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# Agronomic Aspects, Efficiency of Photosystem and Corn Stunting Disease of Popcorn (*Zea mays* Var. Everta Sturt.) Cultivars in Brazil

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**Abstract**

From healthy food to potential culture, the popcorn crop search technologies that allow your expansion, however, the popcorn genotypes need still to be more explored, they are not yet enough to meet the production market needs. Therefore, new agricultural characteristics, technological adjustments of process among farmers, and specific agronomic research for popcorn cultivars will be fundamentals for Brazil to achieve self-sufficiency in the national popcorn business. The objective of this work was to identify the best popcorn maize cultivar to be grow in the state of Goiás, Brazil, through agronomic, physiological and corn stunting disease evaluations. Two experiments, one in northeastern Goiás, and one in southeastern Goiás, were conducted in randomized block design, with three treatments and four replications. Morpho-agronomical and physiological descriptors and the percentage of plants with symptoms of maize bushy stunt (MBS) and corn stunt spiroplasma (CSS) were evaluated in three popcorn maize cultivars (Americano RS20, UENF-14, and Formosa). The joint ANOVA for the two environments showed significant interaction (*p<0.05*) for plant height, ear insertion height, percentage of lodged plant, percentage of prolific plants, percentage of plants with tassel, percentage of plants at the R1 (silk) stage, CSS and number of ears per plot. The UENF-14 cultivar presented the same response for ears per plot in both environments, presenting significantly higher (*p<0.05*) means and mean yield (2.200 kg $ha^{-1}$), when compared to the other cultivars. The mean percentages of MBS were higher in the northeastern region. The UENF-14 cultivar is recommended for popcorn maize crops in Goiás, Brazil, because it presented phenotypic plasticity for total yield, MBS and CSS, and high efficiency of photosystem II.

**Keywords:** Agronomic performance, Chlorophyll a, Maize bushy stunt, Corn stunt spiroplasma, Ecophysiology

## Introduction

Brazil has a high food production capacity due to favorable soil and climate conditions, mainly in the Cerrado biome, which encompasses the highest national grain production area; this biome presents porous, permeable, and well-drained soils, well defined seasons, good rainfall levels, and plain reliefs, which facilitates mechanization [1]. Brazil is the third highest world grain exporter country, with an estimated expansion of 27% in grain production and 15.3% in planted area for 2030 [2]. The estimated area used for grain production in the 2020/2021 crop season was 65.5 million hectares, 4.0% higher than the previous crop season, mainly due to the growth of soybean and maize areas; thus, Brazil may reach a historical grain production of 266 million Mg [3].

Maize production in Brazil reached 103 million Mg $ha^{-1}$ in 2019/20. Most of this production is from the states of Mato Grosso (31.3%), Paraná (16.7%), Goiás (10.4%), Mato Grosso do Sul (10.1%), and Minas Gerais (7.4%), which summed 72.2 million Mg, representing 75.8% of the national production [2-3]. However, popcorn maize cultivars are little grown by Brazilian farmers due to the low technological investments that make them more susceptible to pests and diseases, when compared to the grain maize cultivars. The production in the 2018/2019 crop season was only 289,000 Mg, which were grown in approximately 67,000 hectares [4]. Thus, popcorn maize (*Zea mays* var. Everta) plants require more studies to ensure high yields in field conditions, since it is a good agricultural alternative due to the higher added value when compared to grain maize, the export potential, and its adaptation to several regions of Brazil [5]. This adaptation is related to morphophysiological peculiarities; this species presents $C_4$, annual, cespitose, erect, low-tillering, and monoecious plants, known as one of the most efficient plants in light energy storage [6].

However, the low genetic variability and small number of cultivars available in the market prevents the expansion of this crop; the evaluation and introduction of different cultivars to different locations enables the identification of the most adapted and stable under specific environmental conditions. Studies about popcorn maize have indicated good performance of cultivars grown in the states Minas Gerais, Rio de Janeiro, Pará, and Mato Grosso, but no reports for the state of Goiás [7,8,9,10].

Agronomic attributes, such as resistance to lodging, yield, and tolerance to pests and diseases, should be considered to evaluate different genetic materials of popcorn maize, focused on identifying superior genotypes. However, effects of oxidative damages induced by increases in severity of biotic and abiotic stresses, and the inhibition of these antioxidant systems that affect biochemical processes of plant species, should be considered when evaluating photosynthetic aspects that affect directly production factors [11,12].

