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WATER STRESS INDEX IN MAIZE HYBRIDS IN EARLY GROWTH STAGE UNDER WATER VARIATION

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ABSTRACT

Drought causes morphological changes in corn, especially during the initial phase of its development. This study aimed to evaluate the sensitivity of different maize hybrids to water stress, using the Crop Water Stress Index (IEHC) and infrared thermometer to monitor the water status of plants in the early stages of development. The maize cultivars B2620 PWU, AG8701 PRO 4, P3808 VYHR and DKB360 PRO 3 were tested, submitted to a randomized block design (DBC), in a 4 x 2 x 5 factorial scheme, with 4 replications. The study considered 4 corn hybrids, 2 levels of water replacement (100% and 50% of crop evapotranspiration) and 5 evaluation times (15, 22, 29, 36 and 43 days after emergence - DAE). The lower (LBL) and upper (UBL) baselines for the IEHC calculation were determined by the lowest and highest air temperatures recorded throughout the crop cycle. The data were submitted to analysis of variance and, when significant, the qualitative data were analyzed by Tukey's test at $p<0.05$ and the quantitative data by multiple regression. The results indicated that the hybrid DKB360 PRO 3 presented the lowest water stress index, demonstrating greater resistance to water scarcity. In contrast, the hybrid P3808 VYHR was more sensitive to water stress, with larger leaf area. The highest intensity of water stress was observed at 22 days after emergence, which reinforced the importance of leaf architecture in the adaptation of

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plants to water stress and its influence on survival during periods of drought. The water stress index of the crop should be used with weight in the choice of resistant varieties, being better indicated for monitoring the water status of the plant.

Keywords: Zea mays L. Leaf Temperature. Evapotranspiration. Leaf Area.

INTRODUCTION

Corn (*Zea mays* L.) is one of the main crops used in human and animal food, it can be consumed *in natura* or processed. In addition, it is an important *commodity* used in industry as a raw material for the manufacture of food, bioenergy, beverages, derivatives, among others (Pereira Filho; Borghi, 2022). Belonging to the Poaceae family, corn is an annual, robust and upright plant (Ferreira, 2024). It is classified as a species with C4 metabolism, which has a higher efficiency in converting CO_2 into carbohydrates than C3 plants, favoring the production of green biomass and increased yield (Carvalho, 2022).

It is a monoecious plant, whose morphological characteristics result from modifications in the basic structures of grasses, through processes such as suspension, condensation and multiplication. Its morphology includes a cylindrical hurry with compact knots and internodes, adventitious roots, and tillers. The leaves, arranged alternately, wrap around the stalk, ending in the tassel. Although corn has vegetative and reproductive aspects that can be influenced by environmental factors, many of these characteristics have been improved throughout the process of domestication and natural selection. This resulted in a vigorously growing crop capable of reaching up to four meters in height. The plant cycle begins with germination and, when emitting the tassel, a vegetative phase ceases, starting reproduction. This dynamic culminates in the production of grains, the main objective of corn cultivation (Magalhães et al*.,* 2002; Lorscheiter et al*.*, 2025).

The estimate for corn production in 2025 is 120.6 million tonnes, representing a growth of 5.1% compared to 2024, driven by the increase in the average yield, which should reach 5,613 kg $^{ha-1}$, with an increase of 4.5% (IBGE, 2025). This growth is also expected in Minas Gerais, where the more favorable climate for the implementation and development of the crop contributes to higher production. For the first harvest, Conab projects a production of 3.99 million tons, which means an increase of 2.5%. In this same harvest, productivity tends to grow by 9.2%, reaching 6.2 tons per hectare (Valverde, 2024). Thus, both favorable weather and productivity improvements should result in significant corn crop performance, both nationally and statewide.

Progress in the genetic improvement of corn has allowed the emergence and sale of varieties with greater productive capacity, reduced size, erect leaf structure and distinct cycles. This advance is the result of crosses between pure lines and their corresponding cultivars, providing the grains with vigorous resistance and high productivity. In 1909, the American researcher George Harrison Shull presented the first basic model for the production of hybrid maize seeds (Caetano et al., 2022).

