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AGRONOMIC AND PHYSIOLOGICAL INDICATORS FOR SELECTION OF WATER RESTRICTION-TOLERANT GRAIN SORGHUM GENOTYPES

Abstract – Selection of tolerant plants is essential to meet the challenges of food production. The objective of this study was to evaluate agronomic and physiological characteristics as indicators for the selection of water restriction-tolerant grain sorghum genotypes. The experiments were conducted in 2014, 2015 and 2016. Two trials were installed in each year, one subjected to full irrigation and the other to water restriction. In the first one, irrigation was performed periodically, at a 2-day interval, to maintain soil moisture close to field capacity. In the second one, irrigation was suspended in the pre-flowering period, keeping the restriction for 30 days. Four sorghum genotypes were used: 9503062 and 9618158 - drought sensitive (S); 9910032 and P898012 - drought tolerant (T). The experimental design was randomized blocks with four replicates. Stomatal conductance, relative chlorophyll content, photosynthetically active leaf area, plant height and yield were evaluated. Joint analysis of the experiments subjected to full irrigation and water restriction of the three years was performed. Under water restriction it was not possible to distinguish between sensitive and tolerant materials. The characteristics evaluated in this experiment did not allow a conclusive distinction between tolerant and sensitive genotypes.
Keywords: *Sorghum bicolor* L., drought, water deficit, grain yield, stomatal conductance.

INDICADORES AGRONÔMICOS E FISIOLÓGICOS PARA SELEÇÃO DE GENÓTIPOS DE SORGO GRANÍFERO TOLERANTES À RESTRIÇÃO HÍDRICA

Resumo - A seleção de plantas tolerantes é essencial para enfrentar os desafios da produção de alimentos. Objetivou-se avaliar características agronômicas e fisiológicas como indicadores para a seleção de genótipos de sorgo granífero tolerantes à restrição hídrica. Os experimentos foram conduzidos nos anos 2014, 2015 e 2016. Em cada ano foram instalados dois ensaios, sendo um submetido à irrigação plena e outro à restrição hídrica. No primeiro, a irrigação foi realizada periodicamente, com turno de rega a cada dois dias para manter a umidade do solo próxima à capacidade de campo. No segundo a irrigação foi cortada no período pré-florescimento, mantendo a restrição por 30 dias. Foram utilizados quatro genótipos de sorgo: 9503062 e 9618158 - sensíveis à seca (S); 9910032 e P898012 – tolerantes à seca (T). O delineamento experimental foi em blocos ao acaso, com quatro repetições. Avaliou-se: condutância estomática, teor relativo de clorofila, área foliar fotossinteticamente ativa, altura de plantas e produtividade. Foi realizada a análise conjunta dos experimentos submetidos à irrigação plena e à restrição hídrica dos três anos. Sob restrição hídrica não foi possível distinguir os materiais sensíveis dos tolerantes. As características avaliadas neste experimento não permitiram a distinção de forma conclusiva dos genótipos tolerantes em relação aos sensíveis.
Palavras-chave: *Sorghum bicolor* L., seca, déficit hídrico, produtividade de grãos,

Developing water stress-tolerant plants is essential to face the challenges of food production, particularly in arid and semi-arid regions that are vulnerable to environmental stresses (Badigannavar et al., 2018). The selection of tolerant cereals is part of the solution to this problem.

As a drought-tolerant crop, sorghum is widely grown in the most arid areas of the world. Endowed with morphological and biochemical mechanisms that confer xerophyte characteristics, this species has a natural waxiness that conditions it to lose less water during transpiration (Tardin et al., 2013). Under conditions of water stress, the plant has defense mechanisms that reduce its metabolism and curl up its leaves and, after this period, the normal state of development returns in an extraordinary way (Magalhães & Durães, 2003).

Although it shows wide adaptation to abiotic stresses, the response may vary depending on the time when the stress is experienced (pre-flowering or post-flowering, for example) and from genotype to genotype. Such variation may be due to morphological and physiological changes (Borrell et al., 2006).

