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Tolerance to delay in drying of hybrid maize seeds related to parental line and temperature

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ABSTRACT: This study aimed to evaluate the effect of genetic composition and arrangement between female and male parents on tolerance to delayed drying of maize seeds, evaluating the physiological quality and enzyme expression. Ears were harvested close to the stage of physiological maturity (around 35% moisture) and the genotypes were identified as line 1 (L1), line 2 (L2), the hybrid (HB – ♀L1 and ♂L2), and the reciprocal hybrid (HR – ♀L2 and ♂L1). For assessment of physiological quality, CDR (4x6x2) was used, consisting of four genotypes, six times of delay before artificial drying (10, 18, 24, 28, 32, and 40 hours), and two drying delay temperatures (42 and 48 °C). DIC (4x3) was used for enzymatic expression, consisting of four genotypes and three delay times before artificial drying (10, 24 and 40 hours) at 48 °C. Analysis of variance F ($p < 0.05$), Tukey's test ($p < 0.05$), and analysis of polynomial regressions were performed on the data. Lineage arrangement affects seed tolerance to drying delay. Therefore, susceptible lines should not be used as female parents. The seeds of the line most susceptible (L2) to delay in drying exhibit less expression of α-amylase (α-AM).

Index terms: α-amylase, deterioration, germination, LEA proteins, vigor.

RESUMO: Objetivou-se avaliar o efeito da composição genética e arranjo entre progenitores fêmea e macho sobre a tolerância ao atraso na secagem de sementes de milho, avaliando a qualidade fisiológica e a expressão enzimática. As espigas foram colhidas próximo ao ponto de maturidade fisiológica (cerca de 35% de umidade) e genótipos identificados como linhagem 1 (L1), linhagem 2 (L2), híbrido (HB – ♀L1 e ♂L2) e o híbrido recíproco (HR – ♀L2 e ♂L1). Para avaliação da qualidade fisiológica, foi utilizado DIC (4x6x2), constituído de quatro genótipos, seis tempos de atraso antes da secagem artificial (10, 18, 24, 28, 32 e 40 horas) e duas temperaturas no retardamento de secagem (42 e 48 °C). Para avaliar a expressão enzimática, utilizou-se DIC (4x3), consistindo de quatro genótipos e três tempos de atraso antes da secagem artificial (10, 24 e 40 horas) à 48 °C. Em posse dos dados, foram realizados a análise de variância F ($p < 0,05$), teste de Tukey ($p < 0,05$) e análise de regressão polinomial. O arranjo das linhagens afeta a tolerância das sementes ao retardamento na secagem. Linhagens suscetíveis não devem ser usadas como parentais femininos. As sementes da linhagem mais suscetível (L2) ao retardamento da secagem apresentam menor expressão de α-amilase (α-AM).

Termos para indexação: α-amilase, deterioração, germinação, proteínas LEA, vigor.

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INTRODUCTION

The hybrid maize seed market is extremely competitive and demanding related to seed quality. The term seed quality is attributed to the combination of traits that determine the value of seeds for sowing, relating performance potential to the interaction among the genetic, physical, physiological, and seed health attributes (Rocha et al., 2018).

Hybrid maize seeds are mainly harvested near the stage of physiological maturity (SPM), when there is a more significant accumulation of dry matter and high physiological potential (Oliveira and Morais, 2017). However, seed moisture is high, around 35%, and special care, such as immediate drying, is extremely important.

The combination of high ear moisture and high temperature on the seed mass for extended periods brings about a deterioration process and early consumption of seeds reserves, depreciating seed physiological quality (Castro et al., 2015).

Factors such as transport logistics and receiving seeds in Seed Processing Plants (SPPs) and the production region and climate, affect seeds and contribute to the occurrence of the situations cited above. When the seed drying has been delayed the seed deterioration process begins, characterized by an increase in respiratory activity and an increase in the temperature of the seed mass. In some situations, the time between harvesting and seed drying in the SSP can exceed 50 hours, due to the distance or logistics between the production fields and the SPP. In addition, under tropical conditions, the transported load of seeds tends to increase the temperature because of the lack of oxygen in the seed mass, high external temperature, and long transport time (Carvalho et al., 2019).

Concerning it, the genetic constitution of the seed must be considered (Andrade et al., 2013). In addition to the choice of parental, the arrangement of these parental as female and male is relevant because it can affect the traits of the seeds produced (Prazeres and Coelho, 2016). Working to obtain hybrids tolerant to drought stress, Abreu et al. (2019) report significant reciprocal effects.