The genetic improvement of corn consists of successive self-fertilizations to choose desired attributes until pure lines are obtained. Based on these lines, several types of hybrids are created, such as: simple (crossing of two inbred lines), modified simple (hybrid female parent between similar progenies of the same lineage), triple (crossing a single hybrid with a hybrid composed of a third line), double (crossing between two simple hybrids), top cross (crossing a line or hybrid with a variety) and intervarietal (crossing between two varieties) (Sobrinho; Wetzel, 2024).

Breeding more productive hybrids requires more analysis under various edaphoclimatic conditions, which makes it crucial to implement appropriate management practices to increase crop productivity.

Corn production faces several challenges that can irreversibly compromise its profitability and productivity. Among these challenges, the uniformity of the stand, related to the sowing process, vulnerability to pests and diseases, soil management and climatic conditions stand out. In the early stages of development, maize is especially sensitive to both excess and scarcity of water in the soil (Crop Nutrition, 2024). In addition to limiting growth and development, water stress has a critical impact on flowering and grain filling, times when the plant requires adequate soil moisture for its full development (Silva, 2019). Water deficit is one of the main factors that interfere with corn growth and yield and can be caused by irregular rainfall distribution, given that it is a crop normally implanted in the off-season period. In order to mitigate the effects of low water availability in this period, the supplementary irrigation technique is usually used (BEM, 2018).

Drought, by causing water stress, causes physiological and morphological changes in plants, negatively affecting their growth and productivity. This stress reduces photosynthesis, due to the decrease in cell expansion caused by damage to the photosynthetic apparatus. As a consequence, there is a reduction in biomass, plant height, stem diameter, and leaf area (Guimarães et al., 2019; Silva et al., 2020). In addition, water deficit impacts several aspects of plant development, such as decreased leaf area, photosynthetic rate, sprouting, nutrient absorption, and photoassimilate translocation (Lopes, 2022).

To mitigate the negative effects of this stress, in addition to supplemental irrigation, it is crucial to choose varieties or hybrids resistant to soil water variation. This is important to achieve good efficiency in water use, that is, a greater accumulation of dry matter per unit of water applied, resulting in better profitability (Fabris, 2016). The absorption, transport and transpiration of water in plants result in the interaction between evaporative demand from the atmosphere, stomatal resistance, water availability in the soil and root density.

Water is essential to meet physiological needs, transport nutrients and regulate temperature through perspiration. Under conditions of water stress, plants activate cellular adaptation mechanisms, such as greater root development, smaller leaf cuticle size, thickness and waxiness, changes in leaf angle, stomatal control, accumulation of intermediate metabolites, osmotic adjustment and resistance to cellular dehydration.

Most studies on water deficit in maize analyze water restriction from the reproductive stage, however, water deficit can occur before the reproductive stage and in more than one stage of development. There have been few studies on the responses to water restriction in maize hybrids in the initial phase of their cycle, and this topic is relevant, because in many producing regions it is common to have summers in the early stages of crop development, post-planting, and understanding how maize responds to droughts in this phase is essential to develop strategies and choices to ensure its development in regions where drought occurs in these stages (Ruas, 2018). There are several physiological indicators that can indicate the response of corn to water variability in the soil, among them are thermal.

When the temperature of a leaf exposed to solar radiation increases, the emission of infrared energy also intensifies. Because green plants have high emissivity in the infrared range (between 0.95 and 0.98), the measured radiative temperature can be converted into the actual temperature of the plant. Thus, the use of remote sensors to measure the temperature of the vegetative canopy makes it possible to detect water stress (Nunes, 2012). This can be done using infrared thermometers, which are radiometers that measure energy in the infrared range and are used to estimate the temperature in this region of the spectrum. From the measurements of leaf and air temperatures, it is possible to determine the water stress index of the crop.