Changes in physiological variables are shown before the plant presents symptoms of damages caused to the photosynthetic apparatus, such as leaf senescence and yellowing and decreases in leaf growth and area, providing information on causes that decrease the plant yield [13]. The capacity of plants to tolerate these damages is related to a higher efficiency of the photoprotector system of the photosystem II [14]. Thus, the identification of genotypes with higher photoprotector capacity assists in the choosing of cultivars that are more resistant to abiotic stresses. The objective of this work was to identify the best popcorn maize cultivar to be grown in the northeast and southwest regions of the state of Goiás, Brazil, through evaluations of morpho-agronomic and physiological parameters and

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the percentage of plants with symptoms of Maize Bushy Stunt (MBS) and Corn Stunt Spiroplasma (CSS).

## Materials and Methods

Two experiments were conducted, one at the Northeast in the municipality of Posse (14°05'35"S, 46°22'10"W, and altitude of 811 m) (Location I), and other at the Southwest in the municipality of Ipameri (17°42'5912"S, 48°08'40.49"W, and altitude of 773 m) (Location II), both in the state of Goiás (GO), Brazil. The cultivars evaluated were: UENF-14, which was obtained by the popcorn maize breeding program of the State University of Northern Rio de Janeiro (UENF); Americano RS20, which was acquired from the Isla Seeds company; and Formosa, a local variety whose seeds were donated by local farmers of Formosa, GO, Brazil. A randomized block experimental design was used, in a 3×2 factorial arrangement, with three cultivars, two locations, and four replications. Each experimental plot consisted of four 4-meter rows, with spacing of 0.90 m between rows and 0.25 m between plants. Three seeds were sown by pit to a depth of 0.05 m and the seedlings were thinned at 28 days after sowing.

Fertilizers were applied and incorporated to soil at planting, using 20 kg $ha^{-1}$ of urea, 40 kg $ha^{-1}$ of potassium chloride, and 60 kg $ha^{-1}$ of simple superphosphate. Topdressing was applied using 70 kg $ha^{-1}$ of urea and 20 kg $ha^{-1}$ of potassium chloride, equally split into three applications, at 30, 45, and 60 days after sowing.The morpho-agronomic variables evaluated were: plant stand (PS) at 104 days; plant height (PH) at 104 days after emergence; ear insertion height (EIH) measured with a measuring tape (mm); percentage of lodged plant (PLP); percentage of prolific plants (PPP); percentage of plants with tassel (PPT) at the beginning of tasseling, at 61 days after emergence; percentage of plants at the R1 (silk) stage (PPR1); number of ears per plot (EPP); ear length (EL) measured with a ruler (mm); number of rows per ear (NRE); number of grains per row (NGR); grain weight per ear (GWE); and total yield (TY) estimated by harvesting the total area of the plot (12 $m^2$).PH, EIH, EL, NRE, NGR, GWE, and GA were analyzed in six plants within the evaluation area of each plot; the other variables were analyzed considered all plants of the plot. The number of plants with symptoms of maize bushy stunt (MBS) (phytoplasma) and corn stunt spiroplasma (CSS) (spiroplasma) was evaluated in the two central rows of the plot, using the scale of grades described by [15].

The physiological parameters were evaluated only in Location II, considering the descriptors: leaf area (LA), measured directly in the ear leaf of six plants using a leaf area meter device (CI-202 Portable Laser); and maximum quantum efficiency of photosystem II (Fv/Fm), measured using a portable fluorometer (Junior-Pam; Walz, Germany). The readings were done using a magnetic leaf clip coupled to the fluorometer, in the medium region of the leaf, in the adaxial side of the leaf blade. The measurements were carried out under absence of light. Saturation light pulses of 0.3 s were emitted under a frequency of 0.6 KHz. The fluorescence data were obtained automatically, stored in the fluorometer, and then transferred to a computer using the WinControl-3 program.The data were subjected to analysis of variance and the means were compared by the Tukey's test at 5% probability, using the Genes program [16].

