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# Grain Sorghum Grown Under Drought Stress at Pre- and Post-flowering in Semiarid Environment

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**Abstract**

In the current scenario of climate change, sorghum crop has high growth potential, requiring adaptation and selection studies for the various Brazilian production environments. Sorghum is among the most drought-tolerant cereals; however, extended summer can reduce the size and number of grains in the plant, reflecting into poorer yields. Sorghum breeding programs aim to develop hybrids more tolerant to water deficit, to ensure profitable yield even in the face of drought stress. The objective of the present study was to evaluate the effects of water restriction on grain sorghum hybrids in the pre- and post-flowering phases in the Brazilian semiarid. Twenty-five hybrids were evaluated under controlled irrigation conditions in Nova Porteirinha-MG and Teresina-PI. In the Nova Porteirinha, the hybrids were cultivated under conditions of non-drought stress and with drought stress in pre- and post-flowering stage. On the other hand, in Teresina, the experiment took place with non-drought stress and drought stress at post-flowering stage. The experimental design was in randomized complete blocks, in factorial scheme, with three replications. Drought stress reduced grain yield by more than 40%, showing that even being resistant, sorghum is affected by drought. Hybrids 1168093, 1167092, 1236020 and 1423007 showed high yields in the various environments, outyielding the commercial controls, what allows the recommendation of these cultivars for the semiarid areas or late off-season in the Cerrado region.

**Keywords:** abiotic stress, drought stress, semiarid, *Sorghum bicolor*

## 1. Introduction

Climate change, especially those concerned with availability of water during the crop growing, is among the main problems of world agriculture. In Brazil, in some regions or growing seasons, such as in the Semiarid and during the second crop in the Cerrado, prolonged period of drought is common, alternating with periods of irregular rainfall distribution, causing significant losses in grain yield of cereals. The use of crops that are more tolerant to drought, such as sorghum, can partially mitigate these climate effects. More stable hybrids under drought stress conditions are essential to avoid losses due to these uncontrollable climate variations (Menezes et al., 2015; Reddy, 2019; Batista et al., 2019)

Sorghum is one of the most drought tolerant cereals, presenting good yield potential in regions with irregularity of rainfall, due to its dense and deep root system, leaf stay-green, ability to reduce transpiration through leaf curl, stomatal closure and reduced metabolic processes (Xu et al., 2000; Blum, 2004; Reddy et al., 2009; Mutava et al., 2011; Reddy, 2019). In Brazil, sorghum is a rainfed crop, always in late plantings, when the risk for the growing of corn increases. Sorghum is the best planting option in the Brazilian semiarid and in the so-called late second crop (Santos et al., 2005; Cysne & Pitombeira, 2012; Tabosa et al., 2013; Menezes, 2016). Nevertheless, when planted too late, it can still suffer reduction in its yield.

The lack of local research, especially of tests of cultivars more adapted to regions with adverse climatic characteristics has limited the expansion of sorghum cultivation in Brazil. To minimize the effects of genotypes ×

environments interaction and have greater predictability of behavior, in an efficient and rational way, it is necessary to identify more stable cultivars (Ramalho et al., 2012; Martins et al., 2016). Thus, both evaluation and identification of sorghum hybrids which outstanding performance under these growing conditions is essential, providing the farmer with accurate information for the use of sorghum in its production system.

Drought stress is directly related to the reduction in grain yield, besides reflecting in some morphophysiological characteristics of the plant. Sorghum crop suffers interference from drought in different ways at the developmental stages, depending on whether stress occurs before (pre) or after flowering (post) (Tardin et al., 2013; Batista et al., 2019). In pre-flowering, the plants present leaf curl and discoloration. On the other hand, after flowering, the plants show symptoms of early death, stem collapse and lodging (Borrell et al., 2000; Blum, 2004). The physiological responses to drought tolerance may vary according to the severity and duration of stress imposition, phenological stage and genetic material (Shao et al., 2008; Magalhães et al., 2012). As the time of stress occurrence in rainfed planting is not predictable, it is necessary to study the performance of the hybrids in more than one stress condition.

