Original Research Article

Germination under high temperatures of maize adapted to the Cerrado of Tocantins

Abstract—*The purpose of this study was to evaluate the response of germination and vigor in maize seeds in laboratory conditions, exposure to high temperatures, in order to highlight the most adaptable genotypes at these temperatures. Were supplied three cultivars of the PIONEIRA LTDA. (PIONEIRA HS-9, PIONEIRA HS-14i, PIONEIRA ROBUSTO), to perform the experiment, in addition to the commercial cultivar BRS 3040. After the selection of superior genotypes, were performed at temperatures of 25 reviews, 30, 35 and 40 ºc, these being: germination, first count, seedling dry mass and speed index of the emergence of seedlings. At the temperature of 25°C were made the cold test and seedling length, shoot and root axis. The results were submitted to analysis of variance, comparison of averages by Tukey test, to three genotypes and regression analysis to high school, to three genotypes and the witness commercial. Whereas the maximum temperature of 35°C tested, one could observe that the PIONEIRA HS-6 genotype presented the best adaptation to high temperatures. The PIONEIRA ROBUSTO genotype was more adapted to high temperatures whereas as the highest temperature of 40°C. The BRS 3040 was not adapted to the high temperatures in relation to genotypes produced under conditions of high temperatures of the Cerrado.*

Keywords—*Zea mays, physiological potential, soil temperature, force.*

1. Introduction

Corn is one of the most nutritious foods in the world, being widely used, in various ways, such as in the production of biofuel, directly on the plate of the Brazilians in the form of flour, processed products and a number of derivatives and indirectly as in the manufacture of animal feed [1]. In accordance with the National Supply Company – CONAB, (2018) [2], the corn were harvested in the year 2017-18 the corn acreage, the second harvest was approximately 11.5 million hectares in Brazil, with a production of about 4.7 t/ha, being the responsible for 235,000 tons in Tocantins first crop and 532,800 tons on second.

This intense agricultural activity increases the demand for high-quality seeds and great productive potential, with genetic characteristics that express adaptability to various edaphic factors to which they are exposed during your cycle [3]. As Dutra (2014) [4], one of the obstacles found in the full development of culture, is sowing under high temperatures.

Seeds with greater force tend to emerge with greater speed and establish a proper booth, ensuring for culture an advantage in relation to weed competition [5]. It is of the utmost importance of the development of evaluation methods of germination and vigor of seeds. It is worth mentioning that the choice of the area where the seeds are produced, the climatic conditions during your development, the period in which they were sown, the incidence of pests and diseases and the management in the period of harvest, directly affect the potential Physiology of culture [6]. Martins (2013) [7] points out that the standardization of vigor tests meets obstacles because this attribute can be analyzed through aspects such as the speed of germination, uniformity in temperature, among others

Among these factors, the Tocantins demonstrates long periods of drought coupled with high temperatures interfere with the initial establishment of seedlings of corn. There are still few studies on the relationship of tolerance genes to these climate characteristics. In this way, it becomes necessary the choice of genotypes adapted to these conditions, especially during the periods before and after germination [4].

Among the regulatory factors involved in the germination process is the appropriate temperature as one of the most significant [8]. The incidence of high temperatures compromises the rate of water assimilation, as well as the physiological and biochemical reactions that control the germination process, affecting the rate and percentage of germination [9]. It has a consequent negative effect on seedlings, root system and microorganism activity, causing stress and generating irreversible damage to the development and establishment of the crop.

Based on the assumption, the present work aims to evaluate the response of germination tests and the vigor of different corn genotypes under laboratory conditions, listing which seeds are best adapted to high temperatures.

2. Materials and methods

This study was conducted in the laboratory of Plant Ecophysiology, in the Seed Analysis laboratory and in the experimental area of the University Campus of Gurupi, Tocantins. Maize seeds from the breeding program of the company Pioneira LTDA. Where used in the experiment, which made available three seed genotypes: PIONEIRA HS-9, PIONEIRA ROBUSTO, PIONEIRA HS-14i and the commercial witness BRS 3040, a cultivar from Embrapa

The evaluations were carried out at 25, 30, 35 and 40ºC, which were: germination, first count and seedling length [10], seedling dry mass and seedling emergence speed index [11].