## Results

The joint analysis of variance of the three cultivars in the two environments showed significant interaction ($p<0.05$) for plant height (PH), ear insertion height (EIH), percentage of lodged plant (PLP), percentage of prolific plants (PPP), percentage of plants with tassel (PPT), percentage of plants at the R1 (silk) stage (PPR1), symptoms of corn stunt spiroplasma (CSS), and number of ears per plot (EPP). The plant stand (PS), ear length (EL), number of grains per row (NGR), and symptoms of maize bushy stunt (MBS) presented significant differences only for the environment factor. The number of rows per ear (NRE), and grain weight per ear (GWE) presented no significant differences for none of the sources of variation evaluated; and total yield (TY) presented significant difference for the cultivar and environment factors, with no effect of the interaction between them (Table 1). The lowest PH, EIH, and PPP were found for the

| Source of variation | DF | PS (Number) | PH (cm) | EIH (cm) | PLP (%) | PPP (%) | PPT (%) | PPR1 (%) | MBS (%) | CSS (%) |
|---|---|---|---|---|---|---|---|---|---|---|
| Block | 3 | 24.264 | 351.375 | 8.81 | 2.0556 | 95.16 | 65.173 | 14.0417 | 125.7778 | 198.4861 |
| Cultivars | 2 | 171.166$^{ns}$ | 9849.54$^{ns}$ | 1351.792$^{ns}$ | 0.875$^{ns}$ | 991.792$^{ns}$ | 19.000$^{ns}$ | 290.167$^{ns}$ | 1986.292$^{ns}$ | 118.0417$^{ns}$ |
| Location | 1 | 247.0417** | 39772.04** | 12015.38** | 2.66667$^{ns}$ | 25741.5** | 417.500** | 672.042** | 7280.167** | 3626.042** |
| Cult x Loc | 2 | 33.166$^{ns}$ | 3710.29** | 285.875* | 3.0417* | 879.875** | 162.550* | 216.667** | 334.5417$^{ns}$ | 653.2917* |
| Residue | 15 | 10.4972 | 88.54167 | 73.58611 | 0.6556 | 58.767 | 41.869 | 26.275 | 208.9444 | 122.7194 |
| Mean | | 52.46 | 135.45 | 52.95 | 0.75 | 39.58 | 8.42 | 11.20 | 44.83 | 22.95 |
| CV (%) | | 6.17 | 6.94 | 16.19 | 107.95 | 19.36 | 76.84 | 45.73 | 32.24 | 48.25 |

| Source of variation | DF | EPP (Number) | EL (cm) | NRE (Number) | NGR (Number) | GWE (g) | TY (kg $ha^{-1}$) |
|---|---|---|---|---|---|---|---|
| Block | 3 | 1.819 | 0.635 | 0.6185 | 4.90925 | 37.257 | 24992.71 |
| Cultivars | 2 | 2888.667$^{ns}$ | 33.546$^{ns}$ | 7.2429$^{ns}$ | 191.85$^{ns}$ | 905.252$^{ns}$ | 5108864* |
| Location | 1 | 5310.375** | 31.763** | 0.7848$^{ns}$ | 1137.26** | 3.25607$^{ns}$ | 1305267** |
| Cult x Loc | 2 | 1371.5** | 3.950$^{ns}$ | 1.1778$^{ns}$ | 26.151$^{ns}$ | 78.975$^{ns}$ | 70629.29$^{ns}$ |
| Residue | 15 | 72.319 | 2.343 | 0.8263 | 27.072 | 47.221 | 55960.84 |
| Mean | | 55.29 | 14.04 | 12.69 | 25.15 | 22.34 | 1305.37 |
| CV (%) | | 15.38 | 10.89 | 7.16 | 20.68 | 30.75 | 18.12 |

**Table 1:** Joint analyses of variances for plant stand (PS); plant height (PH); ear insertion height (EIH); percentage of lodged plant (PLP); percentage of prolific plants (PPP); percentage of plants with tassel (PPT) at 61 days after emergence; percentage of plants at the R1 (silk) stage (PPR1); incidence of maize bushy stunt (MBS); incidence of corn stunt spiroplasma (CSS); number of ears per plot (EPP); ear length (EL); number of rows per ear (NRE); number of grains per row (NGR); grain weight per ear (GWE), and total yield (TY) of three popcorn maize cultivars (Americano RS20, UENF-14 and Formosa) grown in two locations, Northeast (Posse) and Southwest (Ipameri) regions of the state of Goiás, Brazil, in the 2019/2020 crop season. ** = significant at 1% probability; *=significant at 5% probability; ns=not significant; CV=coefficient of variation; DF=degrees of freedom.

