# Grain yield, anthesis-silking interval and drought tolerance indices of tropical maize hybrids

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**Abstract:** *Water deficit stress is the abiotic factor with the highest impact on crop yield. The objective of this study was to evaluate grain yield (GY), the anthesis-silking interval (ASI) and drought tolerance indices in maize hybrids. We evaluated GY and the ASI of 86 hybrids under two moisture levels (normal irrigation and water stress) for three consecutive years. The stress susceptibility index, water stress tolerance, drought resistance coefficient, drought resistance index, stress tolerance index and harmonic mean were evaluated. There were significant hybrid x environment interactions for GY and the ASI. Differences in the ASI among environments ranged from 0 to 5 days. The hybrids P3862, 1I873, 1I923, 1I862 and 1J1211 showed high GY, associated with the highest drought tolerance indices. The stress tolerance index and harmonic mean indices can be used to identify higher-yielding maize hybrids in environments with and without water restriction.*

**Keywords**: *Stress tolerance, water stress, water deficit, Zea mays.*

## INTRODUCTION

Many different abiotic stresses affect and reduce the yield of the main cereal crops produced in the world. The factor with the greatest impact on stable production, especially in tropical countries, is water stress (Verma and Deepti 2016). Identification and development of more drought-tolerant maize hybrids through plant breeding is an extremely important strategy with the aim of reducing yield losses in crops under water stress, and this has been adopted by several research institutions (Daryanto et al. 2016). Advances in plant breeding for drought tolerance have been achieved through association of conventional plant breeding and biomolecular techniques, with identification of quantitative trait loci (Zhao et al. 2018) and genomic selection (Dias et al. 2018).

However, the drought tolerance characteristic of crops is probably the most difficult to identify with great precision, since grain yield is a complex trait and is influenced by the genotype by environment interaction and other mechanisms associated with heterosis (Pereira 2016). Thus, in the absence of precise information regarding the complete genetic mechanism of drought tolerance in maize, some secondary characteristics of the plant have been used as selection criteria, such as agronomic traits and molecular markers (Mikić et al. 2016), morpho-physiological mechanisms (Wattoo et al. 2018), and physio-biochemical indicators (Shafiq et al. 2019).

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According to Edmeades (2000), the anthesis-silking interval (ASI) has probably been the secondary trait most useful for improving drought tolerance in maize. In addition, some methods for evaluation and selection of drought tolerant genotypes have been effectively used for maize and other cereal crops. These methods refer to drought tolerance indices obtained from grain yields of the genotypes in environments with and without water restriction (Barutcular et al. 2016, El-Sabagh et al. 2018).

In this regard, Fischer and Maurer (1978) defined the stress susceptibility index (SSI) to evaluate tolerance to water deficit in wheat genotypes. After that, Rosielle and Hamblin (1981) also proposed water stress tolerance (TOL) criteria based on mean yield in environments with and without water restriction. Blum (1984) proposed the drought resistance coefficient (DRC) to evaluate drought-tolerant genotypes. After that, Lan (1998) proposed the drought resistance index (DRI) and Fernandez (1992) the stress tolerance index (STI). More recently, Mardeh et al. (2006) proposed a tolerance index based on the harmonic mean (HM) of the yield of the genotypes under evaluation.

Therefore, there is potential for use of these indices as one more tool to assist in identification and development of drought-tolerant maize hybrids, especially for the second crop season in Brazil. In light of the above, the aim of this study was to identify the highest yielding genotypes with a short ASI and the drought tolerance indices that are most appropriate for selection of maize hybrids in environments with and without water restriction.

## MATERIAL AND METHODS

### Setting up and conducting the trials

The experiments were set up in an area with a Latossolo Vermelho Amarelo soil at the experimental station of Embrapa Milho e Sorgo in Nova Porteirinha (lat 15° 48' 10" S, long 43° 18' 3" W and alt 500 m asl), state of Minas Gerais, Brazil. The local climate is tropical mesothermal, nearly megathermal, due to altitude, with low moisture (semiarid) characteristics. According to Köppen-Geiger, the climate is Aw (tropical with dry winter), leading to long drought periods and a well-defined dry season.