Even if the mechanisms that confer sorghum tolerance to drought are known, the understanding of how the plant, in different stages of its growth, reacts to factors limiting its development becomes necessary. The use of this information aims to allow the expansion of sorghum cultivation, especially in regions with greater problems of drought.

The objective of this work was to carry out the phenotypic selection of grain sorghum hybrids when subjected to drought stress in pre- and post-flowering of the plant, aiming to select those best suited for planting in the Semiarid region and at the second crop in the Cerrado bioma.

## 2. Material and Methods

### 2.1 Location

The experiments were carried out at the experimental station of Embrapa Maize and Sorghum located in Nova Porteirinha-MG and at the experimental station of Embrapa Mid-North in Teresina-PI. These sites are located in a semiarid region, and present a well-defined dry season, allowing water control to be performed only by irrigation. Nova Porteirinha is situated in the mesoregion of the North of Minas Gerais, considered as a semi-arid area. The geographical coordinates are 15°48′ S latitude and 43°18′ W longitude. The climate, according to Köppen, is of the type Aw (tropical with dry winter). The soil of the experimental area is characterized as medium-textured Red-Yellow Latosol. Teresina presents the geographic coordinates of 05°05′ S latitude and 42°48′ W longitude. The climate, according to the classification of Thornthwaite and Mather, is characterized as dry sub-humid, mega-thermal, with moderate water surplus in the summer. Teresina is located in a semi-arid area. The soil of the experimental area is a sandy loam-textured Dystrophic Yellow Argisol. In Teresina-PI, two trials were performed, one with non-stress and another with stress at post-flowering. In Nova Porteirinha-MG, three trials were conducted, one with non-stress, one with drought stress at pre-flowering and another with stress at post-flowering. Each trial was considered an environment, amounting to five environments.

### 2.2 Experimental Area

In the environments with non-water stress, irrigation was performed until the physiological maturity of grains. In the environment with drought stress at pre-flowering, carried out only in Nova Porteirinha-MG, irrigation was cut from 30 to 60 days after sowing, so that the drought stress occurred before flowering. In environments with drought stress at post-flowering, irrigation was cut at the plant booting stage, approximately 45 days after planting, so that drought stress would occur after flowering. In the latter, irrigation was not returned. In all the trials, irrigation by fixed conventional sprinkler system was used. Irrigation management was performed based on crop evapotranspiration. In Teresina-PI, the irrigation depths, summed to rainfall, were of 298.0 mm in the water-stress environment at post-flowering and 501.4 mm in the non-drought stress environment. In Nova Porteirinha, there was no rainfall during the experiment, and the applied irrigation depths were 680 mm in the environment with non-drought stress, 480 mm in the water deficit environment at pre-flowering and 360 mm in the water deficit environment at post-flowering.

In Teresina, the field capacity and permanent wilting point values are 21% and 9% respectively. Under full irrigation, soil moisture remained between 18% and 21%, equivalent to a consumption of 25% of soil water available. On the other hand, under water deficit, the soil moisture varied from 11% to 13%, equivalent to 75% of the available water, below the critical limit of 50% (Doorenbos & Kassam, 1994), characterizing, therefore, the water deficit. In Nova Porteirinha, the field capacity and permanent wilting point values are 22% and 8% respectively. Under full irrigation, soil moisture remained close to yield capacity and, under water deficit regime, the soil moisture ranged from 11% to 14%, equivalent to 75% of the available water, therefore, below the critical limit of 50% required by sorghum crop.