Crops face different drought scenarios, consequently the physiological characteristics that confer drought resistance in specific environments may vary (Ghanem et al., 2015).

Evaluating drought resistance is a complex procedure, as it involves several processes of the plant, often manifesting itself in the significant loss of yield (Badigannavar et al., 2018). A good understanding of the factors that limit yield under drought requires an integrated evaluation of plant response and identification of characteristics involved at agronomic, morphological, physiological and molecular levels (Emendack et al., 2018).

Therefore, the objective of this study was to evaluate agronomic and physiological characteristics as indicators for the selection of grain sorghum genotypes tolerant to water restriction.

Material and Methods

The experiments were conducted at the experimental farm of Embrapa Maize and Sorghum, located in the irrigated perimeter of Gorutuba in the municipality of Nova Porteirinha, Minas Gerais, located in the Brazilian semi-arid region (Longitude 43º 16’ 18.2” W, and Latitude 15º 49’ 51” S), with 540 m altitude, and Aw climate according to Köppen’s classification, that is, tropical with dry winter and average air temperature in the coldest month exceeding 18 °C. The average rainfall of the region is approximately 870 mm, with average annual temperature of 24 ºC, insolation of 2,700 hours year^{-1} and average relative humidity of 65%.

The site and period to install the experiments were chosen based on the history of occurrence of low incidence of rainfall, so that the water supply was controlled only by irrigation, with no interferences of rainfall, along the experiments.

The maximum and minimum temperatures, as well as the average rainfall observed during the period of conduction of the experiments, are shown in Figure 1.

The soils of the site are classified as *Latossolo Vermelho-Amarelo epieutrófico* (Oxisol), with sandy clay loam texture. The experimental design used was randomized blocks, with four replicates, totaling 16 plots. Each experimental plot consisted of four 5-m-long rows spaced by 0.5 m, considering the two central rows as useful area. In each year (2014, 2015 and 2016) two trials were installed side by side, one subjected to full irrigation and the other to water

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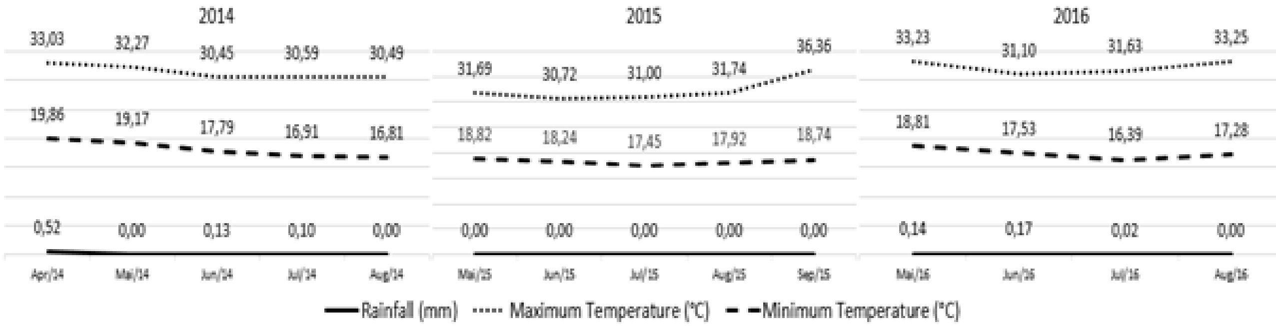

Figure 1. Average rainfall and temperatures (minimum and maximum) referring to the period of conduction of the experiments, in the years 2014, 2015 and 2016, in the municipality of Nova Porteirinha – MG, Brazil (Source: INMET/BDMEP - 2018).

restriction. In each trial, four contrasting sorghum genotypes were used for drought tolerance: 9503062 and 9618158 - drought sensitive (S); 9910032 and P898012 - drought tolerant (T), which constituted the treatments. The genotypes used are experimental hybrids, from the sorghum breeding program of the Brazilian Agricultural Research Corporation - EMBRAPA. They were previously selected and characterized based on data from experiments previously conducted by EMBRAPA.