Thus, this study aimed to evaluate the effect of the arrangement of parental on the production of hybrids regarding tolerance to delay in drying of ears, seed physiological quality, and enzyme expression in the seeds, and thus obtain the best combination of the parental from the perspective of the physiological quality of hybrid seeds, even under delay in drying.

MATERIAL AND METHODS

The seeds were produced in field production located in Paracatu, Minas Gerais, Brazil, at 17°13’21”S and 46°52’31”W, with an average altitude of 688 m, annual rainfall of 1418.8 mm, and annual temperature among 8.2 °C min. and 31.2 °C max. (Cardozo et al., 2018). The climate in the region is classified as Aw, a tropical climate with a rainy summer (Alvares et al., 2013).

The experiments and evaluations were conducted in a partnership between the *Universidade Federal de Uberlândia (UFU)* e *Universidade Federal de Lavras (UFLA)*, and the Hélix Sementes Company, Patos de Minas, Minas Gerais state, Brazil. The trials were sown and evaluated in two crop seasons: the 2018/2018 season sown in March and evaluated at winter and the 2018/2019 season sown in September and evaluated at summer. All trials were conducted in commercial seed production field, irrigated by a center pivot. The genotypes sown belong to the breeding program of the Hélix Sementes Company.

Line 1 (L1) was sown, and by self-pollination, the seeds of the line were produced for analysis; the same procedure was performed for line 2 (L2). Hybrid seeds were obtained by controlled pollination, and *a priori*, established that for the first hybrid, L1 would be used as the female and L2 as the male, thus obtaining the hybrid seeds (HB). For the second hybrid, the reciprocal hybrid (RH), the male and female parental were inverted, with L2 used as the female and L1 as the male. All procedures were taken for isolation, control, pollination efficiency, and assurance of genetic purity. The ears were harvested manually at the stage in which the seeds were near physiological maturity, at 35% moisture

content. For each genotype, 120 ears were manually harvested, with later separation of 10 ears at random for each delay in drying time. All the ears were harvested at the beginning of the morning.

The ears, still in their husk, were put in woven high-density polyethylene plastic bags, Raschel type (allowing moisture and temperature equilibrium with the environment), and it was then placed in biochemical oxygen demand (BOD) chambers without light and ventilation. The seeds produced in the 2018/2018 and 2018/2019 crop seasons were evaluated for physiological quality, with a simulation of two temperatures within each chamber, namely 42 °C and 48 °C. The ears remained in waiting prior to drying for six different periods: 10, 18, 24, 28, 32, and 40 hours. For evaluation of enzyme expression, only the seeds produced in the 2018/2019 crop season were tested, with a simulation of a single temperature (48 °C) and the seeds remained for three periods: 10, 24, and 40 hours prior to drying.

After these periods of waiting for drying, the ears were husked manually and taken to the drying chambers of the seed processing plant, then dried at a temperature of 35 °C (stationary drying), until reaching 13% moisture (wet basis). After that, the samples were shelled manually, and impurities were removed using sieves. The seeds from sieves 16 to 24 were classified and used. Then the seeds were put in multilayered paper bags and stored under non-climate-controlled conditions in a room of the analysis laboratory of Hélix company, while testing was conducted. No chemical treatment was performed on the seeds. Physiological quality was evaluated through the germination test on paper, the emergence test in seedbeds and the cold test. All tests were conducted in the seed analysis laboratory of the Hélix Sementes company.

Germination test: Eight replications of 50 seeds were sown in a roll of "Germitest" (germination testing) paper on two sheets that were previously moistened with water in the amount of 2.5 times the weight of the paper. The rolls were kept in a germination room at 25 °C, with the evaluation of normal seedlings, according to the criteria of Brasil (2009), with a single count on the seventh day after sowing; and the result was expressed in percentage.

Emergence test in the seedbeds: Eight replications of 50 seeds were sown in seedbeds containing sand as a substrate, moistened to 60% water-retaining capacity. At seven days after sowing, the final number of emerged seedlings was counted.

Cold test: Eight replications of 50 seeds were sown in plastic trays containing a mixture of sand and soil at a 2:1 ratio, and moisture was adjusted to 70% of water-retaining capacity. The plastic trays were kept in cold storage at 10 °C for seven days and then transferred to germination chambers at 25 °C for seven days, at which time the emerged normal seedlings were evaluated (Vieira and Krzyzanowski, 1999).