The Crop Water Stress Index (IEHC), combined with the use of an infrared thermometer, allows the evaluation of the water status of corn in the field even before the visual signs of stress are noticeable. Leaf temperature and the temperature difference between the leaf and the air have been widely used in several studies as indicators of water deficit, in addition to serving as a criterion for defining irrigation (Vilatte, 2014).

In this context, the objective of this study was to evaluate the sensitivity of maize hybrids to water stress, using the IEHC, using an infrared thermometer to monitor the water status of plants in early stages of development.

METHODOLOGY

The experiment was conducted in the seedling nursery of the Federal Institute of Northern Minas Gerais – Arinos Campus, with coordinates of latitude 15°55'12.75" S, longitude 46° 8'5.57" W and altitude of 525.0 m. The climate of the classified site is C2wA'a', that is, the climate for the city of Arinos-MG is characterized as subhumid megathermal with moderate water deficit in winter (Oliveira; Oliveira, 2018).

To conduct the study, corn (*Zea mays* L.) was used as plant material, grown in pots and the experimental unit was composed of one plant per pot. The pots had a volume of 5.0 dm^3 liters and the lower part of the pots were filled with a filtering element, making up a 1 cm layer of gravel n° 1, shade type screen and under it, 4 dm^3 of Bioplant commercial substrate was accommodated, which is composed of a mixture of *sphagnum peat*, coconut fiber, rice husks, pine husks, vermiculite, agricultural gypsum, calcium carbonate, magnesium, magnesium thermophosphate and additives (Mendes et al., 2020).

The randomized block design (DBC) was used in a 4 x 3 factorial scheme with 4 replications, with factor A: 4 corn hybrids (B2620 PWU, AG8701 PRO 4, P3808 VYHR and DKB360 PRO 3); and the B factor for 2 irrigation depths (100 and 50% of water replacement) and the C factor were 5 times of temperature measurement (15, 22, 29, 36, 43 days after emergence). The 100% water replacement was determined as the actual evapotranspiration of the crop (ETRc), measured by the average depth retained in 4 weighing lysimeters, that is, by water balance in the soil. The replacement of 50% constituted half of the total water replacement.

To assess the thermal/water stress of the crop, the Crop Water Stress Index (IEHC) was used, according to equation 1 proposed by Carvalho et al. (2022), whose index consists of evaluating the damage caused by the low availability of water transported in the cultivars, mainly by the xylem and other physiological means.

$$IEHC = \frac{(Tc - Tar)}{(Tc - Tar)UBL} - \frac{(Tc - Tar)LBL}{(Tc - Tar)LBL} \quad (1)$$

Where:

EHC = Crop water stress index (varies between 0 and 1)

Tc = Canopy Temperature (°C)

Tar = Air temperature (°C)

LBL = Lower Baseline (°C)

UBL = Upper Baseline (°C)

To supply Equation 1, the air temperature (Tar) (ºC) was measured by a maximum and minimum thermometer installed at a point representative of the boundary conditions of the experiment and the leaf temperature was measured daily by means of a digital infrared thermometer, model TD-965 from the manufacturer Digimess. The lower (LBL) and upper (LBL) baselines were determined, respectively, by the lowest and highest air temperatures measured throughout the crop cycle. Leaf temperature measurements always occur between 08:00 and 10:00 in the morning on leaves of the middle third of each experimental unit.

After data collection and treatment, they were submitted to statistical analysis. When significant by the F test, the quantitative data were evaluated by multiple regression and the qualitative data by Tukey's test at 5% probability ($p < 0.05$) by means of the Sisvar software. Tables and figures were made with Excel software, for a better understanding of the results.

RESULTS AND DISCUSSION

The analysis of variance table (Table 1) shows that the factors that influenced the IEHC were the hybrids and the time of evaluation, with no significant interactions between the treatments. Water scarcity can lead to reduced leaf biomass and stomatal closure, limiting photosynthesis and plant growth. Research indicates that water deficiency causes negative effects on plant development, including restriction of stomatal opening and wilting of leaves (Campos; Saints; Nacarath, 2021).