Soil tillage was carried out using the conventional process with plowing harrow and leveling harrow, and later the area was furrowed. Planting was performed on April 10, 2014, May 15, 2015 and May 11, 2016, respectively, by manual sowing, using 18 seeds per meter. Thinning was done 15 days after sowing, leaving 10 plants per meter, totaling a final stand of 200,000 plants ha^{-1}. Basal and top-dressing fertilizations were performed based on soil analysis according to the recommendation for the crop in the state of Minas Gerais. Cultural practices and phytosanitary treatments were performed according to the need of the crop.

Irrigation was applied using a fixed conventional sprinkler system, with sprinklers spaced by 12 x 12 m, operating pressure of 250 kPa, nozzles of 4.0 x 2.6 mm in diameter and with flow rate of 1.6 m^3 h^{-1}. Crop irrigation for both environments was performed periodically, at a 2-day interval, to keep soil moisture close to field capacity. In the trials subjected to full irrigation, the plots were regularly irrigated, always keeping the soil moisture close to field capacity until the physiological maturity of the grains. In the trials subjected to water restriction, the plots were regularly irrigated, always keeping soil moisture close to the field capacity until the pre-flowering period, at which time water restriction was imposed for a period of 30 days. After this period, water restriction was suspended.

At the end of the water restriction period, the following evaluations were carried out:

- Stomatal conductance (mmol m^{-2} s^{-1}), in three plants per plot, using a porometer (Decagon Devices, Inc., Pullman, WA, USA); and

- Relative chlorophyll content, in four plants per plot, using a portable chlorophyll meter (SPAD "Soil plant analysis development", Minolta SPAD 502 Osaka, Japan).

These evaluations were carried out in the

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morning between 8:00 and 10:00 h, always on the flag leaf.

At harvest, the photosynthetically active leaf area (cm^2) was evaluated in three plants per plot, estimated by the product of the measurements of length and largest width of each photosynthetically active leaf blade multiplied by the coefficient of 0.75 (Balbinot Junior and Backes, 2004); plant height (cm), measured in ten plants per plot, considering the length between the collar region and the apex of the panicle; and grain yield per hectare, obtained by measuring the mass and moisture content of the grains in the plot, correcting the value of the mass for 13% moisture content and extrapolating the result to kg ha^{-1}.

The data were subjected to a joint analysis of variance of the experiments with full irrigation and with water restriction, in the three years, and when significant by the F test ($p<0.05$), the means were compared by Tukey test at 5% significance level.

Results and Discussion

Regarding the stomatal conductance, considering the genotypes within the water regime, the genotype P898012 (T) stood out in relation to the others, which did not differ from one another under full irrigation (Table 1). The genotypes did not differ from one another when subjected to water restriction.

Genotypes P898012 (T) and 9503062 (S) showed lower values of stomatal conductance when subjected to water restriction, compared to full irrigation.

Water restriction caused a 41.63% reduction in stomatal conductance.

Higher values of stomatal conductance were observed in 2014 under full irrigation (Table 2). Under water restriction, 2015 stood out, with plants showing higher values for this variable. It is also observed that, in 2015, there was no difference between the adopted water regimes. In 2014 and 2016, full irrigation led to higher results compared to water restriction.

The degree of stomatal opening adjusts to the oscillations of environmental factors. Under stress conditions, especially water and salt stresses, the reduction in stomatal opening can be seen as a positive response of the plant for water maintenance (Taiz & Zeiger, 2013).

Reduction in stomatal opening is one of the first responses of plants to water stress, which reduces transpiration and photosynthesis and increases leaf temperature. However, the reduction of photosynthesis may also be related to nonstomatal limitations. Thus, when the light excitation energy is superior to the energy used in the photosynthetic process and/or under conditions of above-optimal temperatures, there is accumulation of reactive oxygen species (ROS), such as hydrogen peroxide (Cerqueira et al., 2015), which may not only modify and damage the photosynthetic apparatus due to oxidative stress (Dias et al., 2014), but also affect the stomatal behavior.