Northeast region (Posse) (Table 2). The highest mean PH was found for the Americano RS20 cultivar in the northeast region (123.75 cm), and for the UENF-14 cultivar in the southeast region (228.50 cm). The EIH and PPP of the cultivars presented no difference in the northeast region. However, UENF-14 presented the highest mean (95.75 cm) for these variables, differing statistically from the others when grown in the southeast region.

The Americano RS20 cultivar presented the same responses to PLP in the two environments, with no significant difference between crop locations. The other cultivars presented different response to the environments, with the lowest means in the northeast region. The UENF-14 cultivar presented the same response to PPT in the two environments; however, the other cultivars presented the highest means ($p<0.05$) when grown in the northeast region. Only the UENF-14 cultivar presented different response to PPR1 in the environments, with the highest mean when grown in the southeast region, differing from the other cultivars. Only the Formosa cultivar presented the same response to symptoms of corn stunt spiroplasma (CSS) in the two environments; whereas the Americano RS20 and UENF-14 cultivars presented the highest means when grown in the northeast region. The UENF-14 cultivar presented the same response to number of ears per plot (EPP) in the two environments, with the highest means. The Americano RS20 cultivar presented no difference from UENF-14 in the northeast region, with the highest means when grown in the southeast; however, the Americano RS20 cultivar presented different response from UENF-14, with the lowest means. Although the Formosa cultivar presented the lowest means, its EPP in the northeast were higher than in the southeast region.

The physiological analyses showed significant differences ($p<0.05$) for all evaluated variables. UENF-14 presented the highest means ($p<0.05$) for leaf area (LA), maximum fluorescence (Fm), maximum quantum efficiency of photosystem II (Fv/Fm), and maximum quantum efficiency of photosystem II in the light-adapted state (Fv'/Fm'), differing from the other cultivars. Americano RS20 presented the highest minimum fluorescence (Fo), differing-se statistically from the other cultivars. The highest photochemical extinction coefficients (qP) were found for the Formosa cultivar, whereas Americano RS20 presented intermediate, and UENF-14 presented the lowest values. The UENF-14 and Formosa cultivars presented the highest mean non-photochemical extinction coefficient (NPQ). The highest true quantum yield for $CO_2$ assimilation ($\Phi CO_2$) was found for the UENF-14 cultivar, whereas Formosa presented intermediate, and Americano RS20 presented the lowest values.

## Discussion

The [17] evaluated morphological descriptors for UENF-14 in different locations and found plant height of 182 cm and ear insertion height of 103 cm. Therefore, the edaphoclimatic conditions of the southeast region provided ideal conditions for the cultivar to express the maximum potential, presenting in the present study values 20% higher than those found by [17]. A study with different popcorn maize cultivars (Viçosa, Beija-Flor, IAC 112, Jade, and Zélia) found total height means between 125 and 159 cm, and ear insertion heights between 54 and 79 cm [9]. These results confirm those found in the present work for the Americano RS20 cultivar, which present characteristic of interest for crop mechanization in large areas, enabling the sharing of machinery used for grain maize. These differences regarding prolificacy are related to environmental conditions of each location that affect the genetic performance of the cultivars, since popcorn maize has high prolificacy rate. The [18] evaluated nine popcorn maize hybrids in different sowing times and found that the prolificacy rate affects grain yield, confirming the results of the present work, which shows that UENF-14 had the highest prolificacy rate and, consequently, the highest yield.

The PLP found in the present work were low, 0.25% to 1.75%, differing from the results obtained by [19], who found values higher than 10% for popcorn maize grown in the northeast region of the state of Rio de Janeiro. A study evaluating 16 genotypes and 8 hybrids of popcorn maize in five environments found that the lodging rate was affected by the environment, showing differences between crop locations [20], which was also found in the present work.The PPT and PPR1 are important variables, since they determine the end of the V18 stage and beginning of the reproductive stage [6] enabling the determination of precocity of the cultivars in the environments. An earlier (56 days) and uniform male flowering (tassel) was found in the northeast region. An earlier (71 days) female flowering (emission of style-stigma by the ear - R1) was found for the UENF-14 cultivar in the southeast region, with differences of 4-5 days from the other cultivars. Flowering around 59 days after the sowing was found for the UENF-14 cultivar in the state of Rio de Janeiro [17]. The crop conditions in the present work presented two factors that differ from the conditions in Rio de Janeiro: the altitude of 773 m and the thermal amplitude. The mean temperatures in the state of Goiás is 29 to 31°C; thus, despite the cultivars had better photosynthetic efficiency under mean daily temperatures above 26°C, high temperatures can accelerate the flowering and grain filling processes, or even