Table 2 shows the differences in the water stress index for the maize hybrids. By the test, it was found that the highest IEHC was obtained for the P3808 VYHR hybrid and the lowest for the DKB360 PRO 3 hybrid. It is possible to infer that the DKB360 PRO 3 hybrid is less susceptible to water variation in the medium than the others, since a lower IEHC value means that the plant is more hydrated.

Table 1. Analysis of variance for the water stress index of maize hybrids.

Source of variation	GL	Medium Squares
Block	3	0.00048 ns
Hybrid (H)	3	0,00779 **
Water replenishment (RH)	1	0.00215 ns
Season (E)	3	0,2998 **
H x RH	3	0.00338 ns
H x E	9	0.00193 ns
RH x E	3	0.0038 ns
H x RH x E	9	0.00161 ns
Residue	93	0,00194
CV (%)	13,54	
Average	0,320	

** - Significant at $p<0.01$; ns - Not significant; GL - Degree of freedom; CV – Coefficient of variation.
Source: Authors, 2025

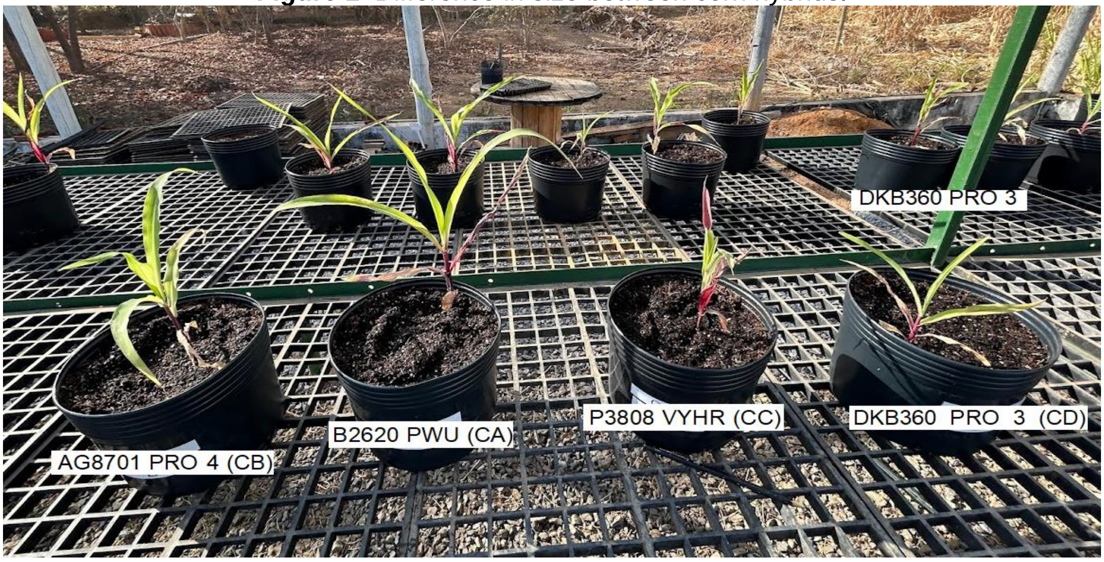
Table 2. Difference between water stress index in maize hybrids.

Hybrid	Average
DKB360 PRO 3	0.308 b
AG8701 PRO 4	0.319 ab
B2620 PWU	0.331 ab
P3808 VYHR	0.345 to

Equal letters in the column do not differ statistically from each other at $p<0.05$. **Source:** Authors, 2025

It should be noted that the hybrid DKB360 PRO 3, among all those tested, had lower plant height, as well as leaf area (Figure 1), so the evapotranspirometric demand of this hybrid is lower, corroborating the result seen in Table 2. This pattern may be associated with the genetic characteristics of each hybrid, which determine its efficiency in water collection and its resistance to environmental stress conditions. Plants with smaller leaf architecture are less sensitive to soil water variation, because with a smaller leaf area, transpiration is reduced, causing less stress to the cultivar (Arruda et al., 2015). The reduction of leaf area in hydrated plants causes a decrease in the growth rate of the plant, especially in the initial stage of growth and, as a result, a lower interception of solar radiation (Andrade et al., 2008), in addition, the inhibition of leaf growth reduces carbon and energy consumption and a greater proportion of plant assimilates can be distributed to the root system (Cavalcante et al., 2009).