Knowing that stomata regulate gas exchange, increments in stomatal conductance imply CO_2 influx into the leaf mesophyll, enabling higher rates of carbon dioxide assimilation. Sorghum plants curl up their leaves in such a way as to leave a narrow leaf angle in response to water and thermal stresses, effectively reducing transpiration and exposure of the leaf area to solar radiation (Hadebe et al., 2017). Factors that delay the dehydration by reducing water loss, such as reduction in stomatal conductance and leaf growth, are processes that also reduce yield.

The sensitivity of sorghum stomatal conductance to soil water availability and vapor

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Table 1. Stomatal conductance (s cm^{-1}) and relative chlorophyll content (SPAD units) as a function of genotypes and water regimes adopted in the cultivation of grain sorghum in Nova Porteirinha, MG.

Genotype	Stomatal conductance		Relative chlorophyll content	
	Full irrigation	Water restriction	Full irrigation	Water restriction
9910032 (T)	155.30 Ba	124.03 Aa	53.57 Aa	48.05 Ab
P898012 (T)	225.68 Aa	79.43 Ab	49.10 Ba	40.26 Bb
9503062 (S)	130.54 Ba	79.77 Ab	52.29 ABa	47.92 Ab
9618158 (S)	102.94 Ba	75.37 Aa	53.22 ABa	51.68 Aa
CV (%)	44.89		7.78	

Means followed by the same uppercase letter in the column and lowercase letter in the row do not differ by ukey test at 5% probability level ($p \leq 0.05$).

Table 2. Stomatal conductance (s cm-1) and relative chlorophyll content (SPAD units) as a function of years and water regimes adopted in the cultivation of grain sorghum in Nova Porteirinha, MG.

Year	Stomatal conductance		Relative chlorophyll content	
	Full irrigation	Water restriction	Full irrigation	Water restriction
2014	218.12 Aa	82.31 Bb	48.74 Ba	40.20 Cb
2015	132.88 Ba	130.06 Aa	49.62 Ba	47.34 Ba
2016	109.84 Ba	56.58 Bb	57.76 Aa	53.39 Ab
CV (%)	44.89		7.78	

Means followed by the same uppercase letter in the column and lowercase letter in the row do not differ by Tukey test at 5% probability level ($p \leq 0.05$).

pressure deficit varies among genotypes (Hadebe et al., 2017). This behavior could be observed in this study (Table 1); however, the results obtained demonstrate the impossibility of this parameter being conclusive for the identification of tolerant genotypes, since the tested materials did not differ from one another under water restriction.

Although there were no large variations in temperature and rainfall (Figure 1) between the years of cultivation, statistical differences were found for stomatal conductance, relative chlorophyll content and photosynthetically active leaf area (Tables 2 and 4). This fact demonstrates the complexity of the expression of tolerance to water restriction, which can be influenced by several factors, such as incidence of pests and diseases, photoperiod, wind speed, relative humidity, competition with weeds, among others that were not evaluated in this study.

Plant species reduce photosynthesis by modifying the photosynthetic apparatus under water stress (Hadebe et al., 2017). The reduction in chlorophyll content is part of this modification. Thus, the analysis of photosynthetic pigments can be an important tool for assessing the integrity of the cell's internal apparatus and provides an accurate technique for detecting plants that are tolerant to water stress (Bacelar et al., 2012). However, in the present study, the relative chlorophyll content did not conclusively distinguish tolerant from sensitive plants to water stress (Table 1).

Genotype 9910032 (T) had a relative chlorophyll content higher than that of P898012 (T) under full irrigation (Table 1). Under water restriction, genotypes 9910032 (T), 9503062 (S) and 9618158 (S) did not differ from each other and were superior to P898012 (T). Only genotype 9618158 (S) did not differ when subjected to both water regimes, and the others showed better results when subjected to full irrigation.