In the germination test, the data of the first normal seedling count and the dry mass of seedlings were obtained. Being this test, made in the germiest paper, in four repetitions of 50 seeds. The paper rolls were placed inside beakers wrapped in plastic bags, tied with elastic and placed upright inside the germinator, aiming to keep the humidity of the rolls constant. The space between the upper end of the rollers and the top of the plastic bag was 15 cm, remaining in the germinator for seven days [12]. The evaluations were made, on the fourth day, the seed vigor was evaluated, being called the first germination count. And on the seventh day of the test installation, the percentage of normal seedlings and non-germinated seeds was estimated [11].

The basic methodology for obtaining the seedling length test was the use of four replicates of ten maize seeds [13]. The seeds were placed with the tip of the radicle facing the bottom of the paper and the embryo facing upwards. The rollers were normally prepared equally to the germination test, where they remained for 120h. The total length of the seedling and its parts were obtained from the division of the sum of the measurements performed in the sub samples by the number of normal seedlings obtained and the results expressed in centimeters, with two decimal places [14]. The test was performed in a germinator regulated at 25 °C and with the absence of light [15]. After five days in the Germinator, the normal seedling count and measurement were performed. It was taken as a measure for the length of seedlings with graduated ruler in centimeters: The total seedling length (from the tip of the primary root to the top of the primary leaf); Length of the aerial part; The length of the main root axis [12].

The germination speed index was performed complying with the norms of the Rules for Seed Analysis [10]. Seedling evaluations were performed in the fourth and seventh day, at the same time, from the day when the first normal seedlings were manifested [11].

The equation used is Maguire

$$GSI = \frac{G1}{T1} + \frac{G2}{T2}$$

Where:

GSI - germination speed index;

G1 e G2 - number of emerged seedlings occurred in the fourth and seventh day;

T1 e T2 - time (days).

The higher the index, the greater the speed of germination of seed [13].

After 7 days, the normal seedlings of each repetition were withdrawn and accounted for. With the help of a stylus, the remainder of the seeds was removed (reserve tissue residue). For the analysis of the dry mass of normal seedlings, these were separated by repetitions in paper bags, placed to dry in a forced circulation greenhouse at a temperature of 65 ºC, until constant mass. After this period the bags were removed from the greenhouse and the masses were measured in scales with the precision of 0.0001g [12]. After determining the total dry mass of the seedlings, this value was divided by the number of seedlings to obtain the average dry mass in grams with two decimal places [13].

In the cold test, soil and sand were mixed in the proportion 2:1, total volume of 3 kg, in trays, over which were distributed in four replications of 50 seeds, about 2 kg of the mixture and then covered with the remaining 1 kg. The substrate and water were conditioned at 10 °C, separately, one day before the experiment. On the day of the experiment, the substrate, seeds, and water were added to the trays, which were sealed. Then, the trays were arranged in a chamber previously regulated at 10 °C, where they remained for seven days. After this period, the lid of the trays was removed and transferred to the environment at a temperature of approximately 25 °C for seven days. The evaluation was performed considering only the normal seedlings emerged and the result was the mean of the percentages obtained in the four replications [12].

Analysis of variance was submitted to the statistical data of the average seedling length test and cold test of the three genotypes and the commercial witness BRS 3040, through the Sisvar program [16] and the averages compared by the Tukey test at 5% probability. Similarly, to evaluate the effect of temperature on the germination of cultivars, and in this test, a 4 × 4 factorial design was performed to correspond to combinations of four temperatures (25, 30, 35 and 40 ˚C) and the four genotypes, and in these they proceeded to Regression analysis, by the program SIGMAPLOT (2008) [17], testing the linear and quadratic models.