### *2.3 Experimental Design*

The experimental design was a randomized complete block, in a factorial design of 3 × 25 in Nova Porteirinha and 2 × 25 in Teresina, with three replications. The plots consisted of four rows three meters in length, and the two central rows being considered useful area. Twenty-four grain sorghum hybrids belonging to Embrapa Maize and Sorghum and one hybrid (50A70) belonging to Pioneer Company (Table 2) were evaluated.

Soil tillage was carried out in a conventional manner, with one plowing and two harrowings at pre-planting. Soon afterwards, the area was furrowed and set to the 0.5 m spacing inter-rows. The fertilization was performed according to the results of soil analysis and crop requirement, using 350 kg ha$^{-1}$ of formula 8-28-16 (NPK), in addition to 72 kg ha$^{-1}$ of N at topdressing, using urea as a nitrogen source at 30 days after planting. Sowing was manually, distributing about 15 seeds m$^{-1}$ at a depth of 3 cm. At 20 days after sowing, thinning was performed leaving nine plants m$^{-1}$ to obtain a final stand of 180,000 plants ha$^{-1}$.

### *2.4 Trait Evaluation*

Grain yield consisted of the weighing of the grains harvested in the useful area of each plot and converting the data to kg ha$^{-1}$. The data were submitted to individual variance analysis, having considered the effect of the hybrids as fixed and the other effects as random. As it was found that the ratio between the largest and the smallest mean square of the residue of the individual variance analysis did not exceed the 7:1 ratio, the joint analysis of the assays was performed (Banzatto & Kronka, 2006). Soon afterwards, the data were submitted to adaptability and stability analysis by means of the GGE biplot method (Yan et al., 2000).

### *2.5 Statistical Analysis*

The GGE biplot model utilized was: $Yij - \mu - \beta j = \alpha i + y1 \cdot \varepsilon i1 \cdot \rho j1 + y2 \cdot \varepsilon i2 \cdot \rho j2 + \varepsilon ij$. where, $Yij$ represents the average grain yield of the genotype i in the environment j; $\mu$ is the general mean of the observations; $\beta j$ is the main effect of the environment; $\alpha i$ is the main effect of the genotype $i$; $y1$ and $y2$ are the scores associated to the first (PC1) and to the second principal component (PC2) respectively; $\varepsilon 1$ and $\varepsilon 2$ are the values of the PC1 and PC2, respectively, of the genotype of order i; $\rho j1$ and $\rho j2$ are the values of the PC1 and PC2, respectively for the environment of the order $j$; and $\varepsilon ij$ is the error associated with the model of the $i^{\text{-th}}$ genotype and $j^{\text{-th}}$ environment (Yan et al., 2000). The analysis used the GGEGui package implemented in the R software (R Development Core Team, 2016).

## 3. Results and Discussion

### *3.1 Analysis of Variance*

The joint analysis of variance displayed significant effects for the hybrids x environments interaction, indicating that the hybrids reacted in a distinct way to the environments. The effect of hybrids was also significant, showing variability among the genotypes. The coefficient of variation (14.52%) was low, emphasizing the satisfactory experimental quality for the trials at field level.

The overall mean of grain yield in all the environments was 4.151 kg ha$^{-1}$ higher than the national mean obtained in 2019, which was of 2.973 kg ha$^{-1}$ (CONAB, 2019). When evaluating the average grain yield in each local, the drought stress reduced grain yield by 45% and 48% in Nova Porteirinha-MG, in the environments with stress at pre- and post-flowering, respectively, and in Teresina-PI by 58% in the stressed environment at post-flowering (Table 1). Despite being more tolerant to drought than other cereals, sorghum when subjected to drastic drought stress has it yield reduced. Extended summer are common in the semiarid region and off-season crop in the Cerrado bioma, making the selection of drought tolerant cultivars fundamental to warrant to the farmer reduced risk of yield fall.