Higher values of relative chlorophyll content were obtained in 2016, under both water regimes (Table 2). In 2015, there was no difference between water regimes, but in 2014 and 2016 higher values were obtained under full irrigation. In all years, plants subjected to full irrigation showed higher relative chlorophyll content. There was an average reduction of 9.74% in the relative chlorophyll content in plants subjected to water restriction. It is important to highlight that stomatal conductance was also higher when the genotypes were subjected to full irrigation. From this result, it can be inferred that the photosynthetic rates were higher in plants that were subjected to full irrigation.

According to O'Neill et al. (2006), cultivars that maintain higher chlorophyll contents under water deficit are expected to have a better ability to tolerate this condition, due to the close relationship between chlorophyll, photosynthetic potential and yield. Thus, the values of relative chlorophyll content were considered low in the genotypes P898012 (T) and 9910032 (T) compared to 9503062 (S) and 9618158 (S), under water restriction conditions.

Chlorophyll content varies according to the phenological stage of the crop and is genotype-dependent (Wang et al., 2014). The plant's ability to remain green during grain filling under water stress conditions is called delayed senescence or "stay green", which allows the continuation of photosynthesis, which can result in grain filling and higher yields compared to senescent genotypes (Tolk et al., 2013).

According to Netto et al. (2005), SPAD readings below 40 indicate the onset of chlorophyll deficiency, which affects the photosynthetic process. Santana et al. (2017), evaluating twelve commercial hybrids of grain sorghum under conditions with and without water restriction in Teresina-PI, obtained SPAD values of 53.9 with restriction and 56.0 without restriction. Magalhães et al. (2010), evaluating morphophysiological and production characteristics of six sorghum genotypes subjected to water stress in a greenhouse, found SPAD values at the beginning of stress ranging from 53.11 to 60.08. Similar results were obtained in the present study, in which the mean SPAD values with water restriction were 40.20, 47.34 and 53.39 for the years 2014, 2015 and 2016, respectively. Under full irrigation, the means were 48.74, 49.62 and 57.76 for the years 2014, 2015 and 2016, respectively (Table 2).

For Efeoğlu et al. (2009), the reduction in chlorophyll content is associated with the acceleration of leaf senescence caused by water deficit. Therefore, such reduction can have an impact on production as it reduces photosynthetic efficiency, which is directly related to the amount of chlorophyll in the leaves (Santana et al., 2017).

For the photosynthetically active leaf area, in crops under full irrigation, in the years 2014 and 2016, genotype P898012 (T) showed lower values compared to the others, while in 2015 there was no difference between genotypes (Table 3). Under water restriction, genotype P898012 (T) showed the lowest

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value of leaf area in all years, and genotype 9503062 (S) stood out positively in relation to the others in 2016. In 2014, the cultivation under full irrigation led to superior results for all genotypes, except 9618158 (S). In 2015, the genotypes did not differ in response to the adopted water regime, except for P898012 (T), which had better results under full irrigation. In 2016, cultivation under full irrigation led to superior results for all genotypes, except P898012 (T).

On average, the reduction of photosynthetically active leaf area of plants subjected to water restriction was equal to 35.69% compared to those under full irrigation. Genotype 9910032 (T), under full irrigation, did not differ between years of cultivation; however, under water restriction, worse results were observed in 2014 (Table 4). Genotype P898012 (T) showed better results in 2014 and 2015, regardless of the water regime adopted. Genotype 9503062 (S) showed better results in 2014 and 2016, under full irrigation; when subjected to water restriction, it showed better results in 2015 and 2016. Genotype 9618158 (S) did not differ in relation to the years under both water regimes adopted.

Table 3. Photosynthetically active leaf area (cm²) as a function of years, genotypes (tolerant (T) and sensitive (S)) and water regimes adopted in the cultivation of grain sorghum in Nova Porteirinha, MG.