Evaluations of proteins and enzymes were performed in the biotechnology laboratory in the seed sector of the Universidade Federal de Lavras, Lavras, Minas Gerais state, through analysis of the abundance of heat-resistant proteins and expression of the alpha-amylase (α-AM) enzyme.

Heat-resistant proteins (LEA proteins): the seeds were ground together with polyvinylpyrrolidone (PVP) and liquid nitrogen, and 100-mg samples were weighed for each material. After that, 1 mL of extraction buffer solution (50 mM of Tris-HCl pH 7.5; 500 mM of $MgCl_2$; 1 mM of PMSF) was added to the samples. The samples were centrifuged at 14,000 rpm for 30 minutes at 4 °C; the supernatant was incubated in a water bath at 85 °C for 15 minutes and once more centrifuged as before. Finally, the supernatant was poured into new test tubes. A quantity of 50 µL from each sample was applied in 12.5% (separator gel) and 6% (concentrator gel) polyacrylamide gel. The running buffer used was Tris-glycine + SDS pH 8.9, and the electrophoretic run was performed in a vertical system at ambient temperature and a constant voltage of 150V for four hours. After the run, the gels were stained in 0.05% Coomassie Brilliant Blue solution for 24 hours and decolorized in ethanol/acetic acid/water solution at 5:10:85. The gels were evaluated over a transilluminator, considering the variation in the intensity of the bands (Alfenas, 2006).

*Alpha-amylase (*α-AM): the seeds were moistened in "Germitest" paper for 24 hours at the temperature of 35 °C. Later the seeds were ground together with polyvinylpyrrolidone (PVP) and liquid nitrogen, and 100-mg samples were weighed for each material. The buffer 0.2 M Tris HCl pH 8.0 + 0.1% of β mercaptoethanol was used for extraction, adding 250 µl of the extraction buffer solution. The samples were homogenized in a vortex and kept in a refrigerator for

12 h. After that, they were centrifuged at 10,000 rpm at 4 °C for 30 minutes. The electrophoretic run was performed in a system of discontinuous polyacrylamide gels at 7.5% (separator gel) and 4.5% (concentrator gel) + 0.5% starch. The gel/electrode system used was Tris-glycine pH 8.9. The sample's quantity of 50 µL of the supernatant was applied, and the run was performed at 120 V for six hours. The revelation was carried out according to Alfenas (2006).

A completely randomized experimental design (CRD) was considered in a 4 × 6 × 2 factorial arrangement for the physiological quality trial, involving different combinations of the parental, six waiting times before drying, and two temperatures during the waiting period. The averages values of the two crop seasons were considered and analyzed. For the trial with an abundance of proteins and enzyme expressions, a CRD was used in a 4 × 3 factorial arrangement, involving four combinations of parental (genotypes) and three waiting times before drying, only in the second crop season.

After analyses of the statistical presuppositions, analysis of variance was used on the data with the assistance of the R software (R Core Team, 2019) at 5% probability by the F test ($p < 0.05$). Next, the averages values were compared using Tukey's test at 5%, and polynomial regression analyses were performed. The fitting of mathematical models was significant at 5%, with greater determination coefficient and proper biological relation.

RESULTS AND DISCUSSION

There were triple interactions for the physiological quality trial - genotype, time, and temperature of delay in drying - for all the physiological tests. The coefficients of variation were 2.75% for germination, 1.60% for seedbed emergence, and 1.52% for vigor.

Germination

An accentuated reduction in germination was not observed for the genotypes evaluated that were subjected to the temperature of 42 °C during the periods of delay in drying. However, at the temperature of 48 °C during the periods of delay in drying, there was reduction in germination percentage for some the genotypes evaluated. The hybrids HB, RH and L1 lineage did not show accentuated reduction in their percentages of germination. This reduction was more pronounced in seeds of L2, even at the beginning of the period of delay in drying (Table 1).

Carvalho et al. (2019) did not observe a reduction in germination in maize seeds subjected to 36 hours of delay in drying at 31% moisture at a temperature of 40 °C. Nevertheless, at 50 °C, beginning at 36 hours of delay before drying, there was a reduction in germination. Castro et al. (2015) observed no reduction in germination percentage in maize seeds with up to 40% moisture at 40 °C for up to a 48-hour delay before drying.