Table 1. Average grain yield (kg ha$^{-1}$) of 25 grain sorghum hybrids grown under non-water stressed conditions and with stress at pre- and post-flowering

| Treat. | Hybrids | NP-NS | NP-PRE | NP-POST | T-NS | T-POST | Mean |
|---|---|---|---|---|---|---|---|
| 1 | 1423037 | 9522 | 2929 | 3890 | 3592 | 1368 | 4260 |
| 2 | 1324241 | 8775 | 5674 | 4913 | 1266 | 813 | 4288 |
| 3 | 1324228 | 7950 | 3809 | 4271 | 4180 | 720 | 4186 |
| 4 | 1167048 | 9120 | 3892 | 4275 | 3882 | 3714 | 4977 |
| 5 | 1167093 | 9234 | 4007 | 5016 | 4121 | 2527 | 4981 |
| 6 | 1421038 | 6078 | 3195 | 2245 | 2163 | 895 | 2915 |
| 7 | 1423007 | 8814 | 5080 | 3604 | 3523 | 1033 | 4411 |
| 8 | 1239017 | 9160 | 4895 | 5197 | 2710 | 502 | 4493 |
| 9 | 1244003 | 8557 | 5626 | 4852 | 1864 | 240 | 4228 |
| 10 | 1168093 | 8463 | 5434 | 5418 | 5121 | 1209 | 5129 |
| 11 | 1516037 | 9331 | 5602 | 4447 | 1848 | 491 | 4344 |
| 12 | 1167092 | 9719 | 4708 | 3905 | 2760 | 1740 | 4567 |
| 13 | 1516043 | 8170 | 4032 | 5015 | 3022 | 969 | 4242 |
| 14 | 1516049 | 8572 | 3788 | 5086 | 2404 | 949 | 4160 |
| 15 | 1167017 | 8020 | 5597 | 4080 | 2993 | 2135 | 4565 |
| 16 | 1421007 | 5580 | 3685 | 2134 | 3033 | 1458 | 3178 |
| 17 | 1527039 | 7327 | 4289 | 4668 | 2784 | 1092 | 4032 |
| 18 | 1527052 | 7932 | 5193 | 4335 | 3008 | 875 | 4269 |
| 19 | 1236020 | 9413 | 4417 | 4593 | 3017 | 982 | 4485 |
| 20 | 1105661 | 7616 | 4742 | 4808 | 1276 | 1177 | 3924 |
| 21 | 1236043 | 5768 | 4519 | 3800 | 1017 | 445 | 3110 |
| 22 | 1421037 | 6381 | 3248 | 2735 | 1913 | 874 | 3030 |
| 23 | 50A70 | 8831 | 5524 | 4463 | 1720 | 419 | 4191 |
| 24 | BRS373 | 7826 | 3840 | 4444 | 1820 | 500 | 3686 |
| 25 | BRS330 | 8066 | 5331 | 3817 | 2161 | 1256 | 4126 |
|  | Mean | 8169 | 4522 | 4240 | 2688 | 1135 | 4151 |

*Note*. NP-NS: Nova Porteirinha-MG, Non-stressed; NP-PRE: Nova Porteirinha-MG, with stress at pre-flowering; NP-POST: Nova Porteirinha-MG, stress at post-flowering; T-NS: Teresina-PI Non-stresses; T-POST: Teresina-PI, stress at post flowering.

### *3.2 Adaptability and Stability Analysis*

The best way to visualize the data of various experiments, when genotypes × environments interaction is significant, is through adaptability and stability analysis. GGE biplot is one of the most used methods to estimate these, for being both efficient and of easy interpretation

In the GGE biplot method are presented the main components (PC1 and PC2), which are derived from the decomposition of the singular values of the effects of the genotypes and genotypes × environments interaction. The first of the principal components (PC1) indicates the adaptability of genotypes being, thus, highly correlated with yield. On the other hand, the second of the principal components (PC2) indicates the phenotypic stability, thus the genotypes with PC2 closest to zero are the most stable (Yan et al., 2000). In the present study, the first (PC1) and second (PC2) principal components explained 75.92% of the total variation of the data (Figure 1), respectively, indicating safety in using only two axes to explain data variation. According to Rencher (2002), at least 70% of the total variance must be explained by the first and second principal components of the plot.