A total of 86 single-cross maize hybrids were evaluated, consisting of 79 experimental maize hybrids from the breeding program of Embrapa Milho e Sorgo and 7 commercial maize hybrids (AG8088, DKB390, 30F35, 30F53, P3862, BRS1055 and 2B707), under two moisture levels (normal irrigation and water deficit/ water stress). An incomplete block experimental design was used with 6 common treatments (1I953, 1J1203, 1J1132, 3H842, BRS1055 and 2B707) in a strip plot with four replications, for three consecutive years of evaluation.

Each plot consisted of a 4-m length row, with 0.8 m between rows. The area used for data collection was 3.2 m² per plot. Sowing occurred in May 2011, 2012 and 2013. Final plant density corresponded to 60,000 plants ha⁻¹. Fertilization at sowing was NPK 8-28-16 at the rate of 400 kg ha⁻¹. Topdressing of urea at the rate of 200 kg ha⁻¹ was performed when the plants were in the three fully expanded leaf (V3) and six fully expanded leaf (V6) stages.

A drip irrigation system was used and water stress was imposed through suspending irrigation in the plots of the environment with water restriction (A1) at 45 days after sowing (45 DAS) until harvest. In the environment without water restriction (A2), irrigation was performed regularly until the R3 stage, based on crop evapotranspiration, maintaining moisture at field capacity. The other crop management practices were performed according to crop needs to obtain the highest yield of the hybrids evaluated.

### Characteristics evaluated

The grain yield of each hybrid was evaluated in environments with water restriction ($GY_{A1}$) and without water restriction ($GY_{A2}$) in grams per plot, which was transformed into kg ha⁻¹ at 13% moisture. In addition, the anthesis-silking interval (ASI) was evaluated as the difference in days between male flowering, when 50% of the plants of the plot had tassels releasing pollen, and female flowering, when 50% of the plants of the plot had visible style-stigmas in the ears, in both environments ($ASI_{A1}$ and $ASI_{A2}$).

The drought tolerance indices used were the stress susceptibility index (SSI), according to Fischer and Maurer (1978):

$$SSI = \frac{\left(1 - \dfrac{GY_{A1}}{GY_{A2}}\right)}{\left(1 - \dfrac{mGY_{A1}}{mGY_{A2}}\right)}$$

; tolerance to water stress (TOL), according to Rosielle and Hamblin (1981): $TOL = GY_{A2} - GY_{A1}$; drought resistance coefficient (DRC), according to Blum (1984): $DRC = \dfrac{GY_{A1}}{GY_{A2}}$; drought resistance index (DRI), according to Lan (1998):

$$DRI = GY_{A1} \times \frac{\left(\dfrac{GY_{A1}}{GY_{A2}}\right)}{mGY_{A1}}$$

; stress tolerance index (STI), according to Fernandez (1992): $STI = \left(\dfrac{GY_{A2}}{mGY_{A2}}\right) \times \left(\dfrac{GY_{A1}}{mGY_{A1}}\right) \times \left(\dfrac{mGY_{A1}}{mGY_{A2}}\right)$;

and harmonic mean (HM), according to Mardeh et al. (2006): $HM = 2 \times \dfrac{(GY_{A2} \times GY_{A1})}{(GY_{A2} + GY_{A1})}$. In all cases, $GY_{A1}$ and $GY_{A2}$ were the grain yields, in kg ha$^{-1}$, of each hybrid in environments with and without water restriction, respectively; and $mGY_{A1}$ and $mGY_{A2}$ were the mean of grain yields, in kg ha$^{-1}$, in environments with and without water restriction, respectively.

## Statistical analysis

Joint analysis of variance of GY and the ASI was performed considering the environments with water restriction (A1) and without water restriction (A2) in the three years of evaluation. The adjusted means of GY for the environmental conditions, $GY_{A1}$ and $GY_{A2}$, were applied to the selection indices SSI, TOL, DRC, DRI, STI and HM. All variables and indices were evaluated by the Scott Knott test at the 5% significance level. Spearman's correlation analyses were established between all pairs of variables. Statistical analyses were performed using the R statistical software (R Core Team 2019).