Figure 1. Difference in size between corn hybrids.



Source: Authors, 2025.

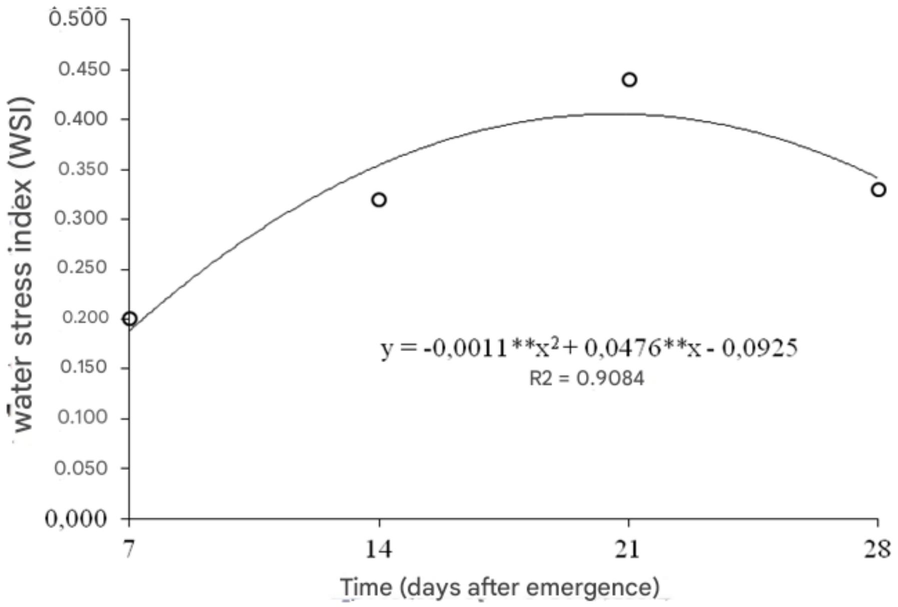
The hybrid DKB360 PRO 3 developed even with the limited water supply in the soil, since there was no significant difference between the water replacement fractions (Table 1). In this study, it was observed that the DKB360 PRO 3 hybrid, even with reduced size, was not influenced by lower water availability, possibly due to its C4 metabolism, which is more photosynthetically efficient. For Cavalcante et al. (2009), plants subjected to lower water availability modulate stomatal opening, limiting carbon absorption for photosynthesis, which leads to lower plant growth.

The hybrid P3808 VYHR was more sensitive to soil water variability (IEHC = 0.345), possibly due to its larger size and larger leaf architecture. The larger the leaf area, the greater the transpirant surface of the plant and the greater the water loss (Adorian et al*.,* 2015). Large total leaf areas have a large surface area for water evaporation, which can be advantageous for cooling the leaves. However, this trait can also lead to rapid depletion of soil water or excessive and harmful absorption of solar energy. On the other hand, larger leaves have greater resistance in the bordering layer, dissipating less thermal energy per unit of leaf area through direct heat transfer to the air (Taiz *et al.,* 2017). These results are corroborated by Silva et al. (2003) who investigated the relationship between leaf architecture and water use efficiency, highlighting the impact of excessive transpiration in conditions of water deficit.

Figure 2 shows the behavior of the IEHC as a function of the days after the emergence of the hybrids (evaluation period). The mathematical model adjusted in the statistics was the second-order one, where it is observed that the highest IEHC was ~0.4 at 22 DAE.