The effects of high temperature, especially 48 °C, were different among the genotypes (Table 1). The lines were more sensitive, exhibiting low percentages of germination over the periods of delay in drying. L2 was the most affected, showing only 59% germination at the end of the period studied. L1, as well as the RH, had germination percentages above 88%. The HB was less affected; it was more tolerant to the study conditions and had germination percentages above 95%. The difference between the germination percentages expressed between the hybrids may be the result of the exchange of parental, since L2, less tolerant, was used as the female for obtaining RH, indicating that the use of the more sensitive line as the female can affect the resistance of the hybrid to delay in drying.

This result is related to the process of maize seed formation from the endosperm, a triploid organ (3n) that has two-thirds of its constitution (2n) coming from its female and only one-third coming from its male (1n) (Marcos-Filho, 2015). Therefore, the effect of the female is important in the production of high-quality hybrid seeds. Furthermore, Abreu et al. (2019) found significant reciprocal effects in obtaining hybrids tolerant to drought stress, highlighting the importance of the correct choice of the female.

For the tendency of germination according to delay in drying times at the ambient temperature of 42 °C (Figure 1A), differences were not observed in HB, L1 and L2, with averages values of 92%, 81%, and 98%, respectively. Only RH reduced germination beginning at 18 hours (Table 1), with the lowest germination percentage at 33 hours of delay in

drying (Table 1). All the percentages observed were above 80% (Figure 1A). In this respect, it is important to emphasize that the minimum standards established for commercial sale of hybrid maize seeds is 75% for basic seed and 85% in C1 and S1 categories (Brasil, 2013).

At 48 °C, there was no difference among the times of delay in drying for HB, which maintained a high average value of 97% germination (Figure 1B). For RH seeds the beginning of deterioration was observed at 14 hours, with the lowest germination percentage at 32 hours. For L1, there was no model fitted, and it exhibited an average value of 91.62% germination over the periods of delay in drying. Though the germination of these genotypes was affected by the periods of delay in drying at the temperature of 48 °C, their percentages of germination were not below 85%. In contrast, in L2,

Table 1. Germination percentage of seeds from four maize genotypes: line 1 (L1), line 2 (L2), the hybrid (HB – female L1 and male L2), and the reciprocal hybrid (RH – female L2 and male L1) according to temperatures and periods of delay in drying.

Delay in drying (hours)	Temperature of delay environment (°C)	Genetic material*			
		L1	L2	HB	RH
10	42	91 Ba	80 Ca	98 Aa	89 Ba
	48	94 Aa	77 Ba	95 Aa	91 Aa
18	42	93 Ba	80 Ca	99 Aa	94 Ba
	48	95 ABa	72 Cb	98 Aa	92 Ba
24	42	92 Ba	82 Ca	99 Aa	95 ABa
	48	90 Ba	74 Cb	98 Aa	90 Bb
28	42	88 Ba	82 Ca	98 Aa	89 Ba
	48	89 Ba	63 Cb	97 Aa	89 Ba
32	42	96 Aa	82 Ca	99 Aa	89 Ba
	48	92 Bb	76 Db	99 Aa	85 Cb
40	42	92 Ba	80 Ca	99 Aa	94 Ba
	48	90 Ba	59 Cb	97 Aa	94 ABa
CV (%) = 2.75%					

*Mean values followed by the same uppercase letter in the row and lowercase letter in the column in each period of delay do not differ from each other at 5% probability by Tukey's test. CV: Coefficient of variation.

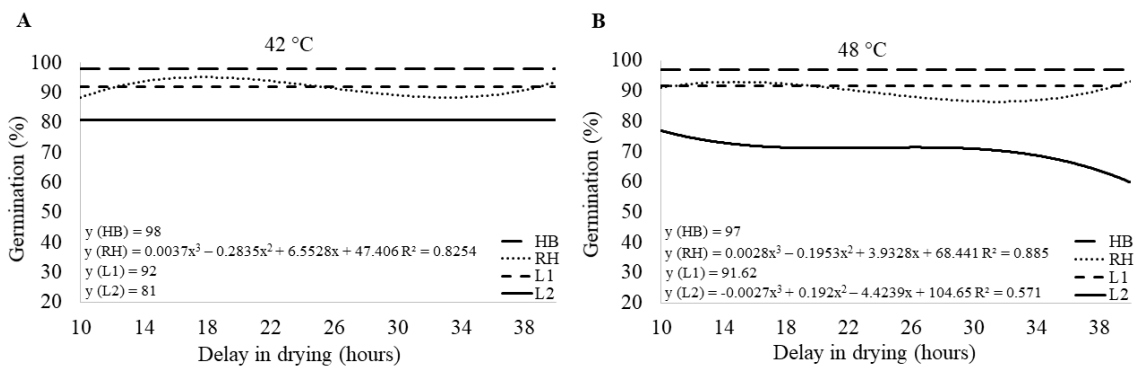

Figure 1. Germination percentage of seeds from four maize genotypes: line 1 (L1), line 2 (L2), the hybrid (HB – female L1 and male L2), and the reciprocal hybrid (RH – female L2 and male L1) at the temperatures of 42 °C (A) and 48 °C (B) during the period of delay in drying.