## RESULTS AND DISCUSSION

In general, there was low rainfall during the period of plant development in the field over the three years of evaluation (Figure 1). There was no rainfall in the months of June and July, and in the other months rainfall was less than 7 mm. Only in May 2012 were there rains of greater magnitude (~41 mm). However, considering that water stress was imposed only at 45 DAS, that is, when plants were in the month of June, this higher amount of rainfall probably did not influence the effectiveness of discrimination of the hybrids evaluated under water restriction.

In this context, Makumbi et al. (2011) and Cooper et al. (2014) highlighted that the capacity for discrimination of maize hybrids with higher GY under unfavorable conditions is effective in the vegetative growth stages and, especially, in the reproductive stages. For that reason, it is necessary that the trials conducted in the field be developed in environments with considerable rainfall restriction during plant development, corroborating the results of this study.

The precision observed in carrying out and evaluating the experiments was good since the coefficient of variation was considered to be of low magnitude, 15.59% for GY and 33.84% for the ASI, and never exceeding 20.35% for all the drought tolerance indices. The hybrid × environment interaction was significant ($p < 0.05$) for GY and the ASI, indicating that the hybrids responded differently to the environmental variations between the environments with (A1) and without (A2) water restriction.

For the A1 environment, the ten hybrids that had the highest GY were P3862, 1I923, 1I862, 1J1133, 1L1434, 1L1473, 1J1211, 1J1143, 1J1121 and 1L1454 (Figure 2). These hybrids had grain yield higher than 5800 kg ha$^{-1}$, which represents an increase of more than 25% in relation to the overall mean in this environment with water restriction. The GY in the water restriction environment ranged from 2199
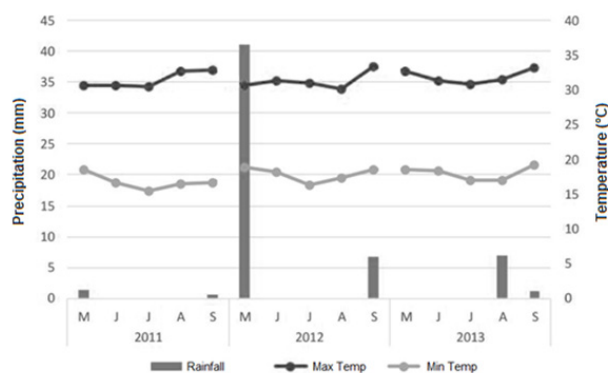