To support the accomplishment of the work, the soil temperature was measured. This measurement was performed in the experimental area of the UFT, occupied with maize, a digital soil thermometer (Incoterm 9791.16.1.00) was used, the depth of 5 cm. The readings made from 6 a.m. to 6 p.m., every hour, held on June 5, 2017. Data were collected at four different sites: no-tillage with irrigation, conventional planting with irrigation, conventional planting without irrigation, no-tillage without irrigation, demarcated by cuttings. The ambient temperature was also determined in the same place and day.

3. Results and Discussion

The cultivar PIONEIRA ROBUSTO and PIONERIA HS-14i did not differ between each other and its length is statistically as BRS 3040. The influence of vigor is explicit in relation to the probability of germination and its velocity, mass and total length of seedlings [18] [19].

The PIONEIRA ROBUSTO and PIONEER HS-14i materials showed no significant difference with the means of PIONEER HS-9. BRS 3040 presented the lowest mean value, without differing statistically from the others (table 1). Such information agrees with the asseveration given by Dan et al. (1987) [20], who stated that vigorous seeds originate seedlings with higher growth rate, explained due to greater aptitude in the conversion of storage tissue reserves and the greater Incorporation of these through the embryonic axis.

The root length of the seedlings could not be used as a selection factor in this experiment since none of the genotypes showed any difference in this item ($p \leq 0.05$).

The BRS 3040 obtained a lower germination percentage than the others, but it was not significantly different from the PIONEIRA ROBUSTO. The cold test has an expressive efficiency in relation to stress resistance, because it tends to identify the storage potential of seeds, seedling emergence potential and the separation of genotypes at distinct levels of vigor, especially when using the tray method because there is greater ease in standardization [21].

Table 1 - The average total length of seedling (TLS), length aerial (LA), length of the root axis (LRA) and cold test (CT) of three corn genotypes and a witness commercial, submitted to a temperature of 25°C. Gurupi, Tocantins, 2017.

	Traits evaluated			
Genotypes	TLS (cm)	LA (cm)	CR (cm)	CT (%)
PIONERIA HS-9	28,97 A	15,10 A	14,06 A	71,50 A
PIONEIRA ROBUSTO	29,65 A	15,66 A	13,99 A	54,00 AB
PIONERIA HS-14i	29,68 A	14,87 A	14,82 A	70,00 AB
BRS 3040	23,45 A	11,61 B	12,23 A	33,50 B
CV (%)	11,48	14,31	19,31	29,19

Medium followed by the same letter, uppercase in the columns within each feature, do not differ by Tukey test ($p \leq 0.05$).
three genotypes and a witness commercial submitted to a temperature of 25◦C. Gurupi, Tocantins, 2017.

All cultivars presented quadratic and significant responses ($p \leq 0.05$) in the number of seeds germinated in the first count (FC) (Figure 1). They also presented significant coefficients of determination ($p < 0.01$) and above 0.77, in all materials presented The magnitudes of the regression coefficients were significant, highlighting that the increase in temperature, especially above 30 ºC, generated a reduction in the number of seeds germinated in the FC.