already in the first period of delay in drying evaluated, 10 hours, the percentages of seed germination were below 85%. With longer times of delay in drying, it exhibited values below 75%. The deterioration process intensified beginning at 27 hours of delay in drying at 48 °C, showing greater sensitivity of this genotype to the conditions of delay in drying.

The combination of high moisture and temperature in the seed/ears mass and low ventilation during drying delay to loss of dry matter and consequent reduction in maize seed germination and physiological quality (Santos et al., 2012; Sena et al., 2017).

Emergence test in the seedbed

The temperature of 42 °C led to point reductions in seedling emergence for the genotypes evaluated. However, at 48 °C, the reduction in seedling emergence was more accentuated, not only for the lines, but also for the hybrid combinations. In addition, the lines were more sensitive, especially L2, showing lower tolerance of this genotype to the study conditions, since the reduction in seedling emergence was identified in the first periods of delay in drying, with only 60% seedling emergence at the end of the 40 hours of study (Table 2).

Most of the statistical differentiation indicated greater quality for HB, followed by RH, L1, and L2 (Table 2). The assertive position of female and male parental in hybrid seed production is crucial since the hybrid may have genotypic and phenotypic traits coming from the maternal effect (Santos et al., 2017). This confirms the importance not only of the choice of parental, but also their arrangement, with the relevance of the female in the definition of tolerance of the hybrid to delay in drying.

The lines exhibit a lower capacity of seedling emergence in relation to their hybrids (Gomes et al., 2000). Hybrid seeds generally have greater vigor and germination capacity than their respective lines due to gain in heterosis.

Accentuated reduction in seedling emergence, below 80%, was not found at 42 °C (Figure 2A). At 48 °C, a reduction in seedling emergence of HB occurred beginning at 36 hours of delay in drying. For RH, there was a reduction in seedling

Table 2. Emergence percentage of seedlings coming from seeds of four maize genotypes: line 1 (L1), line 2 (L2), the hybrid (HB – female L1 and male L2), and the reciprocal hybrid (RH – female L2 and male L1) according to temperatures and periods of delay in drying.

Delay in drying (hours)	Temperature of delay environment (°C)	Genetic material*			
		L1	L2	HB	RH
10	42	87 Db	93 Ba	95 Aa	90 Cb
	48	89 Ba	81 Cb	93 Ab	92 Aa
18	42	88 Da	93 Ca	96 Aa	94 Ba
	48	87 Bb	72 Cb	96 Aa	87 Bb
24	42	88 Ca	88 Ca	99 Aa	92 Ba
	48	80 Cb	76 Db	97 Ab	83 Bb
28	42	83 Ca	95 Aa	95 Aa	92 Ba
	48	76 Cb	67 Db	95 Aa	89 Bb
32	42	89 Cb	93 Ba	98 Aa	92 Ba
	48	92 Ba	86 Cb	94 Ab	86 Cb
40	42	86 Da	93 Ca	97 Aa	94 Ba
	48	84 Bb	60 Cb	85 Bb	94 Aa
CV (%) = 1.6%					

* Mean values followed by the same uppercase letter in the row and lowercase letter in the column in each period of delay do not differ from each other at 5% probability by Tukey's test. CV: Coefficient of variation.