**Figure 1.** Weather data from the three years of experimental evaluation of 86 maize hybrids in Brazil.
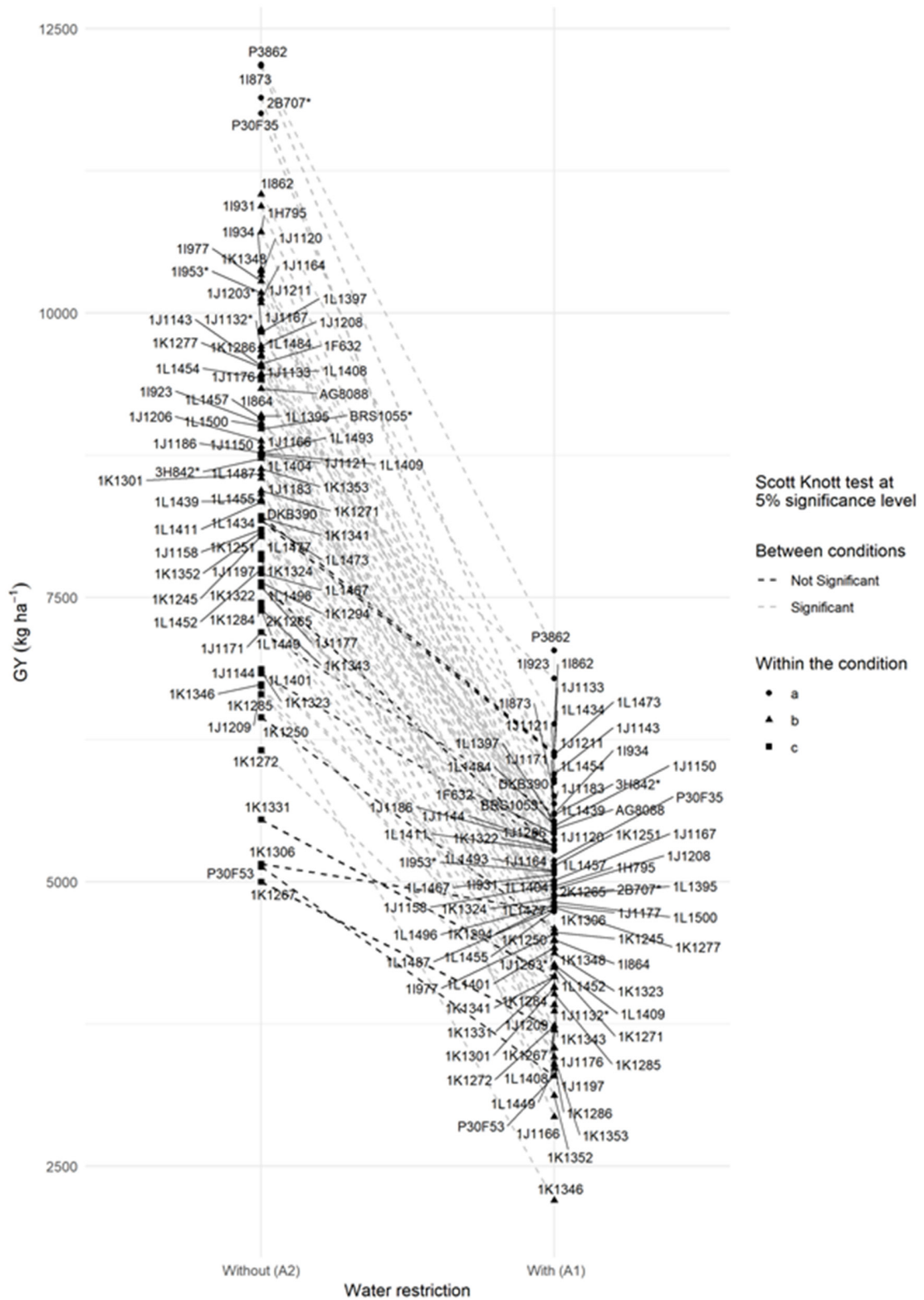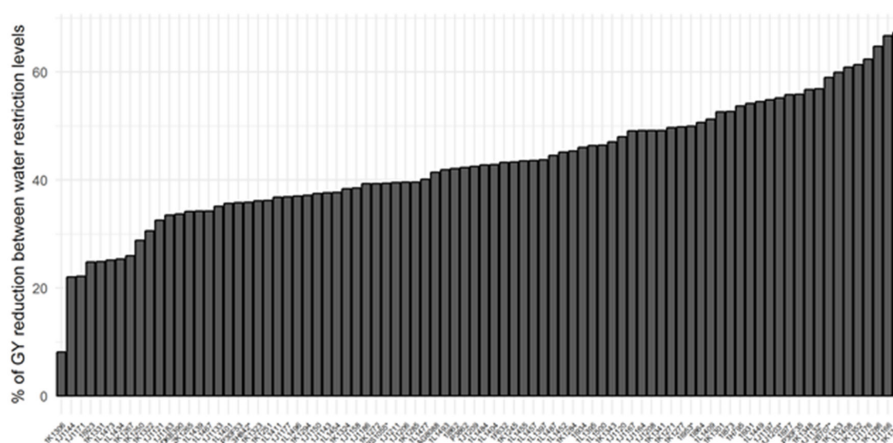
**Figure 2.** Grain yield (GY) of 86 maize hybrids in environments with (A1) and without (A2) water restriction.

kg ha$^{-1}$ to 7032 kg ha$^{-1}$, with a mean GY of 4606 kg ha$^{-1}$. These hybrids showed potential for use in environments with low water availability. Obtaining hybrids with good GY in environments with water restriction and a significant increase in environments without water restriction has been the aim of many plant breeding programs (Cooper et al. 2014).