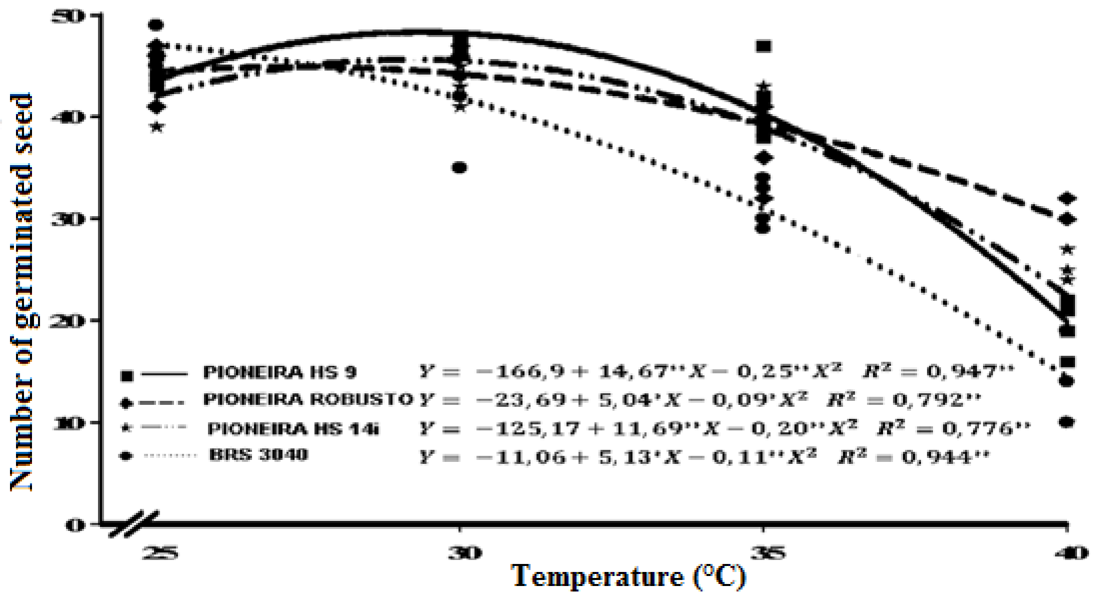

Figure 1: Seedlings germinated in the first count of three genotypes and a witness, according to the trade increase of temperature. Gurupi, Tocantins, 2017.

The PIONEIRA HS-9 (48.3), PIONEIRA HS-14i (45.8), PIONEIRA ROBUSTO (46.8) and BRS 3040 (48.7) genotypes reached maximum seed germinated at the first count at temperatures of 29.3; 29.2; 28 and 23.3 °C, respectively. This is due to the environmental condition of the development region, Tocantins, which suffers from high temperatures, imposing climatic limits on corn production [22]. In addition, the Tocantins is characterized by having about 80% of its area inserted in the ecosystem of central brazilian Cerrado, which in full summer, presents days of drought due to the influence of the continental tropical Mass (mTc) [23].

At temperatures above 35 °C, the PIONEIRA ROBUSTO genotype exhibited favorable results, presenting seed values germinated in the first count higher than the others, since it presents the lowest slope coefficient value of the regression model Quadratic (0.09), that is, which presents a lower variation of germination responses in relation to the temperature increase.

All materials developed in high temperature conditions were significantly different from BRS 3040 (figure 1), developed in the Sete Lagoas region (Minas Gerais) with an altitude of approximately 700 meters above sea level. The municipality has an annual average temperature of around 22.1 °C [24], however, it is a region that presents the same climatic risk in which the culture is inserted, because it also presents a certain irregularity in the pluvimetric distribution, giving rise to droughts of different proportions [25].

The characteristic number of seeds germinated in the first count is of fundamental importance. Since, besides being used as a vigor test [26], it also determines that the faster the twinning is the greater the possibility of formation of the ideal booth [27]. However, Amaro et al., (2015) [28], classifies the first count test as a low sensitivity for characterization of different physiological quality levels of the seeds.

All genotypes developed under high temperature conditions were significant when compared to BRS 3040 (table 2), launched in a region of high altitudes.

Table 2 – Comparisons (test T) among three corn genotypes of the PIONEIRA LTDA. and a witness in the function of the first count (FC), germination (G), normal seedlings (NS), germination speed index (GSI) and seedling dry mass (SDM).

Genotypes	FC	G	NS	GSI	SDM
PIONEIRA HS-9 x PIONEIRA ROBUSTO	p≥0,05	p≥0,05	p≥0,05	p≥0,05	p≥0,05
PIONEIRA HS-9 x PIONEIRA HS-14i	p≥0,05	p≥0,05	p≥0,05	p≥0,05	p≤0,05
PIONEIRA HS-9 x BRS 3040	p≤0,01	p≤0,01	p≥0,05	p≤0,01	p≥0,05
PIONEIRA ROBUSTO x PIONEIRA HS-14i	p≥0,05	p≥0,05	p≥0,05	p≥0,05	p≥0,05
PIONEIRA ROBUSTO x BRS 3040	p≤0,05	p≤0,01	p≥0,05	p≤0,01	p≥0,05
PIONEIRA HS-14i x BRS 3040	p≤0,05	p≤0,05	p≤0,05	p≤0,05	p≤0,05

The increase in temperature from 30 º C promoted a decrease in the percentage of germination, in which all the genotypes presented quadratic and significant responses (p ≤ 0.05) based on this temperature increase (figure 2). The coefficients of determination showed values above 0.79 and with significance for all samples.