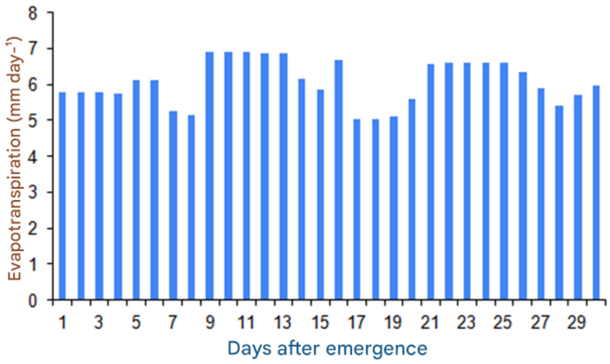
The interval close to DAE 22 was characterized by a considerable increase in water stress, a direct result of the increase in daily evapotranspiration (Figure 3). This behavior was not attributed to the hybrids, due to the growth in size being linear with time for the observed period (initial growth).

Figure 2. Corn water stress index as a function of the evaluation period.



Source: Authors, 2025.

Figure 3. Evapotranspiration of maize hybrids over the evaluated period.



Source: Authors, 2025.

Factors such as solar radiation, wind, humidity and air temperature influence this evaporating power, with incident solar radiation being the main determinant of evapotranspiration (Sediyama et al., 2011; Matzenauer et al., 1998).

It is noted that the DKB360 PRO 3 hybrid demonstrated lower sensitivity to water stress compared to P3808 VYHR. This is due to lower height and leaf area, characteristics that interfere with the reduction of transpiration and, consequently, the adaptability of the hybrid to abiotic stress. These results highlight the relevance of morphophysiological attributes in the choice of hybrids more apt to environments with water limitation.

In previous studies, working with the hybrids in this study and under the same experimental and boundary conditions, Silva et al. (2025) found that the hybrid DKB360 PRO 3 had the worst growth, among the variables tested, with the exception of the number of internodes. The hybrid AG8701 PRO 4 had the highest leaf area in all the evaluated seasons (22, 29, 36 and 43 days after emergence) and the hybrid P3808 VYHR had leaf area equivalent to the hybrid B2620 PWU at 29, 36 and 43 DAE. In contrast to the results found here, it is observed that hybrids modulate their water loss by transpiration and, consequently, the IEHC varies. Therefore, caution is pertinent to infer about the choice of hybrids resistant to water deficit, however, it is possible to infer about the momentary water status of the hybrid/cultivar.

For a deeper understanding of hybrids' responses to water stress, it is essential to conduct research that investigates the correlations between biochemical and physiological parameters. In addition, the diversification of soil conditions is a pertinent approach, involving the experimentation of hybrids in soils with different physicochemical characteristics.

The results highlight the importance of additional studies to better understand the responses of maize hybrids to water stress. Variables such as chlorophyll content, leaf temperature, phenology, and average root diameter are essential to identify more drought-tolerant hybrids, helping in the development of crops resilient to climate change (Moreira, 2020). In addition, measuring the water potential of leaves and analyzing the correlation between stomatal conductance and photosynthesis rates are key to understanding the response of plants to water stress (Lopes, 2022).

FINAL CONSIDERATIONS

The results indicate that the hybrid DKB360 PRO 3 stood out as the most efficient under water restriction conditions compared to the hybrids AG8701 PRO 4, B2620 PWU and P3808 VYHR, which obtained IEHC values of 0.319, 0.331 and 0.345, respectively. Its low water stress index, associated with smaller size and reduced leaf area, contributed to a lower evapotranspiration demand.

On the other hand, the hybrid P3808 VYHR presented the worst performance under water stress, registering the highest IEHC value (0.345). Its high size and wide leaf area increased the transpiration surface, intensifying water loss and sensitivity to soil moisture variation.

The water stress index of the crop should be used with weight in the choice of resistant varieties, being better indicated for monitoring the water status of the plant.

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