Year	Genotype	Full irrigation	Water restriction
2014	9910032 (T)	2455.64 Aa	860.76 BCb
	P898012 (T)	1201.25 Ba	276.47 Cb
	9503062 (S)	2774.66 Aa	1334.45 ABb
	9618158 (S)	2073.63 Aa	1906.10 Aa
2015	9910032 (T)	2394.08 Aa	1920.63 Aa
	P898012 (T)	1587.40 Aa	975.55 Bb
	9503062 (S)	2156.58 Aa	2194.19 Aa
	9618158 (S)	1972.14 Aa	1859.69 Aa
2016	9910032 (T)	2499.52 Aa	1230.55 Bb
	P898012 (T)	622.84 Ba	187.40 Ca
	9503062 (S)	2987.33 Aa	2232.51 Ab
	9618158 (S)	2498.03 Aa	1242.39 Bb
CV (%)	25.09		

Means followed by the same uppercase letter in the column and lowercase letter in the row do not differ by Tukey test at 5% probability level ($p \leq 0.05$).

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Table 4. Photosynthetically active leaf area (cm^2) as a function of genotypes (tolerant (T) and sensitive (S)), years and water regimes adopted in the cultivation of grain sorghum in Nova Porteirinha, MG.

Genotype	Year	Full irrigation	Water restriction
9910032 (T)	2014	2455.64 A	860.76 B
	2015	2394.08 A	1920.63 A
	2016	2499.52 A	1230.55 AB
P898012 (T)	2014	1201.25 AB	276.47 AB
	2015	1587.40 A	975.55 A
	2016	622.84 B	187.40 B
9503062 (S)	2014	2774.66 AB	1334.45 B
	2015	2156.58 B	2194.19 A
	2016	2987.33 A	2232.51 A
9618158 (S)	2014	2073.63 A	1906.10 A
	2015	1972.14 A	1859.69 A
	2016	2498.03 A	1242.39 A
CV (%)	25.09		

Means followed by the same uppercase letter in the column do not differ from each other by Tukey test at 5% probability level ($p \leq 0.05$).

Plant growth and yield are promoted by photosynthesis and depend on the interception of light and, consequently, on leaf area. In general, photosynthesis is proportional to leaf area (Taiz & Zeiger, 2013) and this is, therefore, a valuable parameter to evaluate the effects of water stress on plants. Photosynthetic efficiency depends on the photosynthetic rate per unit of leaf area and the interception of solar radiation, which, among other aspects, are influenced by the characteristics of the canopy architecture and the size of the photoassimilation system. Thus, the leaf surface of a plant is the basis of the potential yield of the crop.

In an experiment evaluating 21 sorghum genotypes in relation to post-flowering water stress, Rakshit et al. (2016) observed that drought-tolerant materials, under conditions of post-flowering water restriction, suffered a reduction of 0.5% per day in the photosynthetically active leaf area, while sensitive materials had a reduction of 1.2% per day. According to Taiz & Zeiger (2013), leaf expansion is a process driven by turgor and extremely sensitive to water deficit. Inhibition of cell expansion causes a slowness in leaf expansion at the beginning of the development of water deficits (Santana et al., 2017).

With the results obtained under the experimental conditions of this study, the photosynthetically active leaf area did not prove to be a good parameter for the conclusive identification of tolerance, since the evaluation of this characteristic did not differentiate tolerant genotypes from the sensitive ones (Table 3).

Among the various characteristics, plant height is a fundamental morphological phenotype that directly indicates plant growth, is highly predictive of biomass and final grain yield (Wang et al., 2018) and has been reported by several authors (Geipel et al.,

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2014, Li et al., 2016, Schirrmann et al., 2016).

Higher plant height was shown by the genotype 9910032 (T), under both water regimes, but better results were obtained under full irrigation (Table 5). Average height was equal to 1.18 m for genotypes subjected to full irrigation and 1.10 m for those subjected to water restriction, a reduction of 6.77%. Similarly, Tardin et al. (2013) found means of plant height for grain sorghum hybrids between 1.05 and 1.54 m under full irrigation and between 0.75 and 1.30 m under water restriction.