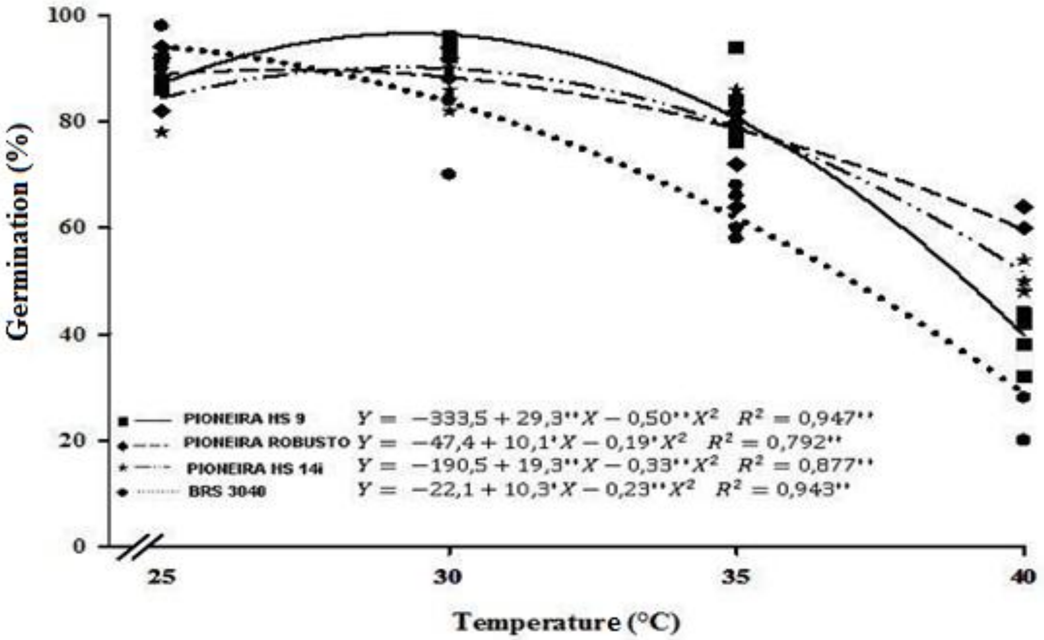

Figure 2: Germination of three genotypes and a witness, according to the trade increase in temperature. Gurupi, Tocantins, 2017.

The genotypes PIONEIRA HS-9 (95.4), PIONEIRA HS-14i (89.2), PIONEIRA ROBUSTO (85.5) and BRS 3040 (93.1), presented maximum values at the temperatures 29.3; 29.2; 26.5 and 22.3 °C, respectively. This happens due to the process of adaptation occurred in the production of these genotypes, in regions where the climate that prevails is tropical semi-humid [29]. However, BRS 3040 demonstrated that develops best in mild temperatures. The results corroborated with data from Sbrussi and Zucareli 920140[30], which report that the optimum temperature for germination of corn seeds is between 22 and 34 °C. Furthermore, when the temperature is increased above 2 °C, there is a decrease in productivity, which illustrates very well the behavior of genotypes developed in Sete Lagoas (Minas Gerais) [31].

Also, the PIONEIRA ROBUSTO obtained higher percentages of germination (Figure 2) and the smallest value of β2 of inclination of the quadratic regression model when subjected to higher temperatures, (0.19), being then considered the seeds with greater force. The tolerance for above-average temperatures can pose a direct relationship with the plant's performance on the field, this factor can then be used efficiently as a test for the assessment of seed vigor [32].