These results are even more relevant considering that, in Brazil, the greater percentage of maize production is concentrated in the second crop season, when water availability conditions are not ideal, leading to drastic reductions in yield in certain situations (Clovis et al. 2015). For the A2 environment, four hybrids that had the highest GY according to the Scott-Knott test at the 5% significance level were P3862, 1I862, P30F35 and 2B707. In this environment, the GY ranged from 5000 kg ha$^{-1}$ to 12186 kg ha$^{-1}$, with a mean yield of 8532 kg ha$^{-1}$.

Reduction in GY between the A2 and A1 environment ranged from 8.13% (1K1306) to 67.38% (1K1346) (Figure 3). Mean reduction, considering grain yield between the environments with and without water restriction, was 46%, which shows the effectiveness of imposing stress and the possibility of gene expression in response to environmental stress under water restriction. In this regard, identification of maize hybrids with lower yield reduction in stressful environments means greater stability in production, which is also desirable (Mi et al. 2018).



**Figure 3.** Percent of grain yield (GY) reduction between environments with and without water restriction of 86 maize hybrids.
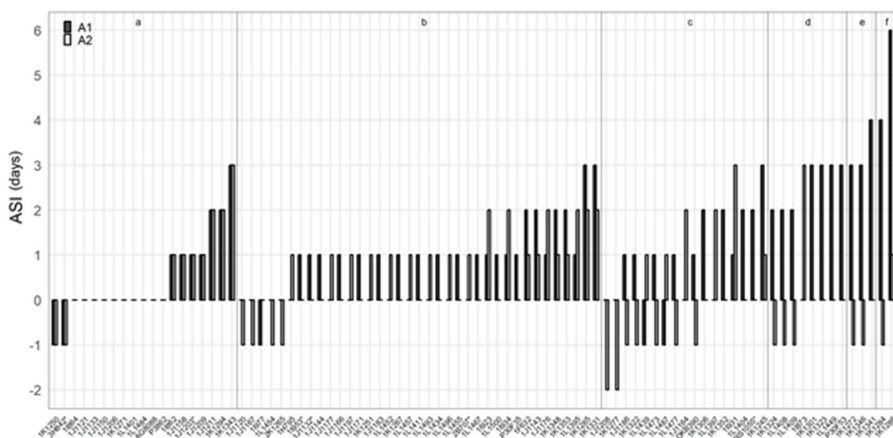


**Figure 4.** Anthesis-silking interval (ASI), in days, of 86 maize hybrids ordered according to the smaller difference between environments with (A1) and without (A2) water restriction. Groups of difference in days between A1 and A2, according to Scott Knott 5% significance level, ranging from 0 (a) to 5 days (f).

Despite the significant hybrid × environment interaction, most hybrids (65%) exhibited a difference between the $ASI_{A1}$ and the $ASI_{A2}$ equal to zero or equal to 1, group a and b, respectively, in Figure 4. Ten hybrids had an ASI equal to zero for both environments, and the greatest difference of the ASI within and between the environments was 5 days (Group f). Differences in the ASI can occur due to differences in the date that tasseling or upper ear development begin, or because of changes in the development rate or duration of these organs. However, according to Edmeades et al. (2000), grain set is generally limited when the ASI is greater than 5 days in individual plants.

Regarding the drought tolerance indices, SSI ranged from 0.49 (1J1171) to 1.57 (1J1176) and TOL ranged from 1298 (1K1267) to 7014 (2B707) (Figure 5). For these indices, lower values indicate more drought-tolerant hybrids and hybrids more efficiently selected for higher yields in environments with water restriction (Jafari et al. 2009, El-Sabagh et al. 2018). For the DRC, DRI, STI and HM indices, higher values indicate hybrids tolerant to drought, and these indices generally show greater efficiency in identifying superior hybrids in both environments (Jafari et al. 2009, El-Sabagh et al. 2018). Values ranged from 0.78 (1J1144 and 1J1171) to 0.28 (1J1176) for DRC, from 1.14 (1I923) to 0.16 (1K1346) for DRI, from 1.30 (P3862) to 0.21 (1K1346) for STI and from 9242 (P3862) to 3314 (1K1346) for HM. The hybrids 1I923, 1L1434 and 1L1473 were located in the groups with the best values for all drought tolerance indices, according to the Scott-Knott test at the 5% significance level.

