmental conditions, which have not been assessed so far. This study will help the researcher to uncover the critical areas of sweet sorghum biomass production in semiarid regions that many researchers were not able to explore. Thus a new theory on how spacing arrangements and environmental factors affect this crop development may be arrived at.

REFERENCES

1. CONAB., 2017. Acompanhamento da Safra Brasileira de cana-de-acucar. V. 3. Companhia Nacional de Abastecimeto, pp: 1-77.
2. Do Valle Lozano, E., L.I.M. Blanco, G.U. Alcantara, L.C. Nogueira, S. Ciaramello and G.H.G. Costa, 2018. Effect of application of flowering inhibitor on sweet sorghum. Afr. J. Agric. Res., 13: 196-201.
3. Jaiswal, D., A.P. De Souza, S. Larsen, D.S. LeBauer and F.E. Miguez *et al.*, 2017. Brazilian sugarcane ethanol as an expandable green alternative to crude oil use. Nature Climate Change, 7: 788-792.
4. De Oliveira, A.B., N.L.M. Alencar, J.T. Prisco and E. Gomes-Filho, 2011. Accumulation of organic and inorganic solutes in NaCl-stressed sorghum seedlings from aged and primed seeds. Sci. Agric., 68: 632-637.
5. Almodares, A. and M.R. Hadi, 2009. Production of bioethanol from sweet sorghum: A review. Afr. J. Agric. Res., 4: 772-780.
6. Rao, S.S., J.V. Patil, P.V.V. Prasad, D.C.S. Reddy and A.A. Kumar *et al.*, 2013. Sweet sorghum planting effects on stalk yield and sugar quality in semi-arid tropical environment. Agron. J., 105: 1458-1465.
7. Da Silva, T.M., M.F.Q. Lopes, A.B. de Oliveira, A.L.S.P. Nogueira, I.E.T. Viana and B.F. da Trindade Lessa, 2017. Physiological quality of sweet sorghum [*Sorghum bicolor* (L.) Moench.] seeds in response to planting density in semi-arid region. Aust. J. Crop Sci., 11: 694-700.
8. Fischer-Filho, J.A., G.G.C. Gomes, A.C. Bolonhezi, J.A.V. Oliveira and B.T.R.R. Santos, 2014. Sacarino characteristics of growth of hybrid sorghum. Ciencia Tecnol.: Fatec-JB, Jaboticabal, 6: 11-15.
9. Albuquerque, C.J.B., F.D. Tardin, R.D.C. Parrella, A.D.S. Guimaraes, R.M. de Oliveira and K.D.J. Silva, 2012. Sweet sorghum in different row spacing and plant densities in Minas Gerais state, Brazil. Rev. Brasil. Milho Sorgo, 11: 79-95.

10. Tang, C., C. Sun, F. Du, F. Chen, A. Ameen, T. Fu and G.H. Xie, 2018. Effect of plant density on sweet and biomass Sorghum production on semiarid marginal land. Sugar Tech., 20: 312-322.
11. Da Silva, J.M.F., A.S. Dutra, F.T. da Camara, A.A. Pinto and F.E. da Silva, 2017. Row spacing, plant density, sowing and harvest times for sweet sorghum. Pesquisa Agropecuaria Trop., 47: 408-415.
12. Embrapa, 2013. Sistalka Brasileiro de Classificacao de Solos. 3rd Edn., Empresa Brasileira de Pesquisa Agropecuaria, Bras, Page: 353.
13. Alvares, C.A., J.L. Stape, P.C. Sentelhas, G. de Moraes, J. Leonardo and G. Sparovek, 2013. Koppen's climate classification map for Brazil. Meteorol. Zeitschrift, 22: 711-728.
14. ESTATCAMP., 2016. Software action, 2016. Disponivel em. ESTATCAMP., Sao Carlos, Brazil.
15. Silva, F.A.S. and C.A.V. de Azevedo, 2009. Principal components analysis in the software Assistat-statistical attendance. Proceedings of the 7th World Congress on Computers in Agriculture Conference, June 22-24, 2009, American Society of Agricultural and Biological Engineers, Reno, NV., USA.
16. Ferreira, D.F., 2011. Sisvar: A computer statistical analysis systalk. Cienc. Agrotec., 6: 1039-1042.
17. De Oliveira, A.B., N.L.M. Alencar and E. Gomes-Filho, 2012. Physiological and Biochemical Responses of Semiarid Plants Subjected to Water Stress. In: Water Stress, Rahman, M.R. (Ed.)., Vol. 43, InTech, Crotia, pp: 58.
18. Nunes, R.L.C., A.B. de Oliveira and A.S. Dutra, 2014. Agronomic performance of onion hybrids in Barauna, in the semi-arid region of Brazil. Rev. Cien. Agron., 45: 606-611.
19. Buso, W.H.D., H.S. Morgado, L.B. Silva and A.F. de Souza Franca, 2011. Utilizacao do sorgo forrageiro na alimentacao animal. Rev. PUBVET., 5: 1143-1149.
20. Pereira-Filho, I.A., R.C. Parrella, J.A.A. Moreira, A. May, V.F. Souza and J.C. Cruz, 2013. Avaliacao de cultivares de sorgo sacarino [*Sorghum bicolor* (L.) Moench] em diferentes densidades de semeadura visando a caracteristicas importantes na producao de etanol. Rev. Bras. Milho e Sorgo, 12: 118-127.
21. Lima, A.M., D.T. Santos and J.C. Garcia, 2011. Viabilidade economica e arranjos produtivos. Agroe. Rev., 3: 43-45.
22. Williams-Alanis, H., F. Zavala-Garcia, G. Arcos-Cavazos, M. del Carmen Rodriguez-Vazquez and E. Olivares-Saenz, 2017. Caracteristicas agronomicas asociadas a la produccion de bioetanol en genotipos de sorgo dulce 1. Agron. Mesoamericana, 28: 549-563.
23. Dutra, E.D., A.G.B. Neto, R.B. de Souza, M.A. de Morais, Jr., J.N. Tabosa and R.S.C. Menezes, 2013. Ethanol production from the stem juice of different sweet sorghum cultivars in the state of Pernambuco, Northeast of Brazil. Sugar Tech., 15: 316-321.
24. Mekdad, A.A.A. and M.M. Rady, 2016. Productivity response to plant density in five Sorghum bicolor varieties in dry environments. Ann. Agric. Crop Sci., Vol. 1.
25. Sahu, H. and N. Nandeha, 2018. Effect of planting density and levels of nitrogen on yield and yield attributes of sweet Sorghum (*Sorghum bicolor* [L.] Moench) varieties. Int. J. Chem. Stud., 6: 2098-2101.
26. De Oliveira, A.B., E.H. Silva do Nascimento, E.C. Marques, V. Ruppenthal and J. Eneas-Filho, 2018. Differential responses of antioxidative defense system to NaCl in grain and forage sorghum during germination and seedling establishment. Aust. J. Crop Sci., 12: 1064-1071.