The commercial witness was not significant because it was launched in a place with higher altitude than the other genotypes, having the highest germination percentage at a temperature of 25 °C (91.65%) and the lowest percentage at temperatures of 30 °C, 35 °C and 40 °C, respectively, being 79.9%, 56.65% and 21.9%, which demonstrates their greater adaptability to the mildest climates and lower temperatures.

Due to the increase in temperature (Figure 3) all cultivars were responsive and significant (p ≤ 0.05), and the number of normal seedlings (NS), with coefficients of determination (p ≤ 0.01) also significant and higher than 0.64, in which the higher the value, plus the model if the sample is inserted. With the increase of this temperature in particular above 25 ºC, there was a significant reduction in the number of NS, based on the magnitudes of the regression coefficients. The commercial witness

BRS 3040 presented the most unsatisfactory behavior when subjected to a temperature of 40 °C.

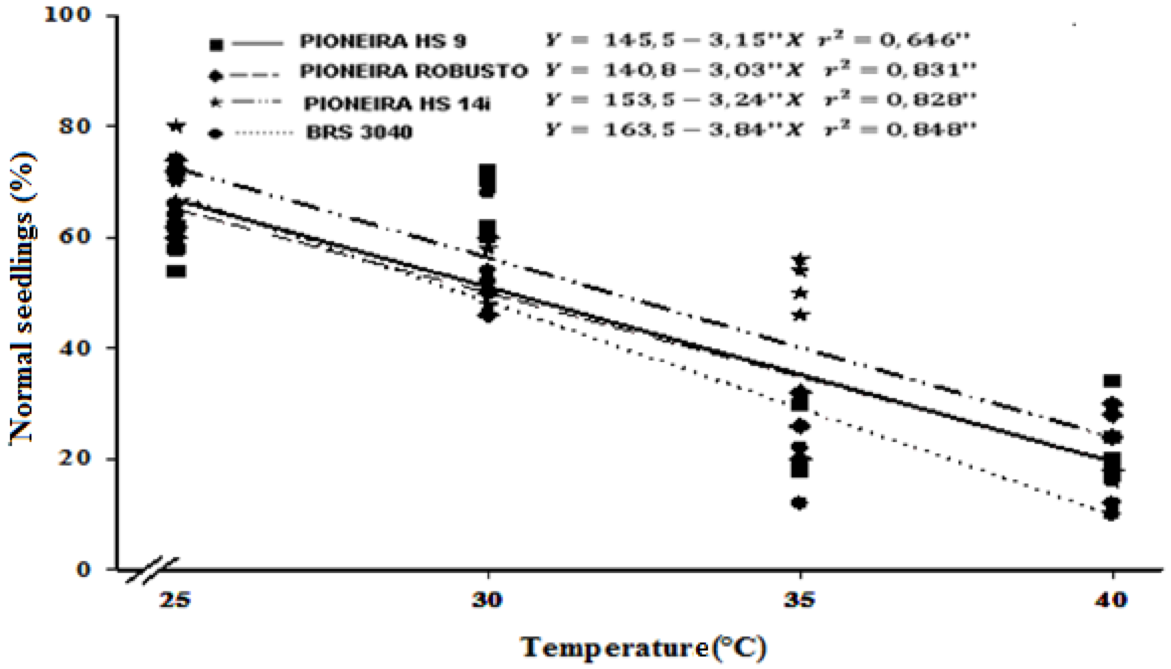

Figure 3: Normal seedlings obtained in the germination of three corn genotypes and a witness, according to the trade increase in temperature. Gurupi, Tocantins, 2017.

The PIONEIRA HS-14i genotype reached the highest value of the β1 (-3.24) slope of the linear regression model at temperatures above 35 ºC (the negative value of β indicates a decrease in the characteristic with the increase in temperature), that is, it exposed the best adaptability with the highest percentage of NS, being appropriate for places with high temperature occurrence. The PIONEIRA HS-14i was also the only one who exhibited expressive difference when compared to the commercial witness (figure 3). The other materials did not differ from each other. From this, it can be inferred a lower tolerance to the high temperatures of the less vigorous genotypes, and a higher germination speed on the part of the PIONEER HS-14i. Minuzzi et al. (2010) [33], report that seeds with a higher velocity of metabolic processes have higher physiological quality, which causes faster germinations and uniform seedlings.