High correlation values among the tolerance indices evaluated were observed between SSI and DRC (-0.98) and between STI and HM (0.98) (Table 1). The correlation between SSI and TOL, DRC and DRI, and STI and HM were positive and highly significant. Negative and highly significant coefficients were found between the indices SSI and DRC, SSI and DRI, and TOL and DRC. In this respect, the use of only one of these highly correlated indices may be effective in evaluation of maize hybrids, eliminating redundant information.

The correlation coefficient between $GY_{A1}$ and $GY_{A2}$ was non-significant. In general, maize hybrids that have positive and significant correlation coefficients between these characteristics are desired, inferring that the hybrids that have good yield under water deficit stress can significantly increase their grain yield in environments with good water availability (Cooper et al. 2014). However, in situations where hybrids are to be grown in exclusively dry environments, this correlation may not be important in selection (Dias et al. 2018).

$GY_{A1}$ had highly positive and significant correlations (above 80%) with the indices DRI, STI and HM and mean grain yield, suggesting that these indices can be used as secondary criteria in evaluation for identification of maize hybrids that have good yield under water stress. However, DRI had near zero correlation with $GY_{A2}$, which is not favorable in the selection process since maize hybrids are sought with superior grain yield in both environments.

For $GY_{A2}$, the highest magnitude of significant coefficients (above 64%) were observed for the indices TOL and STI. Similar results were observed in barley (Eivazi et al. 2013) and wheat (Anwar et al. 2011) crops, implying that these indices can be used in an effective manner in various crops. For maize hybrid selection in environments with and without

**Table 1.** Spearman correlation coefficients between grain yield in environments with water restriction ($GY_{A1}$) and without water restriction ($GY_{A2}$), stress susceptibility index (SSI), water stress tolerance (TOL), drought resistance coefficient (DRC), drought resistance index (DRI), stress tolerance index (STI), harmonic mean (HM), mean grain yield (mGY), anthesis-silking interval in environments with water restriction ($ASI_{A1}$) and without water restriction ($ASI_{A2}$)

| | $GY_{A2}$ | SSI | TOL | DRC | DRI | STI | HM | mGY | $ASI_{A1}$ | $ASI_{A2}$ |
|---|---|---|---|---|---|---|---|---|---|---|
| $GY_{A1}$ | 0.30 | -0.67 ** | -0.46 ** | 0.66 ** | 0.90 ** | 0.87 ** | 0.91 ** | 0.82 ** | -0.42 ** | 0.01 |
| $GY_{A2}$ | | 0.43 * | 0.65 ** | -0.44 ** | -0.03 | 0.64 ** | 0.58 ** | 0.74 ** | -0.33 ** | 0.19 |
| SSI | | | 0.95 ** | -0.98 ** | -0.89 ** | -0.28 ** | -0.36 ** | -0.19 | 0.12 | 0.12 |
| TOL | | | | -0.95 ** | -0.74 ** | -0.05 | -0.13 | 0.05 | -0.06 | 0.15 |
| DRC | | | | | 0.88 ** | 0.27 | 0.36 | 0.18 | -0.11 | -0.13 |
| DRI | | | | | | 0.63 ** | 0.70 ** | 0.56 ** | -0.25 ** | -0.08 |
| STI | | | | | | | 0.98 ** | 0.97 ** | -0.46 ** | 0.13 |
| HM | | | | | | | | 0.96 ** | -0.45 ** | 0.08 |
| mGY | | | | | | | | | -0.43 ** | 0.16 |
| $ASI_{A1}$ | | | | | | | | | | 0.02 |

*$p$-value ≤ 0.05; ** $p$-value ≤ 0.01.

water restriction, the STI and HM indices can be used effectively. These indices showed high positive and significant correlation with $GY_{A1}$ and $GY_{A2}$, corroborating the results of Barutcular et al. (2016) and El-Sabagh et al. (2018).