Plant height did not differ statistically between years of cultivation under full irrigation, whereas under water restriction, lower values for this characteristic were found in 2014 (Table 6). Among the water regimes adopted, a significant difference was observed only in 2014, in which the full irrigation regime was superior.

Differently from the results of this study, Albuquerque et al. (2011) observed genotype x environment interaction between the grain sorghum cultivars evaluated against the variation of a rainy year and a dry year. The difference in the results was possibly due, in addition to the genotypes used, to the period in which the plants were subjected to water restriction. In the present study, the restriction was imposed in the pre-flowering period, while in the work of Albuquerque et al. (2011) there was possibly stress in several phases.

Table 5. Plant height (m) as a function of genotypes (tolerant (T) and sensitive (S)) and water regimes adopted in the cultivation of grain sorghum in Nova Porteirinha, MG.

Genotypes	Full irrigation	Water restriction
9910032 (T)	1.62 Aa	1.43 Ab
P898012 (T)	1.24 Ba	1.22 Ba
9503062 (S)	0.90 Ca	0.82 Da
9618158 (S)	0.96 Ca	0.96 Ca
CV (%)	10.70	

Means followed by the same uppercase letter in the column and lowercase letter in the row do not differ by Tukey test at 5% probability level ($p \leq 0.05$).

Santos (2003) recommends that grain sorghum height be within the range from 1.0 to 1.5 m, because the harvest is usually carried out with adaptations of harvesters for corn or soybean, which operate within this range. Associated with this, heights below 1.5 m are desired to avoid lodging of plants. Height above 1.0 m is recommended as it is positively correlated with grain yield.

Tardin et al. (2013) concluded that water stress reduced the means of all agronomic characteristics of the crop, which corroborates the results obtained in the present study. Plant height is an extremely important morphological phenotype, but the results obtained demonstrate the impossibility of using this parameter, alone, to conclusively identify materials that are tolerant to water restriction because, under water restriction, it was not possible to distinguish the sensitive from the tolerant ones.

Regarding yield, for the full irrigation regime there were no significant differences between genotypes in all years evaluated (Table 7). Under water restriction, only in 2015 there was a difference between genotypes, with P898012 (T) standing out.

Table 6. Plant height (m) as a function of years and water regimes adopted in the cultivation of grain sorghum in Nova Porteirinha, MG.

Year	Plant height	
	Full irrigation	Water restriction
2014	1.19 Aa	1.01 Bb
2015	1.21 Aa	1.15 Aa
2016	1.14 Aa	1.17 Aa
CV(%)	10.70	

Means followed by the same uppercase letter in the column and lowercase letter in the row do not differ by Tukey test at 5% probability level ($p \leq 0.05$).

Table 7. Yield (kg ha^{-1}) as a function of years, genotypes (tolerant (T) and sensitive (S)) and water regimes adopted in the cultivation of grain sorghum in Nova Porteirinha, MG.

Year	Genotype	Full irrigation	Water restriction
2014	9910032 (T)	5085.00 Aa	3875.00 Ab
	P898012 (T)	4210.00 Aa	5030.00 Aa
	9503062 (S)	5380.00 Aa	3795.00Ab
	9618158 (S)	4945.00 Aa	4550.00 Aa
2015	9910032 (T)	4135.00 Aa	3562.50 Ba
	P898012 (T)	4695.00 Aa	5517.50 Aa
	9503062 (S)	5100.00 Aa	3935.00 Bb
	9618158 (S)	5242.50 Aa	4550.00 ABa
2016	9910032 (T)	8962.25 Aa	6780.75 Ab
	P898012 (T)	8551.25 Aa	5758.25 Ab
	9503062 (S)	7839.25 Aa	6516.50 Ab
	9618158 (S)	8259.50 Aa	6956.50 Ab
CV (%)	14.18		

Means followed by the same uppercase letter in the column and lowercase letter in the row do not differ by Tukey test at 5% probability level ($p \leq 0.05$).