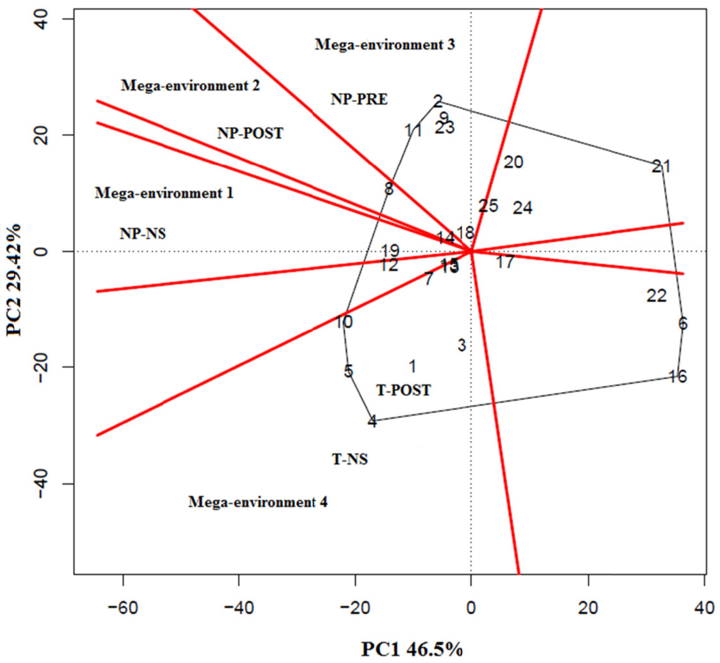

Figure 1. Sectors and mega-environments obtained by the GGE biplot model for grain yield of 25 grain sorghum hybrids evaluated under: NP-NS: Nova Porteirinha-MG, Non-stressed; NP-PRE: Nova Porteirinha-MG, with stress at pre-flowering; NP-POST: Nova Porteirinha-MG, stress at post-flowering; T-NS: Teresina-PI Non-stresses; T-POST: Teresina-PI, stress at post flowering

The viewing of the hybrids performance in each environment occurs by connecting all the genotypes that are at the extreme points of the boxplot and their respective perpendicular lines, forming a polygon (Yan & Kang, 2003). Figure 1 shows a polygon formed by hybrids 1239017 (8), 1516037 (11), 1324241 (2), 1236043 (21), 1421038 (6), 1421007 (16), 1167048 (4), 1167093 (5) and 1168093 (10), so that all other hybrids are located inside the polygon (Figure 1). The boxplot was divided into nine sectors by the vectors from the *biplot* center (0; 0), perpendicular to the sides of the polygon.

When different hybrids are adapted to different groups of environments and the variation between groups is greater than within the group, a mega environment is formed (Yan & Kang, 2003). In the biplot, mega-environments are sectors that contain one or more environments (Figure 1). Thus, in the present study, there was the formation of four mega-environments. Mega-environment 1 was formed by the environment Nova Porteirinha-MG non-stressed (NP-NS), mega-environment 2 was constituted by the environment Nova Porteirinha-MG with drought stress at post-flowering (NP-POST), mega-environment 3 was formed by the environment of Nova Porteirinha with drought stress (NP-PRE) and mega-environment 4 formed by Teresina-PI non-stressed (T-SEM) and stressed at post-flowering (T-POST) (Figure 1). The genotypes located within the same sector are the ones best suited to those environments. Thus, in the sector formed by mega-environment 3, 1324241 (2), 1516037 (11), 1244003 (9), 50A70 (23) and 1527052 (18) were the most adapted. The definition of mega-environments and the relationship between environments help in the identification of cultivars with broad or specific adaptation to certain environments.