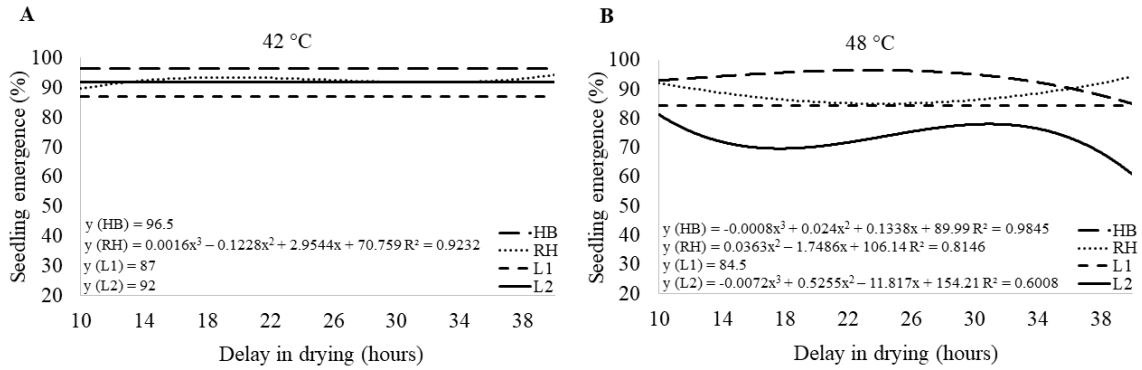

Figure 2. Emergence percentage of seedlings coming from seeds of four maize genotypes: line 1 (L1), line 2 (L2), the hybrid (HB – female L1 and male L2), and the reciprocal hybrid (RH – female L2 and male L1) at the temperatures of 42 °C (A) and 48 °C (B).

emergence between 18 and 26 hours of delay in drying. For L1, no regression model was fitted, with an average value of 84.5% emergence. L2 showed a reduction in germination percentage at the beginning of the delay in the drying period, with a sharp reduction with longer waiting times, after 34 hours, reinforcing the greater sensitivity of this genotype to delay in drying and to high temperatures (Figure 2B).

Fessel et al. (2000) placed maize seed lots with the maximum moisture content of 26% at temperatures of 42 °C and 45 °C for 72 and 96 hours and observed that seedlings emergence in most seed lots declined.

Cold test

At 42 °C, the genotypes had point reductions in vigor, with averages values greater than or near 90%, indicating that at this temperature, even for 40 hours of delay in drying, the vigor of the seeds did not change considerably. At 48 °C, L2 showed a reduction in vigor, especially in the later periods of delay in drying, confirming the sensitivity of this genotype to delay in drying and high temperature (Table 3).

L2 seeds were less vigorous than L1 seeds and the hybrids had greater vigor than both lines; HB was superior to RH (Table 3). In the cold test, lines exhibit lower vigor than the hybrids (Prazeres and Coelho, 2016). Santos et al. (2017) observed lower vigor in the reciprocal hybrid compared to the hybrid.

For vigor over the delay in the drying period at 42 °C, all the percentages were greater than or near 90%, even at 40 hours of delay (Figure 3A). However, at 48 °C, the reduction in vigor was marked in L2, especially from 27 hours on, leading to lower vigor for this line in relation to the others at the end of the 40 hours of waiting before drying (Figure 3B).

There are changes in maize seed vigor after the delay in drying even at milder temperatures (up to 40 °C), especially when the seeds are harvested at higher moisture contents, above 34% (Castro et al., 2015). For example, the viability and vigor of hybrid seeds harvested with up to 31% moisture are not affected up to the temperature of 40 °C in the seed mass with up to 36 hours of delay in drying. However, at 50 °C, vigor is harmed beginning at 24 h of delay in drying (Carvalho et al., 2019).

Enzyme expression

As the delay in drying proceeded, there was a greater accumulation of LEA proteins in the seeds, especially in the lines (Figure 4). The expression of LEA proteins was greater in the lines (Figure 4). The lines were more sensitive to delay in drying and exhibited lower physiological quality, above all with a longer delay time. Thus, this implies a possible relationship between different levels of stress and the accumulation of LEA proteins.

These proteins are synthesized in the seed maturation phase, before or during drying, and prevent high temperatures from hurting the cell membranes, mainly through reducing seed moisture content (Martínez-Muñoz et al., 2019).

Thus, the activity of these proteins is generally linked to the capacity for the protection of the cytoplasm and of the membranes when the process of drying under high temperatures occurs (Taveira et al., 2012; Andrade et al., 2013).

The difference between the intensity of expression of the LEA proteins by the genotypes may also be related to the high polymorphism capacity it has, varying according to the genotype, stage of development, drought stress, and deterioration processes (Andrade et al., 2013; Dutra et al., 2015; Abreu et al., 2016).

Table 3. Percentage of normal seedlings after the cold test coming from seeds of four maize genotypes: line 1 (L1), line 2 (L2), the hybrid (HB – female L1 and male L2), and the reciprocal hybrid (RH – female L2 and male L1) according to temperatures and periods of delay in drying.