| **Cultivars** | **PH (cm)** | | **EIH (cm)** | | **PLP (%)** | | **PPP (%)** | |
|---|---|---|---|---|---|---|---|---|
| | Posse | Ipameri | Posse | Ipameri | Posse | Ipameri | Posse | Ipameri |
| Americano RS20 | 123.75aB | 167.75 bA | 31.25aB | 71.75 bA | 0.75 aA | 0.0 bA | 82.5 aB | 68.00 bA |
| UENF-14 | 100.00bB | 228.50 aA | 37.50 aB | 95.75 aA | 0.25 aB | 1.75 aA | 70.00 aB | 95.75 aA |
| Formosa | 60.50 cB | 132.25 cA | 23.00 aB | 58.50 bA | 0.25 aB | 1.50 aA | 52.50 aB | 53.25 cA |
| Cultivars | PPT (%) | | PPR1 (%) | | CSS (%) | | EPP (und) | |
| | Posse | Ipameri | Posse | Ipameri | Posse | Ipameri | Posse | Ipameri |
| Americano RS20 | 18.25 aA | 2.00 aB | 7.25aA | 9.50 bA | 37.25 abA | 15.75 aB | 80.75 aA | 30.50 bB |
| UENF-14 | 7.27 aA | 8.75aA | 7.00aB | 29.25aA | 45.50 aA | 1.50 aB | 74.25 aA | 74.00 aA |
| Formosa | 12.25 aA | 2.00aB | 3.50aA | 10.75 bA | 23.00 bA | 14.75 aA | 55.50 bA | 16.75 bB |

**Table 2:** Comparison of means from the interaction test for plant height (PH); ear insertion height (EIH); percentage of lodged plant (PLP); percentage of prolific plants (PPP); percentage of plants with tassel (PPT) at 61 days after the emergence; percentage of plants at the R1 (silk) stage (PPR1); incidence of corn stunt spiroplasma (CSS), and number of ears per plot (EPP) of three popcorn maize cultivars (Americano RS20, UENF-14 and Formosa) grown in two locations, Northeast (Posse) and Southwest (Ipameri) regions of the state of Goiás, Brazil, in the 2019/2020 crop season. Means followed by the same uppercase letter in the rows or lowercase letter in the columns are not statistically different from each other.

cause damages to the photosystem, decreasing the plant cycle and, commonly, decreasing grain yield due to the excessive spent of energy [21]. However, the thermal conditions are the factor that most affect the duration of phenological stages, although different genotypes may present different needs for degrees-day [22].

Only the Formosa cultivar presented the same response to CSS in the two environments; the Americano RS20 and UENF-14 cultivars presented the highest mean percentages of the disease when grown in the northeast region. Among the variables affected only by the environment, NRE, EL, and NGR presented the highest mean values when the cultivars were grown in the southeast region (Table 3). The mean percentage of MBS were higher in the northeast region. The high incidence of the disease in this region may be due to the late sowing time (dry season), which present the highest population of the disease vector (*Dalbulus maidis*), potentiating the contamination of plants [23, 24].The higher the NRE and NGR, the higher the grains yield [8-25]; however, the results found in the present work showed the highest grain yields from the northeast region, despite the highest mean NRE and NGR were found in the southeast region. This is probably due to the EPP, which presented the highest means when the cultivars were produced in the northeast region. It is important to note that UENF-14 presented the same response in the two environments. The southeast region presented the lowest MBS means (27%), probably due to the low pathogen pressure in this location. A study assessing the incidence of MBS and CSS in thirty maize hybrids in three locations found variations in tolerance to MBS and CSS between the locations due to the pathogen pressure in each place [24].

| Location | PS | MBS | EL | NGR | TY |
|---|---|---|---|---|---|
| Northeast | 49.25b | 62.25a | 12.89b | 18.27b | 1538.58a |
| Southwest | 55.66a | 27.41b | 15.19a | 32.03a | 1072.16b |