The hybrids that are located at the vertices of each sector present either the best or worst performance (Yan & Tinker, 2006). Hybrid 1239017 (8) is the vertex of mega-environment 2, so it is the most adapted to the environment of Nova Porteirinha-MG, with drought stress at post-flowering, presenting, together with hybrid 1516049 (14), the highest yields in this environment. Hybrids 1324241 (2) and 1516037 (11) were the vertices of mega-environment 3, constituted by the environment of drought stress in Nova Porteirinha at pre-flowering. Mega-environment 4 was formed by vertices 1167048 (4) and 1167093 (5), which are the most adapted to this water-stressed environment. Some hybrids are located in sectors that do not contain environments. This means that these are the worst genotypes in some or in all environments (Karimizadeh et al., 2013), for instance hybrids 1421038 (6), 1421007 (16), 1236043 (21) and 1421037 (22).

### *3.3 Average vs Stability*

The biplot “Average vs. Stability” (Figure 2) presents two axes, with the hybrids ranked in the most horizontal axis. A straight line has been drawn with an arrow passing through the origin of the *biplot*. The arrow points to the higher average performance of the hybrids. The vertical axis passing through the biplot origin separates cultivars with below-average yield from those with above-average. For instance, cultivar BRS 330 (25) is the first with yield below the average and the cultivar 1527052 (18) is the first with yield above the general average. The highest yielding hybrids considering all the environments were 1167093 (5), 1168093 (10), 1167048 (4), 1167092 (12) and 1236020 (19). The lowest yielding hybrids were 1236043 (21), 1421038 (6), 1421007 (16) and 1421037 (22), which are farther from the arrow.

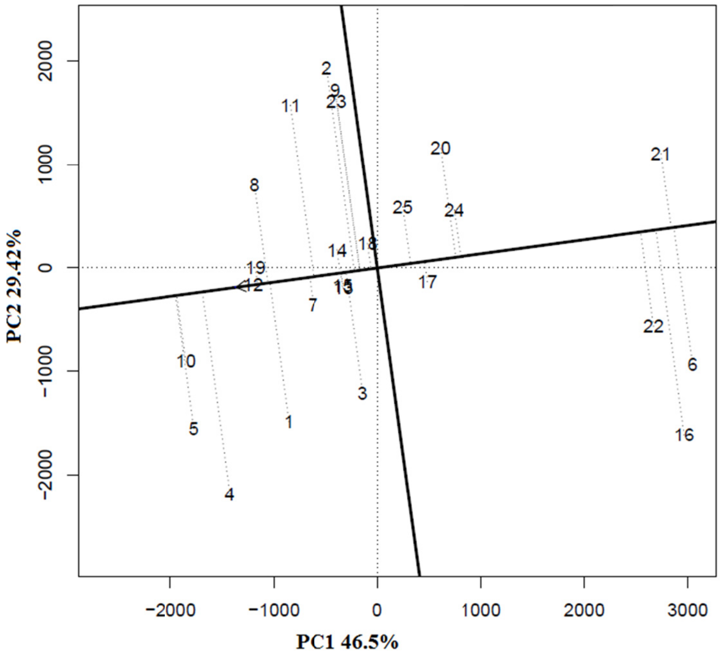

Figure 2. Average *versus* stability obtained by the GGE biplot model for grain yield of 25 grain sorghum hybrids evaluated under: NP-NS: Nova Porteirinha-MG, Non-stressed; NP-PRE: Nova Porteirinha-MG, with stress at pre-flowering; NP-POST: Nova Porteirinha-MG, stress at post-flowering; T-NS: Teresina-PI Non-stresses; T-POST: Teresina-PI, stress at post flowering

Each hybrid is linked to the horizontal axis (Figure 2). The distance from this horizontal axis represents the stability of the genotypes. The greater the distance of the hybrid in relation to the horizontal axis, the lower is its stability (Yan, 2011). Among the highest yielding hybrids, 1167092 (12), 1236020 (19) and 1166093 (10) were more stable than 1167093 (5) and 1167048 (4).