All cultivars presented quadratic responses ($p \leq 0.05$) for the germination velocity index, with the temperature change (figure 4). The coefficients of determination were significant ($p<0.01$) and higher than 0.77 in all genotypes. It was then evidenced the reduction of the GSI with the increase in temperature, especially values higher than 30°C, from the relevances of the coefficients.

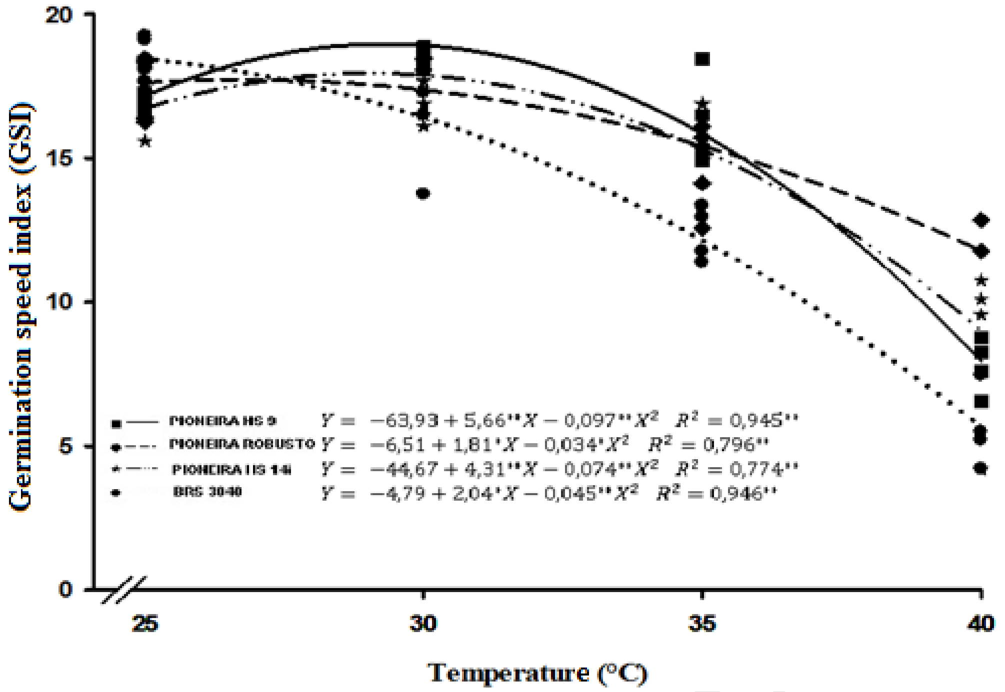

Figure 4: Germination speed index of three corn genotypes and a witness in relation to the commercial temperatures. Gurupi, Tocantins, 2017

According to the data, we emphasize that the PIONEIRA genotypes HS-9 (18.6), PIONEIRA ROBUSTO (17.6), PIONEIRA HS-14i (17.3), and BRS 3040 (18.3) have the highest GSI in 29.1; 29.1; 26.6 and 22.6 ºC. The cultivar PIONEIRA ROBUSTO showed the most adequate when subjected to temperature of 40 °C in view of the others. Obtaining the lowest value of the second coefficient (0.034) of the quadratic regression model. The commercial witness, BRS 3040, was given as the most inadequate at this temperature.

Comparatively, the control and the other cultivars presented expressive responses ($p<0.01$) (figure 3), due to the fact that the genotypes of the company PIONEIRA LTDA. adapt better to the conditions of the southern region of Tocantins, with high temperatures and climate humid. The commercial witness, despite being widely cultivated in the northern and northeastern regions of the country, did not present the same behavior and performance of the other genotypes. The high vigor of the seeds accelerated the metabolic processes, thus providing an accelerated and uniform germination (GUEDES et al., 2015) [15].