In the environment with water restriction, the ASI had a significant negative correlation with GY (-0.42). The ASI in the A1 environment also showed a significant negative correlation with GY in the A2 environment (-0.33) and with the DRI, STI and HM indices. However, the ASI evaluated in the environment without water restriction showed no significant correlation with any variable (Table 1). The selection of maize lines or hybrids with a lower ASI allowed genetic gains
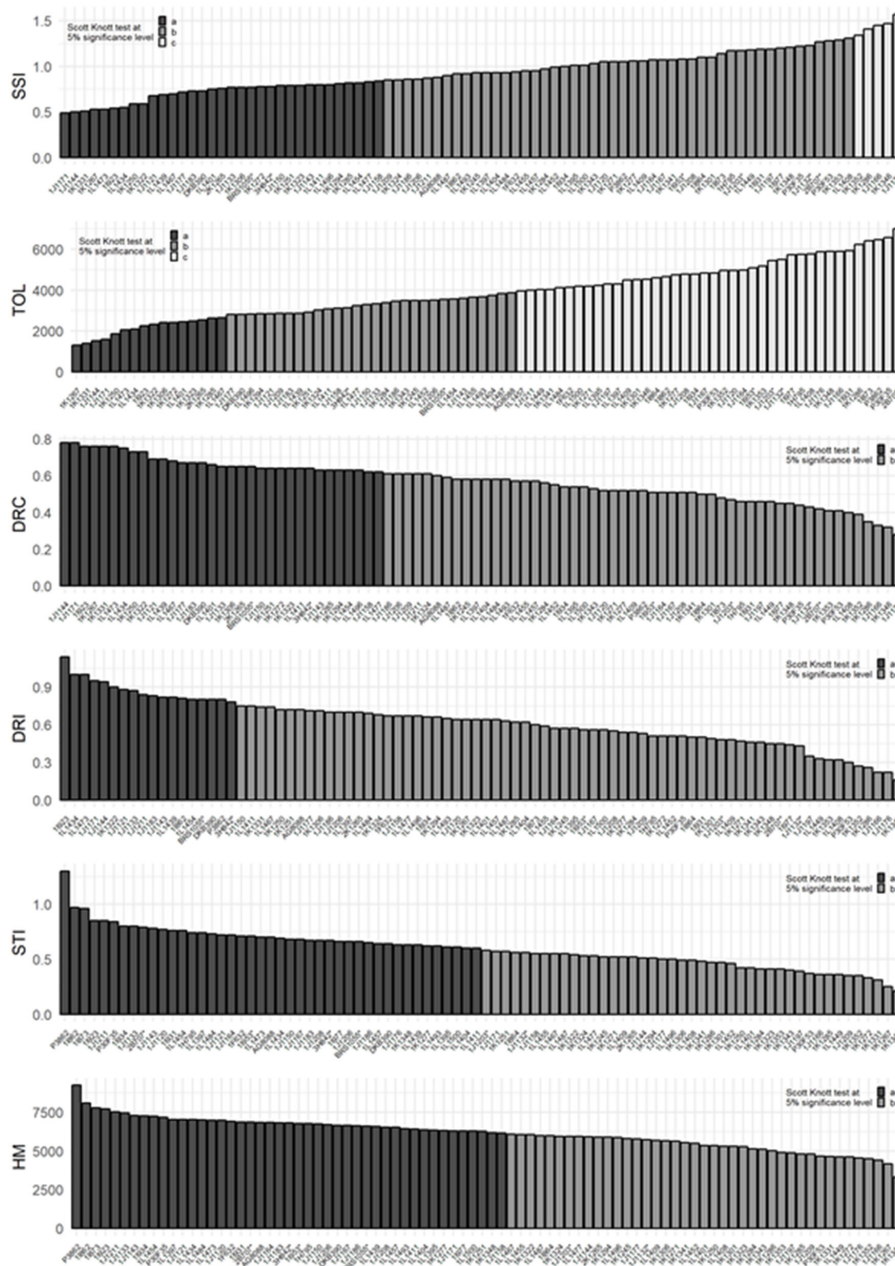