Under water restriction, yield was 15.99% lower. According to Rakshit et al. (2016), water stress during the flowering and grain filling stage can reduce grain yield by 35%.

The yield of genotypes P898012 (T) and 9618158 (S) did not differ from one water regime to the other in 2014. In 2015, only genotype 9503062 (S) reduced yield when subjected to water restriction. In 2016, all genotypes showed better results when subjected to full irrigation (Table 7).

Considering the full irrigation, all genotypes showed higher yield in 2016 (Table 8). The same result was observed under water restriction, except for genotype P898012 (T), which did not differ between years of cultivation.

Almeida Filho et al. (2014), evaluating the yield of 22 hybrids of grain sorghum in different localities, did not observe a significant effect of hybrids in any of the experiments, and most hybrids showed yield above the Brazilian average, which was 2664 kg ha^{-1} in that year (2013). Albuquerque et al. (2011), evaluating grain sorghum cultivars under semiarid conditions, obtained grain yield between 5500 and 7000 kg ha^{-1} in a rainy year and values below 3000 kg ha^{-1} in a year with low rainfall availability. The average yields obtained in the present study was 6033 kg ha^{-1} under full irrigation and 5068 kg ha^{-1} under water restriction. These results far exceed the current Brazilian average yield, estimated at 2856 kg ha^{-1} (CONAB, 2018).

Other authors report reduction in the yield of sorghum under water restriction. Santana et al. (2017) reported a 33.1% reduction in an experiment conducted in Teresina-PI. Batista et al. (2016) observed reductions of 35% and 65% in Nova Porteirinha-MG and Teresina-PI, in the years 2014 and 2015, respectively. Tardin et al. (2013) reported yield reductions of 54% caused by post-flowering water restriction.

The variation of the results due to the different locations in which the trials were conducted, with different edaphoclimatic conditions, genetic materials and management, among other variables difficult to be measured, is clear.

Table 8. Yield (kg ha^{-1}) as a function of genotypes (tolerant (T) and sensitive (S)), years and water regimes adopted in the cultivation of grain sorghum in Nova Porteirinha, MG.

Year	Genotype	Full irrigation	Water restriction
9910032 (T)	2014	5085.00 B	3875.00 B
	2015	4135.00 B	3562.50 B
	2016	8962.25 A	6780.75 A
P898012 (T)	2014	4210.00 B	5030.00 A
	2015	4695.00 B	5517.50 A
	2016	8551.25 A	5758.25 A
9503062 (S)	2014	5380.00 B	3795.00 B
	2015	5100.00 B	3935.00 B
	2016	7839.20 A	6516.50 A
9618158 (S)	2014	4945.00 B	4550.00 B
	2015	5242.50 B	4550.00 B
	2016	8259.50 A	6956.50 A
CV (%)	14.18		

Means followed by the same uppercase letter in the column do not differ by Tukey test at 5% probability level ($p \leq 0.05$).

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The reduction of yield in plants subjected to water restriction can be explained by the combination of several factors. Among them, the lower plant height may imply a smaller leaf area and consequently a reduction in the production of photoassimilates. In addition, water stress in floral differentiation reduces the number of grains per panicle. These grains, due to lack of photoassimilates, will have lower weight, resulting in lower panicle weight and consequently lower yield.

The characteristics evaluated in this experiment did not allow the conclusive distinction of tolerant genotypes from sensitive ones. The imposed water restriction was possibly not sufficient. The sorghum plant has several mechanisms that give it resistance to water stress. In the present study, a 30-day period of water stress was imposed, but it was not sufficient to cause significant differences in yield when compared to plants that were not subjected to stress. Even genotypes considered sensitive also showed tolerance to the water stress imposed for this period of time.

Conclusions

The agronomic and physiological characteristics evaluated in this experiment, for this period of water restriction, did not prove to be good indicators for the selection of grain sorghum genotypes tolerant to water restriction.

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