Regarding the change in time, the temperatures measured in the field presented a quadratic response ($p \leq 0.05$) (figure 5). The magnitudes of the regression coefficients were significant, regardless of the locality of the measurement, and the coefficients of determination resulted in insignificance ($p < 0.01$) and above 0.54 in all the genotypes in question. These magnitudes showed that from 13h there was a change in temperature, according to the change of schedule.

In places with altitudes of 280 meters, temperatures during the day exceed the 30 °C barrier, and the soil reaches temperatures above 46 °C. According to the data, we observed that the soils under no-tillage with irrigation, and without irrigation and conventional planting with irrigation, and without irrigation, and at room temperature, pointed the maximum point at the time of measurement at the temperatures of 28.6; 32.4; 41.4 and 33.5 and 35.3 ºC, in due order.

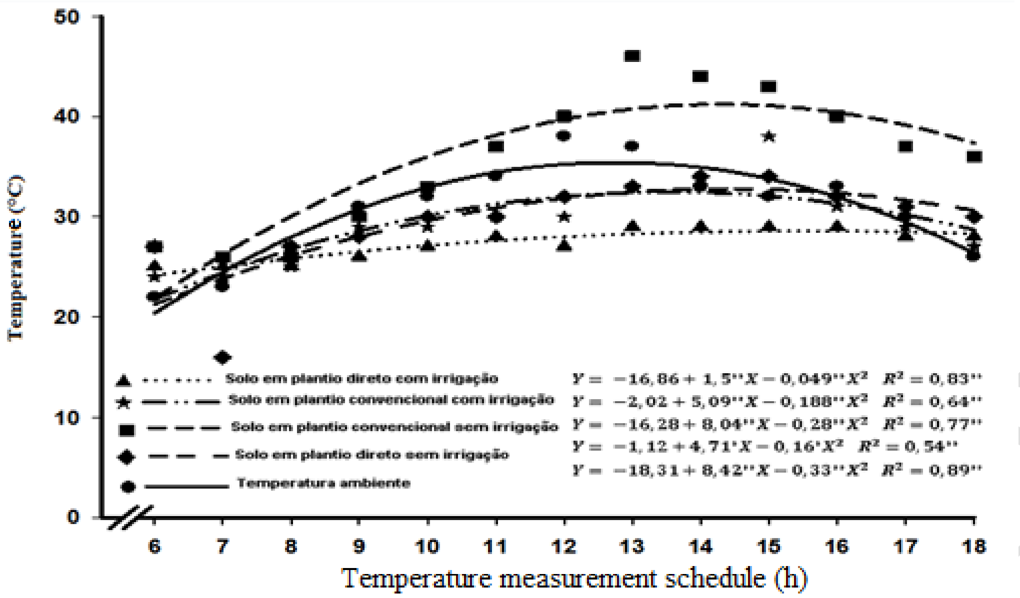

Figure 5: Soil temperature in the experimental area of the UFT, in four different locations and the temperature of the environment as a function of the hours during the day

The planting in the conventional system and without irrigation has a higher temperature, consequently, seeds not adapted to this condition has a lower germination rate, as occurs with BRS 3040, analyzed in this experiment. It is said that the temperature has considerable influence on the speed of germination and the percentage of germinated seeds, besides the emergence, because it acts directly on the biochemical processes that define the germination itself [34]. Then you need to select vigorous seeds as a PIONEIRA ROBUSTO. In the No-tillage system, the maintenance of the straw can maintain the soil temperature below 30 ºC (Figure 5) and also reduce and soil moisture loss by evaporation, conditioning a perfect environment for seed germination in Cerrado regions.

4. Conclusion

The PIONEIRA ROBUSTO genotype of corn demonstrated greater adaptation to higher temperatures, such as the maximum tested at 40 ºC.

BRS 3040 did not present the best performance when compared to the other genotypes produced under high temperature conditions of the Cerrado.

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