Delay in drying (hours)	Temperature of delay environment (°C)	Genetic material*			
		L1	L2	HB	RH
10	42	91 Da	95 Ba	98 Aa	93 Ca
	48	91 Ca	93 Bb	97 Ab	92 Cb
18	42	94 Ca	98 ABa	99 Aa	96 Ba
	48	88 Cb	90 Bb	99 Aa	88 Cb
24	42	92 Ca	90 Db	98 Aa	96 Ba
	48	91 Cb	93 Ba	97 Ab	93 Bb
28	42	87 Ca	97 Aa	98 Aa	94 Bb
	48	79 Db	87 Cb	97 Ab	95 Ba
32	42	97 Ba	94 Da	99 Aa	96 Ca
	48	93 Bb	93 Bb	97 Ab	93 Bb
40	42	90 Cb	93 Ba	98 Aa	98 Aa
	48	91 Ba	74 Cb	96 Ab	96 Ab
CV (%) = 1.52					

* Mean values followed by the same uppercase letter in the row and lowercase letter in the column in each period of delay do not differ from each other at 5% probability by Tukey's test. CV: Coefficient of variation.

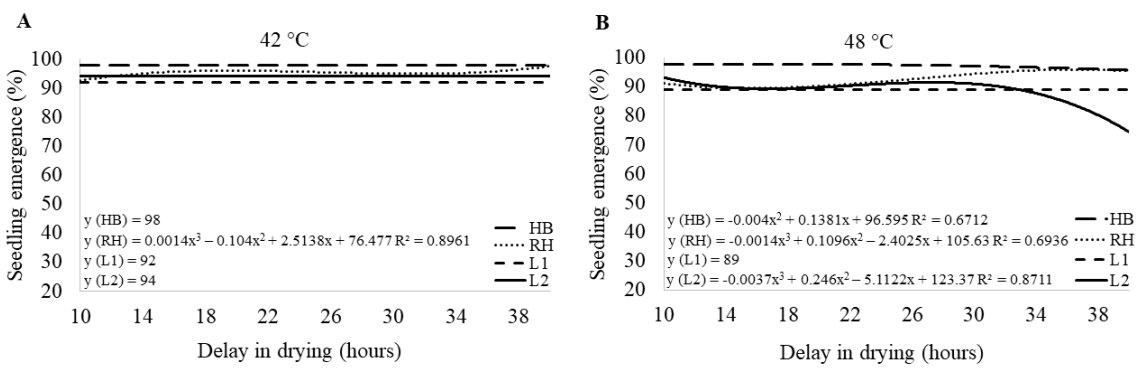

Figure 3. Percentage of normal seedlings after the cold test coming from seeds of four maize genotypes: line 1 (L1), line 2 (L2), the hybrid (HB – female L1 and male L2), and the reciprocal hybrid (RH – female L2 and male L1) at the temperatures of 42 °C (A) and 48 °C (B).

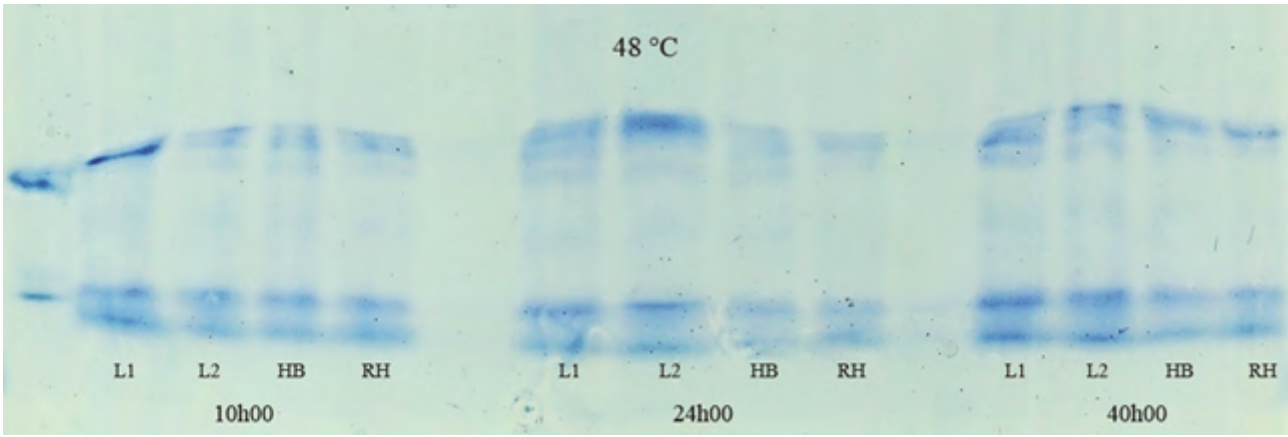

Figure 4. Electrophoretic pattern of heat-resistant proteins (late embryogenesis abundant proteins - LEA proteins) in seeds of four maize genotypes: line 1 (L1), line 2 (L2), the hybrid (HB – female L1 and male L2), and the reciprocal hybrid (RH – female L2 and male L1) under delay in drying for 10, 24, and 40 hours at 48 °C.