**Table 3:** Test of multiple means (Tukey's test) comparing means of plant stand (PS), incidence of maize bushy stunt (MBS), ear length (EL), number of grains per row (NGR), and total yield (TY) of three popcorn maize cultivars (Americano RS20, UENF-14 and Formosa) grown in two locations, Northeast (Posse) and Southwest (Ipameri) regions of the state of Goiás, Brazil, in the 2019/2020 crop season. Means followed by same letter in the columns are not statistically different from each other.

| Cultivars | TY (kg $ha^{-1}$) |
|---|---|
| Americano RS20 | 1053.87b |
| UENF-14 | 2200.00a |
| Formosa | 662.25c |

**Table 4:** Test of multiple means (Tukey's test) comparing means of total yield (TY) of three popcorn maize cultivars (Americano RS20, UENF-14 and Formosa) grown in two locations, Northeast (Posse) and Southwest (Ipameri) regions of the state of Goiás, Brazil, in the 2019/2020 crop season. Means followed by same letter in the columns are not statistically different from each other.

The probability of infection by phytoplasma or spiroplasma is higher under temperatures above 23 °C than under mild temperatures [26]. Therefore, the high incidence of MBS and CSS in the northeast region was probably related to the high temperatures in this location. TY was affected by environment and by the cultivar (Tables 4 and 5). The highest means were found when the cultivars were grown in the northeast region. UENF-14 presented the highest mean yield (2200 kg $h^{-1}$), differing from the other cultivars ($p<0.05$); Americano RS20 presented an intermediate mean (1053.87 kg $ha^{-1}$); and Formosa presented the lowest mean yield (662.25 kg $ha^{-1}$), differing from the other cultivars. The TY found for the UENF-14 cultivar denotes that this cultivar probably present tolerance to MBS and CSS. A study comparing yield components of different popcorn maize cultivars found productions of 1.0409.55 kg $ha^{-1}$ (IAC-112), 1.492.40; kg $ha^{-1}$ (Zélia), and 1.531.80 kg $ha^{-1}$ (Jade), and a mean 100-grain weight of 12.45 g [9]. In the present work, the TY found for the UENF-14 cultivar were higher than those found for the cultivars evaluated by [9] however, the TY found for the Americano RS20 and Formosa cultivars were lower than those found by them. The TY found for the UENF-14 cultivar in the state of Goiás were lower than that found for the same cultivar in the state of Rio de Janeiro by [19].

The physiological variables showed that the agronomic dynamics of the UENF-14 cultivar present maintenance of leaf growth over the crop cycle, reaching a maximum value of 598.26 $cm^2$, measured at the beginning of the grain filling period, with the Formosa cultivar presenting 43% lower leaf area, and the Americano RS20 cultivar presenting 27% lower leaf area. Leaf area indicates the photosynthetic potential of the plant by representing the size of the surface for light energy capture and, consequently, carbon assimilation. The lowest leaf area found for the Formosa cultivar resulted in the lowest total dry matter accumulation and, consequently, the lowest photosynthetic yields and grain yield. The highest minimum fluorescence (F0) was found for the Americano RS20 cultivar, which may indicate the maintenance of open reaction centers of photosystem II, denoting a high spent energy to adapt to the photoinhibitory conditions of the environment. The lowest F0 was found for the UENF-14 cultivar, indicating photoprotection.The highest mean Fm was found for the UENF-14, denoting a high photoreduction capacity of the Qa (Quinone), showing good photochemical capacity, since a low Fm may

| Source of variation | DF | LA | F0 | Fm | qP | NPQ | Fv/Fm | Fv'/Fm' | $\Phi CO_2$ |
|---|---|---|---|---|---|---|---|---|---|
| Block | 3 | 418.07 | 3.731 | 23.01 | 0.00024 | 0.00002 | 0.00006 | 0.00008 | 0.0003 |
| Cultivars | 2 | 69389.21** | 24.49* | 270.81** | 0.0055* | 0.00032* | 0.0038** | 0.0049** | 0.0020* |
| Residue | 6 | 226.22 | 3.49 | 11.88 | 0.00064 | 0.00004 | 0.00009 | 0.0001 | 0.0004 |
| Mean | | 456.64 | 14.76 | 62.5 | 0.882 | 0.02 | 0.781 | 0.771 | 0.661 |
| DMS | | 32.61 | 4.05 | 7.47 | 0.055 | 0.013 | 0.02 | 0.026 | 0.042 |
| CV (%) | | 3.29 | 12.66 | 5.52 | 2.89 | 29.31 | 1.19 | 1.59 | 2.96 |
| Cultivars | | | | | | | | | |
| Americano RS20 | | 433.87b | 17.16a | 60.27b | 0.890ab | 0.030b | 0.772b | 0.751b | 0.636b |
| UENF-14 | | 598.26a | 12.22b | 71.61a | 0.841b | 0.013a | 0.815a | 0.812a | 0.681a |
| Formosa | | 337.81 c | 14.88ab | 55.61 b | 0.914a | 0.017a | 0.755b | 0.751b | 0.666ab |