Figure 5. Stress susceptibility index (SSI), water stress tolerance (TOL), drought resistance coefficient (DRC), drought resistance index (DRI), stress tolerance index (STI), and harmonic mean (HM) of 86 maize hybrids.
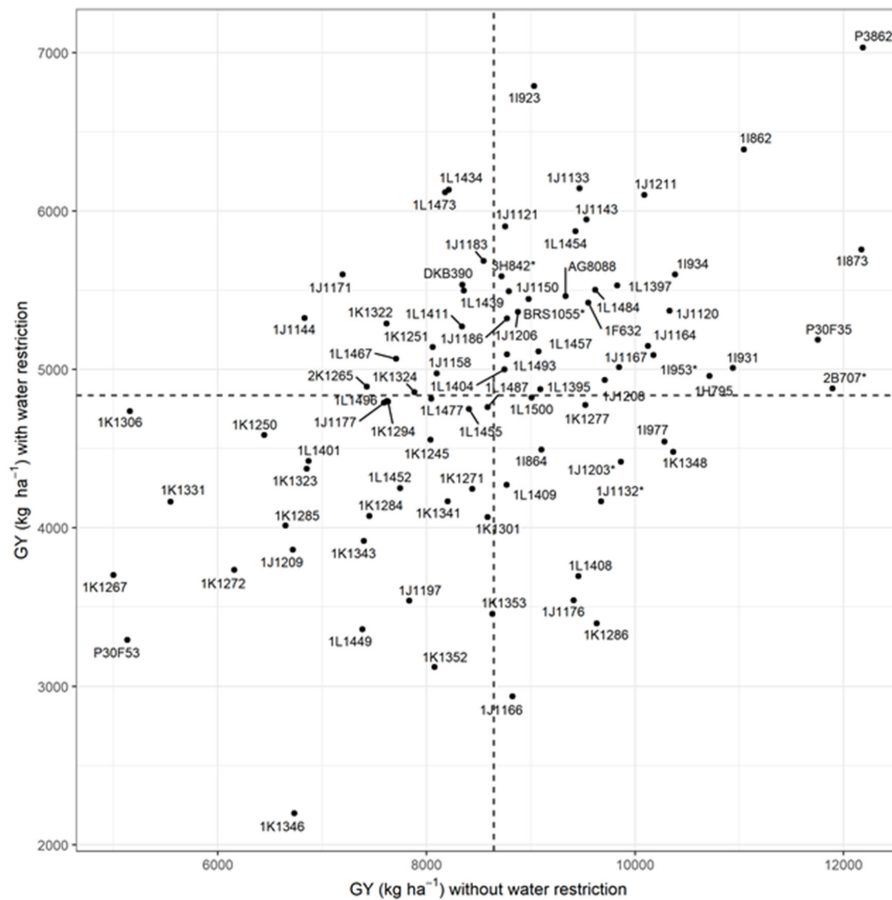
**Figure 6.** Dispersion of mean grain yield (GY) of 86 maize hybrids in environments with and without water restriction.

and had a positive impact on drought tolerance (Musvosvi et al. 2018).

In spite of the low magnitude and the lack of significance between $GY_{A2}$ and $GY_{A1}$, it is possible to identify hybrids that have superior performance in the two cropping situations (Figure 6). The hybrids plotted in the upper right quadrant of the figure are considered more drought tolerant by achieving yield above the average of the environment with water restriction. They are also responsive to higher water availability conditions since their mean grain yield was higher than the mean in the environment without water restriction.

Thus, principally the use of the STI or HM indices allowed identification of drought-tolerant hybrids that had high grain yield in environments with and without water restriction, and the ASI is useful for early selection in environments with water restriction. The best hybrids in this study were P3862, 1I873, 1I923, 1I862 and 1J1211; they had good $GY_{A2}$ and $GY_{A1}$, along with the best values of drought tolerance indices. These results are useful and applicable to selection of genotypes, especially in maize breeding programs for the second crop season in Brazil. Future studies may use these indices to further research on genetic control of drought tolerance in maize.

## ACKNOWLEDGMENTS

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