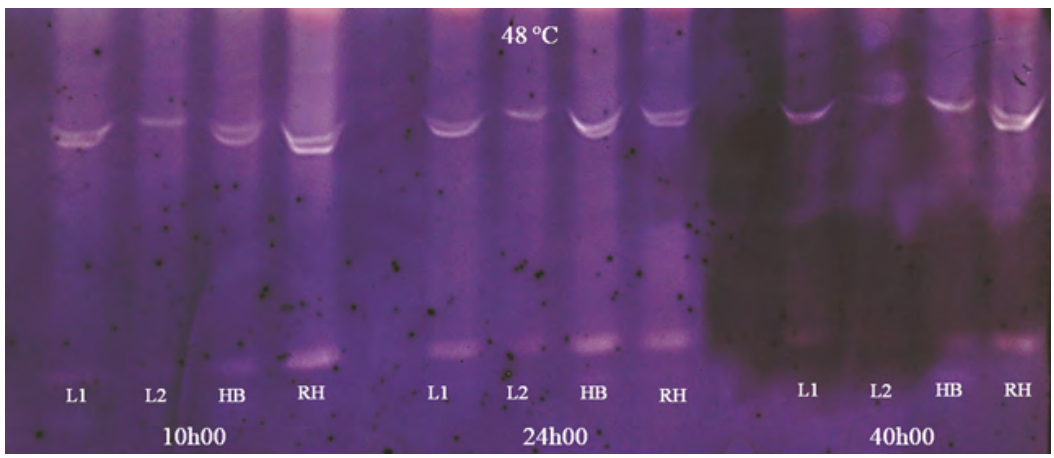

Figure 5. Electrophoretic pattern of the α-amylase enzyme in seeds of four maize genotypes: line 1 (L1), line 2 (L2), the hybrid (HB – female L1 and male L2), and the reciprocal hybrid (RH – female L2 and male L1) under delay in drying for 10, 24, and 40 hours at 48 °C.

The expression of the α-amylase (α-AM) enzyme in the lines was lower than in the hybrids, from the beginning until the delay in the drying period, especially for L2 (Figure 5). This line showed greater sensitivity to the delay, with lower physiological quality. The α-AM enzyme is important for seed physiological quality because it acts in starch hydrolysis, supplying energy for embryo growth. Variation in temperature affects this enzyme, compromising the physiological quality of maize seeds (Santos et al., 2015; Lopes et al., 2017).

Hybrid maize seeds exhibited greater expression of the α-AM enzyme (Figure 5); seed physiological quality was greater in the genotypes. However, Lopes et al. (2017) emphasize that the physiological quality of maize seeds is related to the genotype. Thus, for some authors, the greater physiological quality that hybrid maize seeds have in relation to the lines is due to the gain in heterosis that the hybrid seeds have (Reis et al., 2011; Oliveira et al., 2013).

Consequently, monitoring the temperature of the transported load and of the period between harvesting, transportation, receiving, and drying of ears in the seed processing plants is fundamental for maintaining the quality of maize seeds, with a direct effect of the arrangement of the parental in the obtaining of the hybrid-related to tolerance to delay in drying.

CONCLUSIONS

The lines exhibit greater sensitivity to high temperatures in drying delays in relation to the hybrids, and L2 was the most susceptible.

The temperature of 42 °C affects only the quality of the seeds of the line most sensitive to delay in drying (L2). At 48 °C, the lines exhibit a reduction in their quality in the first 10 hours of delay in drying, and hybrids exhibit reduction only as of the delay in drying period advances.

There are differences between the tolerances of the hybrids and their reciprocals regarding a delay in drying. The female line directly affects the hybrid's susceptibility to drying delay.

As the delay in drying increases, there is a greater abundance of LEA proteins, especially in the lines. The seeds of the line most susceptible to delay in drying (L2) have higher expressions of α-amylase (α-AM).

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