**Table 5:** Analysis of variance and means of leaf area (LA; cm²), minimum fluorescence (Fo), maximum fluorescence (Fm), photochemical extinction coefficient (qP), non-photochemical extinction coefficient (NPQ), maximum quantum efficiency of photosystem II (Fv/Fm), maximum quantum efficiency of photosystem II in the light-adapted state (Fv'/Fm'), and true quantum yield for $CO_2$ assimilation ($\Phi CO_2$), of three popcorn maize cultivars (Americano RS20, UENF-14 and Formosa) grown in two locations, Northeast (Posse) and Southwest (Ipameri) regions of the state of Goiás, Brazil, in the 2019/2020 crop season. ** = significant at 1% probability; * = significant at 5% probability; ns = not significant; CV = coefficient of variation; DF = degrees of freedom. Means followed by same letter in the columns are not statistically different from each other by the Tukey's test at 5% probability.

be related to inactivation of photosystem II in thylakoid membranes, directly damaging the electron flow between photosystems [27,28]. The maximum quantum efficiency of photosystem II (Fv/Fm), calculated by the ratio between Fv (fluorescence) and Fm, denotes the dissipation of photochemical energy and indicates the efficiency of capturing this excitation energy by the opening of reaction centers of photosystem II [29] and, thus, the photosynthetic performance of the plant. Decreases in Fv/Fm may indicate photoinhibition damages when plants are subject to environmental stresses, including cold and drought conditions.The Fv/Fm of the UENF-14 cultivar was close to the maximum limit of 1.0, according to [30]; however, the Formosa cultivar presented the lowest Fv/Fm (0.75), that is the limit of the ideal range.

A study showed a Fv/Fm of 0.81 for maize plants under ideal crop conditions; however, when these plants were subjected to abiotic stresses, the Fv/Fm decreased to 0.767 [31]. The Fv/Fm found in the present work may be related to the Fv'/Fm', which presented similar dynamics; it represents the estimated maximum photochemical efficiency of the PSII for a certain intensity of light [32,33]. The cultivars presented different qP and NPQ coefficients due to the flow of photosynthetic photons. The qP coefficient presented values higher than 0.815, thus, none of the cultivars presented values of Qa (Quinone) completely reduced, i.e., equal to 1. The NPQ coefficient presented values for excitation energy dissipation lower than 0.03. The [14] evaluated tropical grass species and found evidences of damages to proteins of the photosynthetic complex, denoted by the qP values lower than 0.4 and NPQ higher than 0.4; this was not found for none of the cultivars evaluated in the present work. Therefore, the photosynthetic apparatus of these cultivars was not damaged due to photoinhibition, and more photochemical energy of photosynthesis was used. Thus, the crop environment was ideal and the plants needed no photoprotection regulation, which is shown by the dissipation of excess energy absorbed due to increases in the gradient of protons between the lumen and the stroma of the chloroplast [34]. The results found for the fluorescence variables of three cultivars evaluated denote that the UENF-14 cultivar presents a more efficient photosynthetic apparatus (FSII) under the conditions of the region. The well-developed leaf area of this cultivar resulted in the maintenance of the leaf canopy up to the end of the grain filling stage, thus, photoassimilates were available for the drain (popcorn grains), contributing to a high yield.

## Conclusion

The corn stunting diseases affected the efficiency of the photosystem, reduced the leaf area and severely harmed the popcorn crop**.** The growth of popcorn maize is recommended for the edaphoclimatic conditions of the northeast and southwest regions of the state of Goiás, Brazil. Among the cultivars evaluated, UENF-14 is the most indicated, since it showed tolerance to corn stunt spiroplasma and abiotic damages, due to a high efficiency of the photosystem II, and high yield.

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