In general, the most stable hybrids, i.e. those closest to the straight line, were 1167092 (12), 1236020 (19), 1423007 (7), 1516049 (14), 1167017 (15), 1527052 (18) and 1527039 (17). This result does not mean that these hybrids had high yields, but rather that they performed consistently in the environments in which they were evaluated. Hybrids 1167048 (4), 1423037 (1), 1516037 (11), 1324241 (2), 1244003 (9), 50A70 (23) and 1421007 (16) were those most distanced vertically from the straight line, these ones being considered the most unstable. The ideal for selection is choosing high yielding and stable hybrids.

### *3.4 Hybrids Classification*

Another way of observing the performance of hybrids is through concentric circles around the average grain yield (Figure 3). Genotypes situated closer to the center of the concentric circle are more desirable than the others (Yan, 2011). In this sense, the most desirable hybrids are 1168093 (10), 1167092 (12), 1236020 (19), 1239017 (8), 1423007 (7) and 1167093 (5). Stability refers to the ability of cultivars to show predictable performance under environmental changes. The hybrids must have, under different environmental conditions, high yield and its superiority must be stable.

Several hybrids outperformed commercial checks, showing the potential of these crosses as a planting option in these locals and places with drought stress problems. Hybrids 50A70 and BRS 330 proved to be higher yielding than BRS 373, with BRS 330 being more stable than 50A70. The hybrids selected here will enter the Value for Cultivation and Use trial network for future releases for these regions.

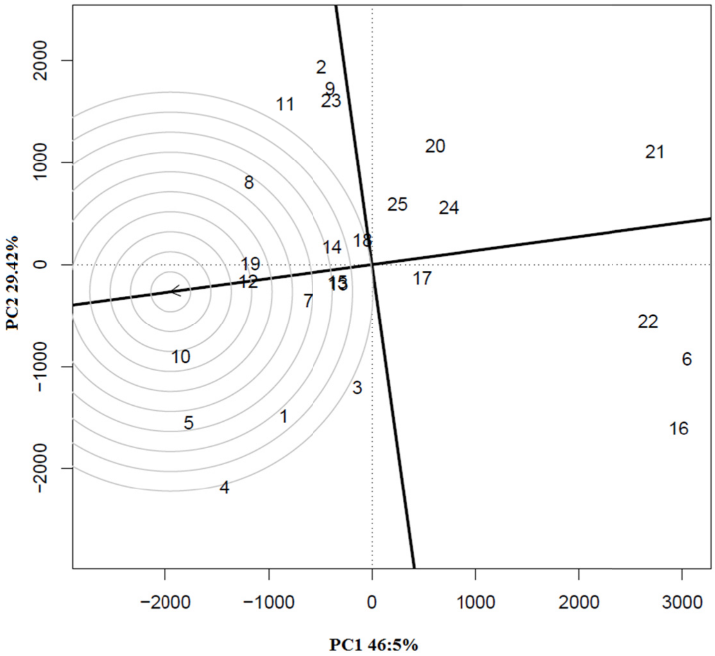

Figure 3. Classification of 25 grain sorghum hybrids according to the GGE biplot model, based on grain yield evaluated under: NP-NS: Nova Porteirinha-MG, Non-stressed; NP-PRE: Nova Porteirinha-MG, with stress at pre-flowering; NP-POST: Nova Porteirinha-MG, stress at post-flowering; T-NS: Teresina-PI Non-stresses; T-POST: Teresina-PI, stress at post flowering

## 4. Conclusion

Although drought-tolerant, sorghum has reduced grain yield when subjected to extreme drought stress conditions. Experimental hybrids 1168093, 1167092, 1236020 and 1423007 presents high grain yield stability and may be recommended for seasons and locals susceptible to drought stress.

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